THE VASCULAR ANATOMY OF THE FOREHEAD RELATED TO FOREHEAD FLAPS AND ITS APPLICATION IN PLASTIC AND RECONSTRUCTIVE SURGERY

Wayne George Kleintjes MMed Plastic Reconstructive Surgery (Stell)

Dissertation presented for the degree of Doctor in Philosophy (PhD), Faculty of Health Sciences at the University of Stellenbosch.

<u>Promotor</u>:
Prof. D. F. du Toit: DPhil (OXON), PhD (Stell), MBChB (Stell), FCS (SA), FICA (USA), FRCS (ED) University of Stellenbosch: Head: Division Anatomy and Histology.

<u>Co-Promotor</u>:
Prof. B. J. van R. Zeeman: MMed (Stell), MBChB (Stell), BSc (Stell) University of Stellenbosch: Previous Head: Division Plastic and Reconstructive Surgery

Dec 2007

DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work at the University of Stellenbosch and has not previously in its entirety, or in part, been submitted at any university for a degree.

.... 30 June 2006

Signature

ABSTRACT:

<u>TITLE</u>: THE VASCULAR ANATOMY OF THE FOREHEAD RELATED TO FOREHEAD FLAPS AND ITS APPLICATION IN PLASTIC AND RECONSTRUCTIVE SURGERY.

<u>Aims</u>: The goal of this study was to identify arterial variations by cadaveric dissection, in the forehead, in order to validate the practicality and implementation of planned forehead flaps and to increase the safety of forehead flaps in plastic and reconstructive surgery.

<u>Hypothesis tested</u>: Unique frontal forehead flaps can be safely based on anatomical dissection and on the presence of the central vein and the anastomosing branches of the frontal ramifications of the angular artery (AA).

<u>Materials & methods</u>: The study had two strategic components: an anatomical cadaveric study and a clinical study, based on the newly described forehead vasculature. The anatomical study consisted of a) dissection of 30 latex infused cadavers and 20 non-latexed cadavers; b) histological assessment of forehead vasculature of 20 cadavers. The clinical applicability study consisted of a cohort of 12 plastic and reconstructive surgery cases, undergoing nasal rhinoplasty, based on the cadaveric study and anatomical vasculature. The research was conducted within an ethical protocol and all patients gave informed consent. The follow-up period is 2 years.

<u>Results</u>: In the cadaveric dissection, the following vessels, relevant to forehead flaps and nasal reconstruction, were consistently identified: DNA, FBSTA, STrA,

TFA, AA, CA, CV, PCA, SOA and OV. Side branch analysis of STrA (N = 43) showed: MCB (60%), LCB (23%), SPA (26%), OB (19%), single VB (47%), medial and lateral VB (53%). Side branches of the supra-orbital artery (SOA) were: LRB (91%), OB (91%), VB (100%), MB (44%), BB (5%) and SVB (9%). Side branch profile of the angular artery (AA) was: DNA (96%), CB (67%) and PCA (47%). In 71% of cases the origin of the PCA was from the angular artery (AA). Individual artery side branches of the forehead were as follows: STrA (9), SOA (6), FBSTA (4), DNA (4), AA (3/4), CA (2) and PCA (2). Average diameter of the small arteries at point of entry ranged from 1 – 2mm (CA < 1mm, PCA < 1mm). The central vein was a constant finding in all dissections and an important landmark. Other constant veins detected included the nasofrontal, ophthalmic, angular, supra-trochlear and facial veins.

Twelve prospective randomized patients met inclusion criteria for nasal flap reconstruction, based on the cadaveric vascular study. Race profile was white (6), mixed (4) and black (2). There were 8 males and 4 females. Disease demographics included cancer (6; melanoma 2, basal cell cancer 5), trauma (3), infections (1) and congenital (1). Post-operative grading was as follows: defects corrected (12/12), subjective improvement (12/12), objective improvement (12/12), partial flap necrosis (1/12) and secondary interventions (debulking or revision 2/12). Doppler assessment for pedicle vasculature showed identification of the following arteries: TFA (85%), STrA (65%), PCA (20%) and AA (25%). Doppler studies further indicated the following small side branches: TFA (49%), STrA (30%), PCA (9%), AA (12%). The central vein was identified in 9/12 (75%)

by ***macroscopic*** examination. In one female with a basal cell carcinoma (BCC), modest dermal stock loss was demonstrated by the application of high frequency dermal ultrasound (Dermascan®). The results of the cadaveric anatomy study show the existence of various important subtle arterial variations in the forehead that are not described in the literature. Many arterial side branches not clearly named and others not described before, were highlighted in this anatomical study. Other observations regarding the anatomical relationships of the forehead nerves were of practical surgical value, the most important being to reduce sensory neuropraxia. The histological study endorsed the cadaver dissection observations and showed the importance of the flap vasculature at the proximal level of the pedicle. The clinical study with follow-up period of 24 months, illustrates an evolving refinement in surgical technique based on the findings of the anatomic vasculature study. A new **method of planning** a "2500-year-old operation" was confidently developed based on the anatomical vasculature observations detected during the cadaver study. The Doppler study suggests that crude arterial variations of the central forehead, in the region of the intended flap pedicle, can **not be** diagnosed and highlighted **accurately** pre-operatively. The macroscopic anatomy of the central vein (clinical landmark) **is an accurate** predictor of underlying arterial variations and **may be more valuable clinically** than the hand-held Doppler examination.

Conclusion: Comprehensive vascular anatomical detail of the forehead was not described accurately or completely by clinical anatomists in the past and does not appear in classic text books of anatomy and morphology. This has led to one-dimensional (arterial) application of the midline forehead flap planning and eventually the introduction of the para-median forehead flap, which has become the modern “work horse” of forehead flaps for nasal reconstruction. Now that in a definitive cadaveric study of the forehead blood supply has been demonstrated, the results show that surgeons will once again be able to embrace the midline forehead flap, only this time there will be possibly no inconsistent descriptions of unnamed blood vessels or ill-defined landmarks for flap planning. New flaps and reconstructive options in or around the forehead will be hopefully planned and executed more effectively and safer based on a more comprehensive understanding of the forehead anatomy and vasculature. The subjective and objective end-point analysis of the clinical study show favourable measured outcomes in the interim follow-up period (24 months) and benefit to the patients, in the presence of a low percentage of flap loss (1/12; 8.3%). The use of pre-operative Doppler assessment helped with flap planning. In one patient, the application of high frequency ultrasound facilitated long term follow-up regarding recurrent tumour formation and enhancement of dermal consistency with anti-aging creams, vitamin A derivations and sunscreens.

Recommendations: The classic anatomy text books and clinical plastic surgery works with their inconsistent descriptions of the central forehead blood supply (arterial and venous) need to be updated. The evolution of the midline forehead flap method is far from complete. The refinement of the one-stage midline forehead flap method without an island is in progress and can clinically be implemented, based on a sound anatomical dissection study.

ABSTRAK:

<u>**TITEL**</u>**: DIE VASKULERE ANATOMIE VAN DIE VOORKOP RELEVANT TOT VOORKOP FLAPPE EN HUL TOEPASSING IN PLASTIES EN REKONSTRUKTIEWE CHIRURGIE.**

<u>**Doel**</u>**:** Die doel van die studie was die identifisering van die arteriële variasies van die voorkop om die praktiese waarde van verskeie vorige voorkop flap ontwerpe te evalueer en ook om die veiligheid van voorkop flappe in plasties en rekonstruktiewe chirurgie te verbeter.

<u>**Hipotese toets**</u>**: Die arteriële variasies van die voorkop en die posisie van die sentrale veen van die voorkop kan gebruik word om voorkop flappe se beplanning en uitvoering te vefyn asook van waarde wees om nuwe flappe te beplan vir gesigs plastiese en rekonstruktiewe chirurgie**.

<u>**Materiaal & metodes**</u>**:** Die studie het twee hoof komponente: Die anatomiese studie en ‘n kliniese studie (opvolg periode 24 maande). Die anatomie studie behels a) disseksie van 30 lateks gevulde kadawers and 20 nie-lateks gevulde kadawers; b) histologiese evaluasie van die voorkop bloedvate van 20 kadawers. Die kliniese studie behels a) 12 plasties en rekonstruktiewe chirurgie gevalle studies; b) ‘n hand-gehoude Doppler studie van 12 pasiente om die pedikel bloedvloei objektief te demonstreer.

<u>**Resultate**</u>**:** Tydens die kadawerstudie is die volgende bloedvate **toepaslik** tot voorkop flap chirurgie en nasale rekonstruksie identifiseer: DNA, FBSTA, STrA, TFA, AA, CA, CV, PCA, SOA and OV. Sytak analise van die STrA (N = 43) het

die volgende getoon: MCB (60%), LCB (23%), SPA (26%), OB (19%), enkel VB (47%), mediale en laterale VB (53%). Sytakke statistieke van die supra-orbitale arterie (SOA) was: LRB (91%), OB (91%), VB (100%), MB (44%), BB (5%) en SVB (9%). Sytak ontleding van die angulêre arterie (AA) was soos volg: DNA (96%), CB (67%) en PCA (47%). In 71% gevalle bestudeer, was die angulêre arterie (AA) die oorsprong van die PCA. Sytak ontleding in die algemeen is soos volg: STrA (9), SOA (6), FBSTA (4), DNA (4), AA (3/4), CA (2) en PCA (2). Die gemiddelde deursnit van die klein arteries op die rand van die orbita variëer van 1 – 2mm (CA < 1mm, PCA < 1mm). Die sentrale vene was 'n konstante bevinding in alle disseksies. Ander konstante venes in die omgewing van die orbita en relevant tot flap chirurgie was die nasofrontale-, optalmiese-, angulêre-, supra-trochleêre-en fasiale venes.

Twaalf (12) pasiënte, gerandomiseer tot nasale/ voorkop rekonstruksie, gebasseer op die kadawer studie, het voldoen aan die protokol insluitingskriteria. Rasseprofiel was wit (6), gemeng (4) en swart (2). Daar was 8 mans en 4 vroue. Siekte demografie van die pasiënte was: kanker (6; melanoom 1, basaalselkarsinoom 5), trouma (3), infeksies (1) en kongenitaal (1). Postoperatiewe gradering was soos volg: defekte gekorrigeer (12/12), subjektiewe verbetering (12/12), objektiewe verbetering (12/12), gedeeltelike flap nekrose (1/12) en sekondêre **prosedures** ("debulking" of revisie 2/12). Die opvolg periode was 24 maande. Tydens Doppler evaluasie om pedikel **bloedvloei** te identifiseer is die volgende arteries geïdentifiseer: TFA (85%), STrA (65%), PCA (20%) and AA (25%). Doppler evaluasie het die volgende klein, arteriële sytakke uitgewys: TFA (49%), STrA (30%), PCA (9%), AA (12%). Tydens prospektiewe Doppler evaluasie, kon die sentrale vene in 9 uit 12 gevalle (75%) uitgewys word. In een vroulike pasiënt met basaalsel karsinoom (BCC), is dermale atrofie en verlies van kollageenbondels gedemonstreer met behulp van hoë frekwensie dermale ultraklank (Dermascan®). Dit is die eerste keer dat hierdie analisemetode gebruik is om dermale atrofie en geassosiëerde kanker in plastiese rekonstruktiewe flap chirurgie te demonstreer. Die resultate van die **anatomiese** studie wys die bestaan van verskeie arteriële variasies in die voorkop wat nooit voorheen in **fyn besonderhede** beskryf was nie. Baie arteriele takke wat nie benoem **is** nie en ander wat nog nie voorheen beskryf **is** nie, is gedokumenteer. Ander observasies met betrekking tot die voorkop senuwees wat van chirurgiese belang is, is ook ingesluit. Die toepassing hier is dat neuropraksie voorkom kan word. Die histologiese studie komplimenteer die disseksie bevindings. Die kliniese studie (met opvolg periode van 24 maande) illustreer die evolusie van verfyning van chirurgiese tegniek gebaseer op die anatomiese studie se bevindings. ‘n Nuwe metode vir die beplanning van ‘n 2500-jaar-oue operasie **is** ontwikkel gebasseer op die **waarnemings** van die kadawer studie. Die Doppler studie het bewys dat die arteriële variasies van die voorkop pre-operatief **getoon** kan word en ook dat die makroskopiese anatomie van die sentrale voorkop **vena** waarskynlik ‘n meer akkurate voorspeller is van arteriële variasies as die Doppler ontleding.

Gevolgtrekking**:** Die vaskulêre anatomie van die voorkop **is** in die verlede nie akkuraat of volledig bespreek nie. Dit het gelei tot ‘n een-dimensionele benadering (arteriëel) tot die midlyn voorkop flap beplanning en later tot die voorstelling van die voorkop flap, wat vandag die moderne “werkesel” van voorkop flappe vir neus rekonstruksie is. Noudat ‘n deeglike studie van die voorkop bloedvoorsiening gedoen is, toon die resultate dat chirurge weereens die midlyn voorkop flap kan gebruik, met die verskil nou dat daar nie vae beskrywings is van “naamlose” bloedvate of onduidelike landmerke vir flap beplanning nie. Nuwe flappe en rekonstruktiewe opsies in die voorkop area kan **beter en veiliger beplan** en uitgevoer word te danke aan ‘n beter **begrip** van die voorkop anatomie en bloed toevoer. Die subjektiewe en objektiewe eindpuntanalise van die kliniese studie is positief en tot die voordeel van die pasiënte in die teenwoordigheid van ‘n lae **voorkoms** van flapverlies as gevolg van nekrose.

<u>Aanbevelings</u>: Anatomie **handboeke** met onakkurate en onvolledige beskrywings van die voorkop **bloedvoorsiening** kan nou opgradeer word. Die evolusie van die midlyn voorkop flap is nog nie voltooi nie. Die verfyning van die een-stadium midlyn voorkop flap sonder ‘n eiland is amper voltooi.

Acknowledgements: Examiners of this thesis

1. Prof P. Hoogland: External examiner: Ph.D., Anatomy (Medically qualified and head of the department of Anatomy, Vrye Universiteit, Amsterdam, Netherlands)

2. Dr S. Kotze: External examiner: Ph.D., Acting head Department of Anatomy and Biosciences, University of Western Cape, South Africa.

3. Prof B. Hartzenberg: Thesis Modurator: M.Med., Head of Neurosurgery Department, Tygerberg Hospital.

4. Mr. B.G.H. Lamberty: International opinion : Anatomy and clinical :M.A., F.R.C.S.: Consultant Plastic and Reconstructive Surgeon Cambridge & Fitzwilliam Hospitals, Cambridge, U.K.

Thesis Supervisors:

1. Prof D.F. du Toit: F.R.C.S., DPhil (Oxon), Ph.D.: Head: Division of Anatomy and Histology, Stellenbosch University, Registered general surgeon.

2. Prof Bennie Van R. Zeeman: M.Med. : Previous head of the Plastic Surgery Department, Tygerberg Hospital Medical School, Stellenbosch University, South Africa.

Research outputs of this thesis:

1. Abstracts:

1.1 Vascular anatomy of the forehead: relevance to flap planning in plastic and reconstructive surgery.

Kleintjes et al, Surg Radiol Anat (2005) vol 27, special issue.

Presented:

European Association of Clinical Anatomy;

8th Congress 2005, Palermo- Italy. (30 Jun- 3 Jul), W. Vorster.

2. Congress Presentations:

2.1. New forehead flaps: Pilot study: October 2003 APRSSA (Association of Plastic and Reconstructive Surgeons of South Africa), Pilansberg**.**

2.2 Arterial variations of the forehead and the central vein significance. APRSSA, October 2005.

2.3 The central vein forehead flap and Doppler study of the forehead arterial variations. APRSSA, October 2006.

3. International Journal Publications:

3.1 Forehead anatomy: arterial variations and venous link of the midline forehead flap. W.G. Kleintjes. Journal of Plastic, Reconstructive and Aesthetic Surgery (JPRAS)= former British Journal of Plastic Surgery. Accepted for publication in October 2006. In Press.

3.2 Doppler study: Forehead arterial variations and macroscopic central vein observations. W.G. Kleintjes. In review at JPRAS. Submitted Sept 2006.

3.3 Clinical study: Central vein forehead flap. W.G. Kleintjes. In review at JPRAS. Submitted Sept 2006.

4. AWARDS:

PRIZE: Best Congress Paper: October 2006 APRSSA

PRIZE: Best International Publication by member of the Association APRSSA Congress 2007.

ACKNOWLEDGEMENTS AND CREDITS:

During this study I depended on the academic excellence, creative research environment that prevails in the pre-clinical (Biomedical Sciences) and clinical academic departments at Stellenbosch University. My sincerest thanks to the following, without whose help this research project and doctoral dissertation would not have been possible.

THE ALMIGHTY: Thank you for the honour and priviledge to share this knowledge. Thank you for the wonders of life, creation of man and science of the human being.

Stellenbosch University: In particular the Faculty of Health Sciences, Tygerberg Campus, Administrative and Teaching where this study has its roots. The basic science research was performed in part at the Division of Anatomy and Histology, Department of Biomedical Sciences, Faculty of Health Sciences, University of StellenboschThe clinical application was performed in an academic department, within an institutional peer-reviewed and ethical protocol.

Tygerberg Academic and Teaching Hospital: In particular the Department of Plastic and Reconstructive Surgery, University of Stellenbosch Medical School.

Prof. D. F. du Toit, Head of the Division of Anatomy and Histology, University of Stellenbosch: My promotor, science mentor, advisor and motivator. Thank you for your guidance, academic and social support during the doctoral study.

Prof. B. J. van R. Zeeman, previous head of the Department of Plastic and Reconstructive Surgery, University of Stellenbosch: My co-promotor and plastic and reconstructive surgery mentor. Thank you for all your unselfish wisdom, advice and clinical guidance.

Dr. K.M. Geldenhuys, PhD, affiliated to the Faculty of Health Sciences, University of Stellenbosch: for expert scientific formulation of the manuscript and dissertation, data processing, critical review, positive input, including stylistic and language aspects. Without this input, the thesis would not have been completed.

Dr. Martin Kidd and Prof. J. Koeslag: Thank you for the invaluable statistical advice.

Mr. Reggie Williams, senior technical officer, Division of Anatomy and Histology, University of Stellenbosch: Thank you for the assistence with cadaver preparation, latex instillation and obtaining references from the medical library, Faculty of Health Sciences, Tygerberg Campus.

Mr. Frank Sitzer and Mr. Johannes Matthysen, senior technical officers, Division of Anatomy and Histology, University of Stellenbosch: Thank you for your technical assistance with preparation for dissections in the Division of Anatomy and Histology, Department of Biomedical Sciences, Faculty of Health Sciences, University of Stellenbosch, Tygerberg Campus.

Mrs. Elize Arends: for technical assistance.

Dr. Christo Muller, senior scientific officer, Division of Anatomy and Histology, University of Stellenbosch: for histological analysis and support with statistics.

Mr. Romeo Lyners, senior technical officer, Division of Anatomy and Histology, University of Stellenbosch: for technical assistance regarding histological analysis of tissue that proved invaluable to this doctoral study.

Dr. Ben Page, PhD: Senior Lecturer in the Division of Anatomy and Histology, Department of Biomedical Sciences, University in Stellenbosch, for expert criticism and input regarding the scientific merit and anatomical nomenclature.

Dr. Jannie Barnard; Dr. Andrew Bruce-Chwatt; Dr. George Morrison, Private Plastic and Reconstructive Surgeons: Thank you for referring relevant patients to me. This kind gesture is appreciated and with your consent, these patients have been included in this dissertation.

Sr. L. Van Wyk and Miss Y Hartzenberg: for assistance with typing and technical advice.

Elective Dutch students, Guido Dees and Johannes Wimmer: Thank you for assisting with dissections, during 2005, in the Division of Anatomy and Histology, University of Stellenbosch.

My family: Thank you for your faithful support and sacrifices during this study.

Thank you to all the students who helped to translate German and French articles. I apologize in advance if, inadvertently, the name of some generous contributor has been unintentionally omitted.

Dr. W. G. Kleintjes: MMED (Stellenbosch)
Division of Plastic and Reconstructive Surgery, Faculty of Health Sciences, University of Stellenbosch, Tygerberg Campus.
Suite 1008, Louis Leipoldt Medi-clinic, Broadway Road, Bellville, 7530.

30 June 2006

TABLE OF CONTENTS **PAGE**

ABBREVIATIONS

GENERAL ANATOMY ABBREVIATIONS (ARTERIAL BRANCHES) AND NOMENCLATURE USED IN THIS STUDY:

AA……………………………………Angular Artery

AFA...Ascending Frontal Artery

ATA...Ascending Temporal Artery

CA...Central Artery

CV...Central Vein

DNA..Dorsal Nasal Artery

DTA...Descending Temporal Artery

FBSTA...Frontal Branch Superficial Temporal Artery

FTFF………………………………..Full Transverse Forehead Flap

ITT...Inferior Transverse Third

LORB...Lateral Orbital Rim Branch

LORV...Lateral Orbital Rim Vertical **Line**

MB...Medial Branch

MCH...Medial Canthus Horizontal **Line**

MCV...Medial Canthus Vertical **Line**

MTT..Middle Transverse Third

OA…………………………………..Ophthalmic Artery

OB..Oblique Branch

OV……………………………………Oblique Vein

PCA…………………………………Paracentral Artery

SOA...Supra-Orbital Artery

SOL...Supra-Orbital Ligament

SON..Supra-Orbital Nerve

SPA...Superior Palpebral Artery (medial)

STrA...Supra-Trochlear Artery

STrV………………………………… Supra-Trochlear Vein

STrN………………………………... Supra-Trochlear Nerve

STT...Superior Transverse Third

TFA...Transverse Frontal Artery

VB..Vertical Branch

PREAMBLE TO THE PHD STUDY

"Beyond the persistent quest for answers that challenge historically set boundaries lie a truth that is so sweet to the soul" (unknown author).

CHAPTER 1

INTRODUCTION

- **GENERAL**

1.1 **GENERAL INTRODUCTION: A PHILOSOPHY**

The question has been asked recently by esteemed plastic surgeons at the International Society of Aesthetic Plastic Surgery (ISAPS) meeting at Spier, Stellenbosch (March 2006): '*why is it that sometimes some surgeons manage to get outstanding results without detailed anatomic knowledge, in contrast to others who don't manage to get great results, despite a greater anatomical understanding?*'

The surgeon who procures a good result must have a logical approach to address the aesthetic problem and operates accordingly, whereas the surgeon who has a purely anatomic approach may theoretically focus too much on correcting the anatomy rather than on the desired clinical result. In the words of Dr. Alain Fogli (France): "*We should not create a new surgical anatomy, but rather restore the anatomy of youth*". The possibility that excessive emphasis on the anatomical approach may lead to 'over correction' and this has to be avoided, as a negative outcome could be experienced.

Comment:

Two different approaches to the cosmetic problem are discernible: the clinical or practical approach and secondly the anatomical or "scientific approach".

The most desirable outcome from this would be that the best surgical result should be obtained from a combination of a practical approach with an underlying anatomic or scientific basis. The effective blending of clinical skill or surgical finesse with an understanding of anatomical knowledge ultimately should lead to a more durable technique and the most consistent clinical results over time.

HOW DOES THIS PHILOSOPHY REFLECT ON NASAL RECONSTRUCTION WITH THE MIDLINE FOREHEAD FLAP (INDIAN RHINOPLASTY)?

This is one of the most important questions in this doctoral dissertation. Keeping in mind that the technique for nasal reconstruction was documented (although crudely), approximately 500 BC, it is a technique that is more than 2500 years old as far as we can gather from historical descriptions (Eisenberg, 1982). Although this technique was the “standard” for nasal reconstructions thousands of years ago, there was not much detail regarding the anatomical considerations of flap design that was transferred to later generations. With time, the “knowledge” of the technique was lost and found and kept secret in the “surgical class” in India. It seems likely that there was either a lack of knowledge or that knowledge was lost about the anatomical considerations of the flap or that a deeper anatomical understanding of the midline forehead flap was never appreciated. There is adequate evidence to suggest that the latter possibility might be true. This anecdotal notion is supported by the fact that in Sushruta's description of the technique, flap necrosis was observed on occasions. The best evidence of an appreciation of an understanding of anatomical relevance, however, is the fact that the clinical or practical approach of using the *central vein* of the forehead as a landmark for flap planning is not mentioned. This would also then to a degree explain the incidence of flap necrosis experienced, as the critical venous drainage was probably not considered essential in their flap planning. We will never know the answer, because of incomplete documentation. Ultimately in our quest for truth and answers, we all should have a common goal: the dedication to improve and relieve the suffering of our fellow human beings. We are the servants of man and need to serve the poor, aged and infirm, by applying our knowledge and keeping up to date. Sushruta wrote: '"Not for self, not for the fulfillment of any earthly desire of gain, but solely for the salvage of suffering humanity should you treat your patients and so excel all those who sell the treatment of diseases as merchandise, gather the dust and neglect of gold" (Eisenberg, 1982). Another important question to answer in this regard is:

WHY HAS THE INDIAN FOREHEAD FLAP TECHNIQUE STOOD THE TEST OF TIME?

It is obvious there has to be some sort of anatomical basis for these earlier results and we know that the ancient surgeons had a good anatomical understanding of blood supply (Eisenberg, 1982; Lascaratos, 1998). Secondly, there also has to be some practical considerations regarding a surgical technique to stand the test of time and to show proof-of-principle, including reproducibility. To ensure consistent clinical results and measured outcomes, we need a solid anatomical foundation. If we analyze the descriptions of Sushruta about nasal reconstruction, it is evident that the cheek (malar area) was first used as a donor site for nasal reconstruction. From there they progressed to the forehead. One can assume that while doing flaps in the cheek area, they became familiar, unknowingly, with the facial and angular artery. It is thus not unreasonable to assume that the ancient surgeons knew that they could base a midline forehead flap on the angular artery and or central vein. By maintaining the arterial inflow into the flap, a good and reliable flap could be created. The choice and selection of this flap thus served at least one practical purpose: it offered the shortest distance of rotation of flap pedicle based on the forehead. Other advantages of the forehead donor site include texture and colour match with the recipient site. Probably moving the donor site to the forehead from the cheek also allowed the donor site to be hidden by hair, and as was found with continued experience, the forehead is a very forgiving donor site and ensures the best aesthetic scars in the face. **The contribution of Karl Langer (1861: cleavage lines, tension lines, retraction lines and minimal extensibility lines) regarding the elastic properties of skin and placement of scars in lines of minimal tension is still a significant contribution to aesthetic surgery today (McCarthy's Plastic Surgery, 1990)**. The anatomical or scientific basis for the "success" of the ancient Indian rhinoplasty **most likely** stemmed from the ancient surgeons knowledge of the angular arteries branches and rich blood supply to the forehead. In conclusion, the Indian rhinoplasty had a practical and scientific anatomical basis that was appreciated and practiced by experienced ancient surgeons. It is a technique that evolved from cheek flaps for nasal reconstruction and to this day is still performed almost as it was originally described.

The contribution to the refinement and improvement of this 2500-year-old surgical technique is clearly demonstrated, from its anatomical basis to its practical application, and is the ultimate perfection of the philosophy: the blending of anatomical knowledge with surgical finesse***.*** Finally, the understanding of the midline forehead flap should not only just be based on its axial arterial supply, but also on its complex venous drainage together with the anatomical understanding of the flap in its entirety. The modern trend of the last half century that made the para-median forehead flap more popular may effectively be destined to change. Amazingly, the 2500-year-old midline forehead flap technique is again re-introduced to the plastic surgery community, this time, unquestionably based on a sound anatomical and physiological foundation.

This doctoral thesis addresses the “arterial and venous circulation regarding the human forehead and nasal areas relevant to the art and practice of flap reconstruction for nasal defects”. The cadaveric dissections are far more detailed than those recorded in leading Anatomy textbooks or dissection manuals (Gray’s Anatomy 1995, McMinn 1993, Grant’s Method of Anatomy 1958, Last’s Anatomy 1964, Cunningham’s Anatomy 1993, Boulieau Grant’s Atlas of Anatomy 1964, Tobias’s Man’s Anatomy 1963, Clementé’s Anatomy 1993, Cunningham’s Dissection Manuals I, II, III, Netter’s Human Anatomy Atlas 1993). New terminology is suggested and introduced regarding previously unnamed side branches that are not accurately documented in the **existing** anatomy literature. The current cadaveric dissections, based on latex fixation of the smaller facial and temporal arteries helped create the basis for the clinical introduction and application of the nasal flap. This was based predominantly on the anatomical presence of the angular artery and central vein. This is a unique contribution to gross anatomy and emphasizes the need for a comprehensive anatomical knowledge of this area if flap surgery is anticipated. The dissertation therefore has two important components: <u>a cadaveric basic science anatomy dissection</u> component and a <u>clinical flap application section</u>, based on new knowledge derived by human dissection at the University of Stellenbosch.

CHAPTER 2

LITERATURE REVIEW & AIMS

- **Review (History, Arteries, Veins, Doppler)**
- **Clinical problems and criticisms**
- **Aims of the study**
- **Research questions**
- **Hypothesis tested**
- **Study groups**

1. Relevant literature review:

1.1 Historical review:

There is evidence that as far back as 3000 BC ancient surgeons had a good approach to surgical and medical problems. The earliest recording of a forehead flap for nasal reconstruction was about 500 to 600 BC by Sushruta. The Indian rhinoplasty method was used since time immorial and there is some controversy whether Sushruta's flap was a free graft based on a leaf configuration. Sushruta probably had a fairly good understanding of the underlying blood supply using the angular artery because they initially used nasolabial flaps for nasal reconstruction. Forehead Flap necrosis was also reported and encountered frequently. This suggests that the anatomical variations of the angular artery was not completely analysed and that the arterio-venous relationship of the central forehead was not understood. It is clear that in the time 500 BC, the art of surgery was quite refined and then, almost all the surgical knowledge gained by the Indians was lost after the Mohammedan conquest in 997 AD by the Arabs.

Lascaratos et al, (1998) suggest that the Arab surgeons learned their skill from Byzantine sources, and ignore the fact that the Arabs conquered India in 997 A.D. (the Mohammedan conquest), and most likely learned their skills directly from Indian surgeons (Eisenberg, 1982).

Religious beliefs hindered the development of surgery in the Middle Ages. Surgery was even banned and outlawed by Pope Innocent III. Certainly the dissolution of Rome by barbaric hordes contributed to the rapid loss of surgical knowledge and skill. Surgery became a disrespected discipline and was scorned upon by politicians and religious leaders.

The Branca's and Tagliacozzi re-awakened nasal reconstruction in the 16th century (Eisenberg, 1982; Micali et al, 1993). In spite of the fact that Tagliacozzi was a renowned Professor of Anatomy and specialised in nasal reconstruction, he made no significant contribution to the use of forehead flaps for nasal reconstruction. He is best known for using bipedicled arm flaps for nasal reconstruction.

It was not until 1794 that this operation became known to the West. Joseph Carpue did the first Indian rhinoplasty in the West in 1814. Since then nasal reconstruction spread rapidly in Europe and the rest of the world (Eisenberg, 1982).

The forehead flap was introduced to America by Kazanjian (1946), who stressed the need to preserve both supra-trochlear arteries and to limit the inferior extent of the dissection to the eyebrow level. This became known as the midline forehead flap and the extent of coverage was often inadequate to cover the caudal aspect of the nasal framework. Millard (1966) then tried to improve the reach problem by designing a para-median pedicle based on a single supra-trochlear artery. It is clear that the midline forehead flap introduced to America was technically different from the Indian method described by Sushruta and is an example of how information translated from one continent to another, in those times, could become distorted. Certainly there were European surgeons (Labat, Lisfranc and Dieffenbach) in the 19th century who already developed modifications of the forehead flap pedicle base and extended it fairly successfully below the level of the eyebrow (see McCarthy's Plastic Surgery). It is thus fair to assume at the time that America was approximately 100 years behind in rhinoplasty developments compared to Europe. With the better rotation and reach obtained with the para-median forehead flap design, the midline forehead flap design (as described by Kazanjian) became less popular after the mid 1960's and there has been a common feeling since then that the para-median forehead flap is the “better flap”. From an anatomical point of view, Ahn et al only mention that one supra-trochlear artery tends to dominate, and that a Doppler probe can be used to locate the dominant artery (Ahn et al, 1998).

Some variations of the classic median forehead flap then developed of which the paramedian forehead flap is the most popular in nose reconstruction. Oblique and transverse forehead flaps were also described. Flap design modifications were described such as the trilobed flap.

Ortiz-Monasterio et al, (1984) commented on a previous article by Marcus and Mazzola (Plast Reconstr Surg; 1983; 72: 408), who wrote about the history of nasal reconstruction and tried to identify the originator of the folded forehead flap. Ortiz-Monasterio corrected the claim by Marcus and Mazzola that Pierre Auguste Labat in 1834 was first to propose a trilobed flap for nasal reconstruction. Labat gave credit to J.M. Delpech's work in 1821.

This trilobed concept was thus developed before Ernst Blasius (1802-1875) published his design of a three-'fingered' forehead flap. Blasius was 19 years old then and his design is therefore just a small modification of the idea of Delpech **(Micali et al, 1993)**

1.2 <u>Arterial forehead anatomy literature review:</u>

Anatomical studies of forehead flaps focused mainly on arterial inflow into the flap. Merkel and Kallius (1910) according to Mangold et al. (1980) attributed the bloodsupply of the central forehead to vertical branches from the dorsal nasal artery (DNA). These branches supply the median forehead flap. There is no description in Plastic Surgery literature of the dimensions, anatomical relationships and vascular pattern variations of these vessels that could be confidently applied to median forehead flap planning, especially if one needs to do flap pedicle modifications. Another point of uncertainty, is the level at which one dissects.

The bloodsupply of the paramedian forehead flap is derived from the supratrochlear artery (STrA), an end branch of the ophthalmic artery (OA). Shumrick and Smith (1992) showed that the STrA runs from the medial superior orbit, usually 1, 7 to 2, 2 cm from the midline, superiorly over corrugator supercillii and pierces through orbicularis oculi and frontalis just below the eyebrow level, continuing superiorly in a subcutaneous plane.

Hollinshead (1954) according to Hayreh (1962) found that the STrA usually pierces the orbital septum to enter the scalp, but may arise anterior to the septum. Hayreh (1962) from 59 orbits found that the OA usually terminates in the STrA and DNA (83%). Other possibilities are STrA & supra-orbital artery (SOA), STrA & DNA & SOA, STrA & DNA & inferior medial palpebral artery (IMPA) and finally the IMPA as a main continuation. The STrA was usually the larger of the two end branches of the OA, but at times equal to the other and rarely smaller. No study has specifically looked at variations in vascular patterns of the STrA in the forehead or described its branches in the forehead.

No modern forehead flap is based on the SOA. Older textbooks have descriptions of oblique forehead flaps based over the SOA origin. Mangold et al (1980) showed that the SOA did not contribute significantly to the overlying skin. It runs at a periosteal level deep to the frontalis muscle. Quain (1892) and Whitnall (1932) according to Hayreh (1962) described the SOA as inconsistent. Meyer (1887) according to Hayreh (1962) is considered the pioneer in the study of the OA and found the SOA absent in 1 out of 20 cases and weakly developed in 3. Hayreh (1962) found the SOA absent in 18, 2 % of specimens where the OA crossed over the optic nerve and absent in 7,1% where it crossed under the optic nerve. It was of medium size in 70 %, abnormally big in 20%, and very small in 10 %.

Horizontal forehead flaps rely on bloodsupply from the frontal branch of the superficial temporal artery (FBSTA). Theodore Dunham (1893) according to Conway et al. used a horizontal forehead flap that crossed the midline for a short distance and it survived with a 5:1 length to width ratio.

It has been well known since then that the face has a good bloodsupply and flaps can survive with a longer length to width ratio than for the rest of the body (1, 5: 1) (Cormack & Lamberty, 1994). Schroder (1967) and Merkel (1980) according to Mangold et al. (1980) also noted communication across the midline between the FBSTA. Behan & Wilson (1973, 1976) according to Cormack and Lamberty (1994) injected radio-opaque media into one superficial temporal artery (STA) in isolated forehead skin of cadavers. They clearly demonstrated flow across the midline and that the dynamic territory of a single STA is made up of four separate angiosomes (Cormack & Lamberty, 1994). The identification of the horizontal level where the FBSTA communicates across the midline has not been mentioned in the literature. In order to raise transverse forehead flaps based on these transverse communications they need to be localized and the anatomical variations clarified.

McGregor & Morgan (1973) according to Cormack and Lamberty (1994) coined axial and random pattern flaps and clarified their distinction. They also showed the existence of a vascular equilibrium between adjacent anatomical territories that can shift if the intravascular pressure in one becomes higher or lower than the other. Smith (1973) showed that random

pattern flaps survived at a 1:1 length to width ratio in rabbits (Cormack & Lamberty, 1994).

Behan & Wilson (1973, 1976) showed how separate anatomical territories can link up to form dynamic territories. They proposed the term angiotome for 'any area of skin that can be cut as a flap which is supplied by an axial vessel but may be extended by its communication with branches of an adjacent vessel'. They showed by injected radio-opaque media into one superficial temporal artery (STA) in isolated forehead skin of cadavers that the medium was able to move across the anatomical territories of the SOA and STA and fill the contralateral STA. The principal vessel supplying the flap was termed the prop artery. The dynamic territory of the forehead, when supprted by one prop artery from the STA, was made up of four angiotomes (the SOA and STrA from both sides of the forehead).

With the better understanding of the bloodsupply and the introduction of axial pattern flaps and later musculocutaneous flaps and fasciocutaneous flaps the length to width ratio of flaps could be increased (McCarthy's Plastic Surgery, 1990). Workhorse flaps of the seventies were axial flaps such as the groin flap (McGregor and Jackson), the deltopectoral flap (Bakamjian) and the temporal based forehead flap.

With the later spread of microsurgery many other donor sites for reconstruction became available. Yet today the standard flap for nasal reconstruction does not require microsurgery and is still a pedicled axial flap.

No previous study has compared the three main arteries of the forehead (FBSTA, STrA and SOA) in terms of their anatomical variations.

Bunkis et al, (1992) presented a 21 year retrospective analysis 17 patients illustrating changing methods for cheek reconstruction. Two forehead flaps were used among other flaps, and from their discussion it was probably based on the Frontal Branch of the Superficial Temporal Artery (FBSTA). This laterally based forehead flap was first described in 1898 (**Cormack & Lamberty, 1994**). Blair first used it for cheek reconstruction in 1933, and it only became popular in 1963 when McGregor used it. At the time, the forehead flap heralded the introduction of the axial vessel concept in cheek reconstruction. **Bunkis et al** made no reference to using a midline forehead flap for cheek reconstruction is made. **Their** discussion does not cover the blood supply in detail or the flap design of the laterally based forehead flap.

Thatte et al, (1990) presented their technique for nasal ala reconstruction with two flag flaps based on the supra-trochlear vessels in a patient with a short forehead, and discussed the problem of a short forehead that precludes the use of a median forehead flap for defects of the lower nose when both cover and lining are needed. In their historical overview they credit the folding of the forehead flap to Serre (1842), and also mention that Calderini credited Petrali (1842).

As discussed previously, the concept of folding of the forehead flap in the last 3 centuries has been credited to J.M. Delpech in 1821 (Ortiz-Monasterio, 1984). The idea of using two flaps from the forehead was mentioned by Blasius

(Hauben, 1984) and therefore it is not original. If one accepts that forehead flaps were performed from at least 500 BC, then it is not unlikely that folding of the flaps were experimented with previously. Since there is no written proof from ancient text, it is fair to credit Delpech with folding of the forehead flap for lining. In the design of the forehead flap by Thatte et al., notes that the pedicle base ended at the eyebrow level. Comparing this to the technique presented in this thesis, there is a loss of almost three centimeters at the pedicle base. This represents a significant difference and it is surprising that Thatte et al. based their flaps so high, especially since pedicle base refinements were published in European literature in the 19th century. Here the contributions of Labat, Lisfranc and Dieffenbach are notable. Another criticism of the technique of Thatte et al, 1990, is that they didn't consider the venous drainage of their flaps, but on that point every previous forehead flap technique can be criticized. It comes as no surprise that Thatte et al.'s flaps became "dusky" at the initial operation, and were delayed for a week before final inset. The cosmetic result of these authors is not favorable, and a better result could have been achieved if the total nose was reconstructed as an aesthetic unit, avoiding the patchy appearance. Thatte et al. mention the possibility of using this flap as an island flap, in a one-stage operation, by removing a skin bridge over the vessels. It is obvious that a flap that becomes dusky at the first stage is going to be even worse off if a skin bridge is removed and the pedicle tunnelled in a one-stage procedure. It is possible to plan a one-stage forehead flap that has no vascular compromise, only if both arterial inflow and venous drainage is considered. This is demonstrated and discussed later in this dissertation.

There is no doubt that since the introduction of the para-median forehead flap it has become more popular than the median forehead flap **(Rohrich et al, 2004; Lee et al, 2004**). **Winslow et al, (2003)** mention that the para-median forehead flaps is most commonly the optimal choice for reconstructing large skin defects on the nose. The median forehead flap, as used by most modern surgeons, with a high pedicle base is probably not thought of as optimal where a large area of tissue is needed, mainly because of the limitations of a high pedicle that decreases flap length and where pedicle rotation may compromise flap circulation.

Zuker et al, (1996) reproted on tissue expansion of the forehead and post-operative shrinkage of the expanded skin that led to alar retraction.

To lessen the forehead donor site scar is favourable for patients with long hair. In Africans with frizzy hair the scalp scar will be more noticeable than a midline forehead scar with time. By utilizing the method of the midline forehead flap shown in this dissertation, the need for tissue expansion will become less. The complication of late flap contraction with expanded skin is also most undesirable.

Any technical forehead flap refinement that can allow for better pedicle length and thereby avoiding tissue expansion of the forehead is of great value.

Pedicle length problems related to design errors are common in the literature (Mclean et al, 1982; Furuta et al, 2000; Rapidis et al, 1998; Rebeiz et al, 1995).

Landmarks of the forehead for flap planning are not well described. Hinderer et al, (1987) mention a vertical line at the lateral canthus. **Siegle (1991)** classified forehead defects as: midline, para-median, or lateral. **Siegle** focused mainly on small local flaps in the forehead and temporal regions for closure of forehead defects.

Misconceptions about the blood supply of galeal flaps are found in the literature highltighting the need for detailed anatomy. **Lari et al, (2002)** describe the blood supply of the galea frontalis flap as coming from the supra-trochlear and supra-orbital arteries from both sides. They acknowledge that the blood supply of this flap has been studied extensively **(Potparic et al, 1996; Fukuta et al, 1994).** The lack of acknowledgement of the contribution from the central artery, dorsal nasal artery and para-central artery (from the angular artery) is a reflection of the poor understanding of the blood supply of the last named arteries. The authors mention that the pericranial vessels do not cross the midline. This is wrong and is proven in the results of this dissertation.

Many existing flaps described have vague descriptions of the bloodsupply and this can be clarified by detailed anatomy studies of the vasculature.

The reverse temporal artery island flap described by Shiau Duen-hern (2003) relies on the reverse arterial flow of the frontal branch of the superficial temporal artery (FBSTA). The author does not elaborate on the specific vascular anatomy of the FBSTA. From the figures shown it is the ascending frontal artery (AFA) that is included in the flap planning. The transverse frontal artery (TFA) which is the other terminal branch of the FBSTA has a transverse course to supply the forehead. The oblique branch of the supra-orbital artery also anastomoses with the TFA or FBSTA along the lateral orbit vertical, usually in the middle transverse third of the forehead.

A surgeon can use a forehead or brow incision for correcting frontal sinus problems and therefore the knowledge of the underlying anatomy is applicable **(Arole et al, 2002; Baroudi, 1964).** The coronal incision is usually preferred. The osteoplastic operation of the frontal sinus involves complete removal of the mucous membrane and sinus obliteration. Some of the complications of the operation are persistent frontal anaesthesia and supra-orbital nerve neuralgia. **The dissection plane for avoiding nerve injury is important and needs to be shown in relation to the blood supply of the forehead.**

1.3 <u>Venous Forehead Anatomy Literature review</u>:

There are no descriptions of venous forehead flaps and therefore the venous drainage has not received any attention. All forehead flap descriptions only refer to the arterial supply and venous drainage is ignored. Taylor et al. (1990) noted that the forehead veins follow the connective tissue architecture and converge from mobile to fixed areas. The veins of the forehead converge to the supero-medial orbit. Vast networks of avalvular oscillating veins exist in most of the face. Most

valves are osteal valves located at the entry of the oscillating veins into the larger directional veins.

Superficial veins of the forehead and scalp can be revealed by constriction at a level below the ears and above the brow. Waterson 1988 studied venous drainage in muscles (Cormack & Lamberty, 1994). Phillip Corso observed that the venous drainage of the forehead was mostly in the muscle compared to the arterial supply that was mostly cutaneous (Corso, 1961).

The design of the island flap in the midline of the forehead as suggested by **Converse and Wood-Smith, 1963**, without reference to the venous drainage shows a technical oversight in the planning of the flap. Since there often is only one prominent vein, which is usually just displaced from the midline on one side, the positioning of the midline forehead flap design becomes critical. The object should be to secure not just adequate arterial inflow, but also optimal venous drainage and flap outflow. This is the reason for the venous congestion and oedema experienced by some surgeons, and explains why this method has not become popular compared to the standard pedicled flap.

It is not entirely true that the temporal flap has a superior blood supply to any other forehead flap as proclaimed by **Eiseman (1978**). The question of which flap has the best bloddsupply can only be answered by the arterial and venous studies of the forehead as in this dissertation.

The possibility of incorporating venous drainage into a potential flap design of the forehead needs attention.

The importance of venous drainage in the temporal flap:

The inferior branch of the superficial temporal vein was seen anterior to the arteries and nerves over the supra-orbital rim, and posterior to the muscles over the supra-orbital rim in the specimens dissected in this study. This is quite low and an incision on the superior margin of the eyebrow is no guarantee of inclusion of this large vein.

Errors in the understanding of the forehead venous drainage as well as the arterial supply are commonly seen in modern literature. This leads to more flap necrosis (Goncalves et al, 2001; Iwahira & Muruyama 1993, Chiarelli et al, 2001).

The major **flap** design flaw **by Goncalves et al, (2001) is** not in the pattern of the flap, but rather in the ignorance of the relevance of the central venous drainage, and consequently **the authors had a high incidence of necrosis**. Had they appreciated the central vein concept of forehead flap planning, they would probably not have had any necrosis. Also the anatomical relationship of the AA and DNA was not appreciated by the authors and this explains their inferior method of pedicle base design and pedicle rotation, leading to more tension on the pedicle that would have compromised their flaps.

Several vague ideas about the blood supply of the para-median forehead flap and the blood supply of the forehead in general are evident in the letter of **Riggio, 2003.** Firstly, a correctly (narrow) designed para-median pedicle will only have the supra-trochlear artery in its pedicle. A broader pedicle, of which the medial border is medial to a vertical line 5 millimetres medial to the medial canthus (the line of the angular artery at the medial canthus), can include the para-central artery from the angular artery if it is present. To include the supra-orbital artery would imply that the pedicle lateral border must extend at least one centimetre lateral to the vertical line of the supra-trochlear artery. Dissecting the pedicle off the periosteum below the supra-orbital rim can be done safely, but is also very risky (from a venous thrombosis point of view). The neurovascular bundle at the supero-medial orbit can also easily be damaged. This will predictably result in a neuropraxia. No concept existed before for the inclusion of a vein in the forehead flap and this could also explain why the lower half of the flap necrosed in his case report. Since the central vein varies in its branching, it is sensible to know the venous drainage pattern of the central forehead and include it in the flap planning. This is an important determining factor in order to select the pedicle design and placement in the midline forehead flap. The para-median forehead flap should be reserved for cases where a midline forehead flap is not safe i.e. previous scarring over the glabella or nose bridge (i.e. the vasculature may be compromised).

Utley et al, (1998) highlight that impaired venous drainage kills flaps quicker than impaired arterial drainage.

Rohrich et al, (2004) reported a 1.2 percent revision rate and thirteen partial flap necroses required revision in 1334 nasal reconstructions. Seventy five percent of reconstructions were completed in two stages. The para-median forehead flap was used in the majority of cases (532 cases; 40 % of the total). Naso-labial flaps were used in 360 cases. No midline forehead flaps were used.

Complications not requiring revision were not included. Of the 16 patients (1.2%) that had complications, twelve were smokers. Nine of the sixteen was associated with forehead flaps. The total number of procedures ranged from one to six. The authors have found that axial flaps such as the forehead flap, naso-labial flap or dorso-nasal flap yield the best aesthetic results. They also suggest the application of less staged flap interventions as there was a trend in certain units in America (Burgett and Menick) to use at least three stages. They used primary de-fatting of the flaps and believe it contributes to less secondary procedures. They are also of the opinion that the para-median forehead flap is the best flap. In summary the authors propose: maximal conservation of native tissue, reconstruction of the defect and not the subunit, the application of primary dermabrasion or laser, primary de-fatting in non smokers, the use of axial pattern flaps, and finally good contour as the aesthetic end point.

The incidence of partial flap necrosis that did not require any revision is not mentioned. Flap necrosis where revision was required, but was not performed for reasons such as patient death or patient lost to follow-up is not mentioned. No midline forehead flaps were used by the authors. This reflects the flap reconstruction trend since the popularisation of the para-median forehead flap by Millard, Shumrick, Burget, Menick and others in the previous century. The para-median forehead flap has become the modern standard **(Rohrich et al, 2004; Lee et al, 2004**), based on the fact that the arterial supply is clearly described and the assumption that the midline forehead flap if based on a narrow pedicle has a risky blood supply. **This is also evident from the fact that the axial vessel in a narrow midline forehead flap has no name.**

The liberal use of primary de-fatting is of concern and this could have led to the few incidences of flap necrosis experienced. Secondary de-fatting at the time of flap inset does not account for an additional stage and is anatomically safer.

The risk of distal flap thinning is acknowledged and it is assumed that it is only a risk factor in smokers **(Sherris et al, 2002; Rohrich et al, 2004**). **The possibility of arterial variations contributing to necrosis is not mentioned**. Based on the variation of the supra-trochlear artery seen in one specimen of this study, where the artery entered the muscle in the middle third and went superiorly at a periosteal level, it is quite possible that this variation could contribute to flap necrosis regardless of whether the patient was a smoker.

Zilinsky et al, (1999) reported an incidence of flap necrosis of almost **30 percent (2/7).** Smoking is identified as a major risk factor. The authors fail to comment on whether the necrosis was related to arterial or venous problems. Two mechanisms of necrosis can be postulated here:

<u>Venous</u>: In the planning of the flap, no attention is given to the venous drainage. Since the vein is superficial in the subcutaneous forehead, its position will be inverted as the pedicle is twisted. As the skin is less pliable than the subcutaneous layers, the most tension will be converted to the base of the pedicle on the skin side, which is directly over the veins in that area. This could explain the high necrosis rate of the authors.

Arterial: Their pictures also show a high pedicle base at the level of the eyebrow, which would make the blood vessels in the flap encounter an acute angle at the pedicle from a vertical superior course to a posterior inferior direction toward the supero-medial orbit. A lower pedicle design can overcome the acute angle created leading to less turbulent flow and chances of vessel occlusion.

1.4 Doppler forehead studies literature review:

Ahn et al, (1998) used a hand-held Doppler to identify the StrA and mentioned that one side tends to be dominant. They tried to identify the dominant StrA. Motomura et al, (2003) used a Doppler probe to identify the FBSTA before surgery. This artery is also readily visible and palpable in the temporal region and lateral forehead.

The rest of the literature relevant to this study is reviewed in the discussion sections of the cadaver and clinical studies.

1.5 CLINICAL PROBLEMS:

If standard axial pattern flaps are not possible as a reconstructive option as a result of previous injury of the arteries, then this would exclude the forehead as a potential donor site. In the case of nose reconstruction, the forehead has been known from time immemorial to be the best or a favouable donor site for nose reconstruction. Therefore, if it cannot be used as a result of arterial damage, the best option for nasal reconstruction may have to be reconsidered. If however there is some possibility of advancing a forehead flap based on an atypical or unnamed arterial pedicle, the forehead as donor site can still be considered. The possibilities of forehead flap designs have not been investigated extensively. Many flap designs to expand the reconstructive arsenal have previously been proposed (see MMED Plast Surg Dissertation, Stellenbosch University, 2003, Medical Library Tygerberg Campus).

The practicality of these flaps can only be assessed if the arterial and venous variations of the forehead are fully understood and integrated.

The vascular anatomy of the central forehead has never been explained in sufficient fine detail to provide the plastic and reconstructive surgeon with specific and accurate landmarks for forehead flap pedicle designs. Most descriptions of the blood supply, including arterial side branches in this area, are vague, ill defined and small arteries and veins are poorly classified. It was Millard (1966) who suggested that the supra-trochlear artery be utilized in the pedicle and so the *para-median forehead flap* developed, presumably based on the assumption that the chief blood supply was more clearly described than for the classic midline forehead flap. The para-median forehead flap has become the preferred standard in modern times. The venous drainage of the flap has been ignored and these flaps have always been described as "*arterialized*" flaps. Temporal based forehead flaps, based on the frontal branch of the superficial temporal artery, are characterized by simple flap designs that usually include large areas of the forehead.

EXISTING PROBLEM WITH CONVENTIONAL FOREHEAD FLAPS:

1.5.1 The existing conventional plan for the design of forehead flaps has been that axial pattern flaps (flaps based on a reliable arterial axis) can be utilized (Grabb and Smith's Plastic Surgery, 5th Ed., 1997 Lippincott-Raven; Plastic Surgery, McCarthy JG, 1990 WB Saunders Company; Rohrich et al, 2004).

CRITICISMS:

1. This plan for the central forehead reconstruction does not take the central **venous drainage** of the forehead into account.
2. The **paucity of knowledge** regarding the consistency or terminal branching of the angular artery has made that the median pedicled forehead flap based on the angular artery be considered inferior to the supratrochlear artery based forehead flap.
3. In the event of damage to a supratrochlear artery, there is no reference in the existing literature **recommending** the midline forehead flap.

1.5.2 There are only a few alternative flap designs of the forehead proposed in the literature (Grabb and Smith's Plastic Surgery, 5th Ed., 1997 Lippincott-Raven; Plastic Surgery, McCarthy JG, 1990 WB Saunders Company).

CRITICISMS:

1. The shortage of alternative flap designs of the forehead limits reconstructive options with the forehead as donor tissue.
2. This may also lead to the exclusion of the forehead as a donor site although theoretically there may still be forehead flap designs possible, that are

unconventional and not accepted as a result of a lack of knowledge of the forehead blood supply. The best tissue for reconstruction may thus be discarded as a reconstructive option because of ignorance of the blood supply of the forehead.

1.5.3 No model of venous forehead flaps exists in theory or practise (See Literature review).

CRITICISMS:

1. Venous-based forehead flaps may not be of clinical significance but if not investigated, we will never know.
2. Venous-based flaps may be a reconstructive option when axial flaps are not available.

1.5.4 Anatomical descriptions of the blood supply of the central forehead are vague and non-specific.

This has led modern plastic surgeons to prefer the forehead flap based on the supratrochlear artery, compared to the central forehead flap, as the flap of choice for nasal reconstruction.

CRITICISMS:

1. No definition of the termination of the angular artery exists, but some details are provided in Gray's Anatomy.
2. There is no accurate study of the arterial variations of the forehead.
3. There is no axial artery of the midline forehead flap specified.
4. Inaccurate descriptions of the blood supply of the midline forehead flap are the norm.

5. Non-specific landmarks exist for the limitations of pedicle modifications of the midline forehead flap.
6. The alternative possible arterial axis of the forehead may not be fully explored.
7. Potential flaps may thus be developed based on a better understanding of the anatomy and the safety and reliability of existing flaps may be increased.

1.5.5 There is no emphasis on the three-dimensional view of the vascular anatomy of the forehead when learning forehead flap techniques from text books.

<u>CRITICISMS</u>:

1. Anatomy knowledge is the road map for the surgeon when operating. If this knowledge is incomplete and not accurately visualized, unnecessary and unpredictable complications may occur.
2. No accurate illustrations demonstrating superficial versus deep branches of the forehead arteries exist.
3. By presenting the anatomy more accurately in textbooks and showing the vascular supply at several levels or using additional audiovisual presentations of dissections, accuracy of surgery will increase.

1.5.6 Temporal based forehead flaps are not considered a reconstructive option for nasal defects.

<u>CRITICISMS</u>:

1. The possibilities of utilizing the transverse forehead flap axis for nasal reconstruction have not been exploited.

1.6 AIMS AND OBJECTIVES:

The basic science component of the study focuses on the vasculature of the forehead (and variations) and the anatomical relationships regarding the potential application of forehead flaps in reconstructive surgery (nasal rhinoplasty). The goal of the anatomical study was to identify constant arterial patterns and variations that one may encounter when operating on the forehead. By knowing the vascular variations it is theoretically possible to increase the safety of forehead flap application and possibly reduce the incidence of post-operative flap necrosis. Constant landmarks for safety planning and harvesting of the pedicle of the midline forehead flap, based on previous anatomical documentation, have been poorly described. The arterial patterns (and venous drainage) of the forehead, can be used to validate previous forehead flap designs. The mystery that is hidden in the blood supply of the central forehead, that is, the exact arteries and veins and their relationship in supplying the forehead, has never been adequately clarified in the literature. This study will attempt to document the finer details of the blood supply in this area. Potential new flaps that can be developed and based on this knowledge are demonstrated.

6.1 Major Aims:

1. To investigate arterial variations of the forehead.

2. To investigate the central vein of the forehead.

3. To explore the surgical application of the new anatomy knowledge.

6.3 Minor Aims:

1. To validate forehead flap designs from the pilot study.

2. To identify consistent forehead landmarks for flap planning.

3. To investigate the clinical application of a hand-held Doppler in identifying forehead arterial variations.

1.7 HYPOTHESES TESTED:

1. Forehead flap design for nasal rhinoplasty can be safely based on a sound anatomical understanding of the underlying vasculature.
2. Anatomically, arterial patterns in the forehead can be divided into 3 axes (vertical, transverse and oblique).
3. There are two prominent anatomical venous axes of the forehead (vertical and oblique).
4. Unique frontal flaps can be safely based on the presence of the central vein “method” and anastomosing branches of the frontal ramifications of the angular artery (AA).

5. Doppler examination is a suitable, non-invasive and objective method to assess forehead flap pedicle vasculature, preoperatively.

1.8 RESEARCH QUESTIONS:

1. What anatomical arterial variations exist in the central forehead?
2. How does the angular artery (AA) terminate?
3. What is the incidence of origin of the oblique branch of the supra-trochlear artery (STrA)?
4. Is there a central artery (CA)?
5. Is there a constant arterio-venous anastomosis at the base of the central vein (CV) in the glabella area?
6. What landmarks can be used to identify the arteries of the central forehead?
7. What is the relationship of the veins to the arteries?
8. What is the relationship of the nerves to the arteries?
9. How can the anatomical knowledge be applied clinically with regard to flap reconstruction?
10. How can forehead flap design and execution be made safer by the applied anatomical and morphological research?
11. What clinical value and potential application is there from the detailed knowledge of the arterial variations of the forehead?
12. Does a hand-held Doppler examination help in identifying the flap pedicle?

1.9 SCIENTIFIC BASIS AND VALIDATION OF THE CURRENT DOCTORAL STUDY

The current study and motivation for research has many advantages over other published studies:

1. Prospective nature: Clinical application and flap decision making is based on basic science end-point analysis and measured outcomes in a human cadaveric study.
2. Power factor of cadavers: largest documented cadaveric study at present.
3. In-depth, anatomical study of the forehead vasculature based on dissection (and comparison/ correlation with existing publications, albeit small studies).
4. Clinical application of reconstructive flaps based on anatomical dissection, study of vasculature, including variations.
5. Application of Doppler examination to confirm vasculature **variations** of pedicled forehead flaps (arteries).
6. Value of three-dimensional dissection in a large cohort of human cadavers, thus avoiding misconceptions that potentially occur if only arteriography is utilized to demonstrate vasculature (see Shumrick et al, 1992, pp 373).

7. Application of the high frequency ultrasound in the diagnosis of solar skin damage and follow-up of skin basal cell carcinoma (BCC), in one patient that underwent reconstructive surgery.

2. Original contributions of the research to the existing medical literature:

See chapter 6 for detail:

1. New perspective and anatomical terminology of forehead vasculature (arteries and veins) based on an original cadaveric dissection study at the University of Stellenbosch and relevant to clinical forehead reconstructive surgery for nasal defects.
2. Development of clinically applicable forehead and nasal flaps for plastic and reconstructive surgery based on the central vein and angular artery method.
3. Development of novel flaps, based on detailed anatomical dissection, for facial reconstruction.
4. Application of Doppler examination to elucidate arterial and venous status of forehead flaps as well as negative factors.
5. Documentation of dermal atrophy, collagen stock loss by high frequency ultrasound in a patient with recurrent forehead basal cell carcinoma (BCC) undergoing reconstructive surgery.

2.1 DOCTORAL STUDY GROUPS:

The study has two arms: Anatomical and clinical application (Phase-1 study), based on new basic science and anatomical knowledge.

Basic Sciences:

2.1.1 <u>Anatomic or cadaveric (dissection) study</u>:

30 randomly selected adult cadavers

(Latex filled and 20 non-filled control cadavers)

2.1.2 <u>Histological study</u>:

20 cadaver foreheads and nasal zones

2.1.3 <u>Additional cadaveric flap technology (N=5)</u>

Clinical Study

3.1) ***<u>Case Studies</u>***. 12 patients (Phase-1 study)

3.2) ***<u>Doppler study</u>*** 12 patients (identification of vascular pedicles)

3.3) ***<u>Flap transfer studies</u>*** 12 patients (Phase-1 study)

3.4) ***<u>Application of new anatomical knowledge</u>*** in the application and design of forehead flaps for nasal reconstruction (rhinoplasty)

End-point analysis refers to conclusions drawn from the studies.

CHAPTER 3

GROSS AND APPLIED ANATOMY RELEVANT TO FOREHEAD FLAP RECONSTRUCTION SURGERY

GENERAL ANATOMY, EMBRYOLOGY, DERMAL HISTOLOGY PERTAINING TO THE ANTERIOR FACE AND RELEVANT TO FOREHEAD FLAPS IN PLASTIC AND RECONSTRUCTIVE SURGERY

- Terminology: “Angiosomes” and venosomes
- Applied anatomy: Flap arterial inflow and outflow
- Central forehead vein: Application for methodology of novel flaps
- Demographics of cadavers (Gross Anatomy)
- Venous Anatomy: Metanalysis (Applied Anatomy)
- Metanalysis: Applied Anatomy (cadaver studies by other authors)
- Face, superficial muscles (anterior aspect): muscles of expression
- Embryology of the face (including molecular regulation)
- Vascular and innervation
- Motor innervation of the face (anterior)
- Sensory innervation of the face (anterior)
- Histology of the facial skin

GLOSSARY: TERMINOLOGY AND DEFINITIONS PERTAINING TO EMBRYOLOGY AND ANATOMY (REFERRED TO IN THIS THESIS)

1. Gastrulation: Process by which a blastula becomes a gastrula, process by which three germ cell layers are acquired (Dorland's Medical Dictionary).
2. Embryonic period: Also called period of organogenesis (occurs from the 3rd to 8th week of development). At this time three germ layers give rise to specific tissues and organs (Sadler 2004).
3. Fetal period: Period from the beginning of the 9th week to birth. Characterized by maturation of tissues and organs and rapid growth of the body (Sadler 2004).
4. Somite: Paired, blocklike mass of mesoderm, arranged segmentally alongside the neural tube of the embryo (Dorland's Medical Dictionary).
5. Branchial: Resembling the gills of a fish (Dorland's Medical Dictionary).
6. Development: Process of growth and differentiation (Dorland's Medical Dictionary).
7. *Hox-genes*: Special gene cluster called the *hox cluster.* Play an important role in morphogenesis and cell differentiation.
8. Anatomy: Gr. *ana*- part+ *tome* a cutting
9. Cartilage: L. *cartilage* gristle
10. Cephalic: Gr.*Kephale* head
11. Chondro: Gr.*chondros* cartilage
12. Dermatome: Gr. *derma* the skin + *tome* a cutting
13. Dermis: Gr. *derma* hide, skin
14. Dorsum: L. the back
15. Epidermis: Gr. *epi*- upon + derma skin
16. Infra-prefix: L. beneath
17. Median: L. *medianus* in the midline
18. Metopic: Gr. *metopon* the forehead

19. Morphology: Gr. *morphe Form* + logos *discourse*
20. Myotome: *Mys* muscle + *tome* a piece cut off
21. Palpebra: L an eyelid
22. Parotid: Gr. *para*- near + *otos* ear
23. Procerus: L *pro* – instead of + cerus L. from Gr. *keros horn*
24. Supra- prefix: L. above
25. Suture: L. *Sutura* a seam
26. CN: Cranial Nerve (See Last's anatomy, 1993)

EMBRYOLOGY OF THE FACE: DEVELOPMENT OVERVIEW RELEVANT TO THE DOCTORAL STUDY

Important landmarks and components of the developing face have been cited by Sadler 2004, 1995 and Larsen 1997. Both the stomodeum and pharyngeal arches form integral components of the developing face (Sadler 2004). Important landmarks in the development of the human face have been cited by Sadler 2004 and summarized as follows:

I. Day 20: (appearance of somites): development week 3 of embryonic life.

II. Day 26: (appearance of branchial arches): development week 4 of embryonic life.

III. Day 35: (differentiation of branchial arches and defects): development week 5 of embryonic life.

IV. Day **36**: (developing face: eye, maxillary swelling and nasal placode visible).

V. Day 37: (developing face: median nasal swelling, nasal pit and lateral nasal swelling visible).

VI. Day 44: (developing face: median nasal swelling, maxillary swelling and nasolacrimal groove visible). Facial prominences consist of neural crest-derived mesenchyme (Sadler 2004).

VII. 5th week: Fronto-nasal prominence, nasal placode and maxillary swelling clearly visible (Larsen 1997).

VIII. Late 7th week: Intermaxillary process clearly visible (Larsen 1997). The medial nasal process fuse at the midline to form the intermaxillary process (Larsen 1997).

IX. 10th week: The intermaxillary process forms the philtrum of the upper lip (Larsen 1997). The nose is formed from five facial prominences (Sadler 2004). Therefore the following structures are critical in the formation of the face: fronto-nasal, maxillary, medial and lateral nasal and mandibular prominences (Sadler 2004). Relevant to plastic reconstruction in this study is the role played by the fronto-nasal prominence: development of forehead, bridge of nose, medial and lateral nasal prominences (Sadler 2004, Bradley 1974, O' Rahilly 2001, Moore 1982, 1988, Baslinsky 1975.

Comment: Sadler 2004 (*Langman's Embryology*) has stressed that the greater component of the human face is derived from neural crest cells that migrate into the pharyngeal arches from the edges of the cranial neural folds. Understanding the molecular regulation of facial development especially the role played by rhombomeres (regulating by fibroblast growth factor III) and *Hox* genes (especially *HOX A3, HOX B3 and HOX D3* is important. A deficiency or excess of retinoids are known to result in severe craniofacial defects (Sadler 2004). Genetics of craniofacial development, *Hox genes* and gastrulation have been reviewed by Sulik et al 1985, Thorogood et al 1997, Trianon et al 2001, Webster et al 1988 and Wilkins et al 2001.

DEVELOPMENT OF VASCULATURE: RELEVANT TO HEAD AND NECK

Key areas in the development of the vasculature are as follows (After Larsen 1998):

- Vasculature is visible at 3 weeks of development.
- First evidence of blood vessel formation is day 17 (blood islands).
- Embryonic hemoblasts form surrounded by endothelial cells.
- Vessel precursors lengthen and interconnect → network.
- Human aortic arches are remnants of the gill vasculature of fishes (pharyngeal arches).
- The third aortic arch forms the common carotid and internal carotid artery. The right and left external carotid arteries sprout from the common carotid arteries.
- “The primitive” embryonic venous system is divided into vitelline, umbilical, and cardinal systems.
- “The bilateral” symmetrical cardinal vein systems are remodeled to drain blood from both sides of the head, neck and body into the right atrium.

- The head and neck are initially drained by an anterior cardinal system.

Important craniofacial anormalies follows malformation of the fronto-nasal process (Larsen 1997). Many have a multifactorial etiology and the importance of the *fetal alcohol syndrome* must be emphasized. A few clinical anomalies are mentioned for interest:

I. <u>Holoprosencephaly</u> (manifestation of the fetal alcohol syndrome caused by the consumption of alcohol during pregnancy).

II. <u>Meckel syndrome</u>

III. <u>Cebocephaly</u>, hypotelorism, cyclopia, trigonocephaly

IV. <u>Craniofrontonasal</u> dysplasia syndrome

V. <u>Hypertelorism</u>

VI. <u>Premature synostosis</u> of cranial vault sutures (Crouzon and Apert syndromes).

VII. Briefly then, *Hox genes* are a special subgroup of “homeobox” genes. They form special gene clusters called the *Hox cluster* or *Hox complex.* *Hox genes* play an integral part in morphogenesis (shaping of body structures and organs). *Hox genes* are in reality selector genes and regulate cell shape formation and cell differentiation. Excessively high concentrations of an acid form of vitamin A, known as retinoid acid, may result in *Hox gene* malfunction leading to head and face malformation (see www.bookrags.com/science). By means of in-situ hybridization, expression of *Hox-7*, can for instance, be detected in the neural fold of embryos, and also in cephalic neural crest (Robert et al 1989, Creuzet et al 2005).

ANATOMY OF THE HUMAN FOREHEAD AND ANTERIOR FACIAL ASPECTS RELATED TO FOREHEAD FLAPS IN PLASTIC AND RECONSTRUCTIVE SURGERY

Osteology: Relevant To the Anterior and Midline Structures Of The Human Face

Although bone grafts do not make out part of this dissertation, it was thought important, from a biomedical science point of view, to briefly describe the deep bony and cartilaginous structures of the anterior face (in the region of the nose, nose bridge and forehead). The important bony and cartilage components are enumerated from superior to inferior (viewed from the anatomical position):

I. Frontal bone (and frontal sinus) (Moore et al, 2006)

II. Frontal process of maxilla (fuses with frontal bone by a suture)

III. Nasal bone (left and right), nasion, glabella, internasal suture, metopic suture

IV. Lacrimal bone groove (Grant 1958)

V. Nasal septum (Grant 1958)

VI. Deep layer: Cribriform plate and perpendicular plate of the ethmoid bone. The nasal septum consisting of the septal cartilage and perpendicular part of the ethmoid lie superior to the vomer (Moore and Daly 2006).

VII. Cartilage of the external nose (after Romanes 1996). Lateral cartilage, lesser alar cartilage, greater alar cartilage with an inferior relationship consisting of fatty tissue of the ala adjacent to the nasal aperture. Deep posterior relation of the nose include, the nasal septum (bony and cartilage components), nasal cavity, inferior concha, inferior meatus, lacrimal fold, nasolacrimal duct, maxillary sinus. Structures lateral to the bridge of the nose, and relevant to flap dissection (i. e. in close proximity to the basal part of the flap) include the lacrimal puncta (superior and inferior), medial palpebral ligament, lacrimal canaliculus, lacrimal sac and nasolacrimal duct (Romanes 1996, Clemente 1997, Gray's Anatomy1995, Mc Minn 1994, Ellis 2002, Grant 1958). The inferior view of the nasal cavities shows the medial and lateral crura of the alar cartilage, fibro-areolar tissue and septal cartilage (Grant 1958).

Muscle attachments (summarized) relevant to the nasal bone, lacrimal bone and frontal bone include (After Romanes 1986, Cunningham 1961, Clemente 1997):

I. Procerus (nasal bone)

II. *Levator labii superioris alaeque nasi* (frontal process of maxilla)

III. Frontal belly of occipito frontalis

IV. Slip of orbicularis oculi (frontal process of maxilla)

FACE: SUPERFICIAL MUSCLES ANTERIOR VIEW (AFTER CLEMENTE 1997)

The relevant musculature pertaining to forehead and nasal flaps are reflected in Table I.

Table I: Superficial muscles of the nasal, forehead, and glabellar regions (facial expression): all supplied by motor fibers (Gray's Anatomy 1996)

Muscle	Nerve supply: innervation
• Frontalis belly, occipito frontalis muscle	Facial nerve (CNVII) [temporal branch]
• Depressor supercilli muscle (Clemente 1997:463)	Facial nerve (CNVII) [temporal branch]
• Procerus muscle	Facial nerve (CNVII) [buccal branch]

• Corrugator supercilli muscle	Facial nerve (CNVII) [temporal branch]
• Levator labii superioris alaeque nasi muscle	Facial Nerve (CNVII) [buccal branch]
• Nasalis muscle	Facial Nerve (CNVII) [buccal branch]

The function of the superficial muscles of the anterior scalp, forehead and nose are reflected in Table II

Table II: Origin, insertion, and action of anterior superficial muscles of the face and forehead (muscles of expression): after Clemente 1997

Muscle*	Origin	Insertion	Action
• **Frontal** belly of occipito frontalis	Continuous with procerus and orbicularis oculi	Galae aponeurotica	Raises eyebrows and wrinkles forehead in expression of surprise
• **Procerus**	Fascia lower aspect of nasal	Skin between eyebrows and	Depression of medial angle of

	bone	lower part of forehead	eyebrow during frowning or concentration
• **Corrugator supercilli** muscle	Medial aspect of supercilli arch	Deep part of skin, superior to the middle of the supraorbital margin	Draws eyebrow medially and inferiorly
• **Levator labii superioris alaeque nasi muscle**	Superior aspect of the frontal process of maxilla	Two slips: alar cartilage and superior of lip with levator labii superioris	Elevation upper lip and dilates the nostril
• **Nasalis muscle**	Transverse part: Maxilla lateral to the nasal notch. Alar part: Maxilla superior to lateral incisor tooth	Bridge of nose, fuses with opposite insertion. Cartilaginous ala of nose	Compress nasal aperture Assist dilatation of nasal aperture in deep inspiration

*After Clemente 1997, *Gray's Anatomy 1995*, Mc Minn 1994, Last's Anatomy.

Surface Anatomy of the anterior aspect and midline of the face, including dermatomes:

The following surface markings are mentioned because of the clinical relevance of marking out and cutting forehead flaps for defect reconstruction on the nose.

I. Forehead, bridge of nose, frontal air sinus.

II. External nose (rigid and cartilaginous parts): Nasal bones, frontal process of the maxilla, ala of the nose, vestibule.

III. Lips and cheeks, vestibule of mouth, maxilla, teeth, maxillary process angle of mouth, chin, mandible, philtrim, margin of mandible, angle of mandible.

IV. Zygomatic arch, zygoma, muscles (sphincters and dilators).

V. Orbit and contents (eye-socket): zygomatic bone and maxilla. Infra-orbital foramen. Supra-orbital foramen and notch.

VI. Frontal process of the maxilla, lacrimal groove.

VII. Eyebrow, superciliary arch, glabella.

Dermatomes of the face (according to Last's Anatomy 1964) are described as follows:

1. Ophthalmic division of N. Trigeminus (CNV): Ophthalmic nerve (I): Relevant branches are:

a). Lacrimal nerve (lateral part of upper lid)

b). Supra-orbital nerve (forehead and scalp to vertex: Mc Minn, 1994)

c). Supratrochlear nerve (middle of forehead up to hair line: Mc Minn, 1994)

d). Infratrochlear nerve (upper lid, "bridge" of the nose: Mc Minn, 1994)

e). External nasal nerve (middle and external nose down to the tip: Mc Minn, 1994).

2. Maxillary division of N. Trigeminus (CNV): Maxillary Nerve (II): Relevant branches:

   a). Infraorbital nerve (palpabral, nasal, labial branches)

   b). Zygomaticofacial nerve

   c). Zygomaticotemporal nerve

3. Mandibular division: of N. Trigeminus (CNV): Mandibular nerve (III). Relevant branches:

   a). Auriculo-temporal nerve

   b). Buccal nerve

   c). Mental nerve

Components of the N. Trigeminus (CNV): English, "trigeminal nerve".

1. The trigeminal nerve is both motor and sensory (Mc Minn 1994).

2. Nuclei: Motor, sensory, mesencephalic, main sensory, spinal.

3. The trigeminal nerve is the largest cranial nerve and supplies the derivatives of the first branchial or pharyngeal arch (Burt et al 1993).

4. The two important functional components are:

    a. Branchiomotor (special visceral efferent, SVE): innervates chewing muscle.

    b. Somato-sensory (general somatic afferent, GSA): these fibers innervate the whole face (Burt et al 1993).

5. The mesencephalic nucleus of V is sited in the midbrain, the main sensory nucleus in the pons, and the spinal nucleus of V in the pons, medulla and upper part of the spinal cord *(pars oralis, pars interpolaris, pars caudalis).* The motor nucleus of V lies medial to the main sensory nucleus in the pons (Burt et al 1993).

6. <u>The sensory nerves</u> of the face are V^1, V^2, V^3 divisions of the trigeminal nerve. The human face develops from three rudiments, frontal- nasal; maxillary, and mandibular process (Grant 1958, Sadler 2004). Each of these divisions is innervated by V^1, V^2, and V^3. The greater auricular nerve C 2 and 3 encroaches on the face and innervates areas over the parotid gland and masseter (Grant 1958).

<u>**Summary**</u>: relevant sensory nerves regarding flap surgery in the forehead region and midline nasal areas include:

a). Supratrochlear N. V^1, midline forehead (ophthalmic division)

b). Supraorbital N. V^1, midline, forehead and scalp (medial ophthalmic division)

c). Infratrochlear N. V^1, lateral aspect of "bridge" of nose (ophthalmic division)

d). External Nasal N. V^1, front and tip of nose (ophthalmic division)

e). Infraorbital N. V^2, side or lateral aspect of nose (maxillary division)

The muscles of facial expression are innervated by the facial nerve or 7th cranial nerve. This includes muscles in the area of fronto-nasal flaps and includes innervation of the frontal belly of occipitofrontalis, procerus, corrugator supercilli, levator labii superioris alaeque nasi and nasalis. These muscles of second branchial (pharyngeal) origin (embryonic mesenchyme) are innervated by branchomotor or special visceral efferent fibres (SVE) (see Bart et al 1993). The intermediate nerve (or "sensory" branch of the facial nerve) contains general visceral afferent, special visceral which are destined for the facial muscles of expression (mimetic musculature). Apart from the mimetic musculature, the motor neurons of the facial nerve innervate other important muscles that include the stylohyoid muscle, posterior belly of the digastric muscle and the stapedius muscle of the middle ear (Bart et al 1993). The temporal branch of the facial nerve innervates the muscles of the upper face including the frontalis and orbicularis oris muscles, the zygomatic branch innervates muscles in the mid-third of the face, and the buccal branch the cheek muscles including the buccinator. Lower face muscles are supplied by the mandibular branch. The nucleus of the facial nerve is situated in the pons. Nerve fibers *en route* to the geniculate ganglion “hitch-hike” around the abducens nucleus and form the facial colliculus in the floor of the fourth ventricle.

GENERAL OUTLINES OF ARTERIES, VEINS, NERVES AND LYMPHATICS OF THE FACE RELEVANT TO FOREHEAD FLAPS AND RECONSTRUCTIVE SURGERY

Basic blood supply of the face: Arterial supply (After Mc Minn 1994)

Main arteries supplying the face

1. Facial artery (superior and inferior labial arteries, superficial temporal artery, transverse facial artery).

2. Supra-orbital and supra-trochlear arteries (branches of the ophthalmic artery). These communicate with the superficial temporal artery thereby allowing a free communication between the internal and external carotid systems (Mc Minn 1994:452).

Arterio-arterio anastomoses and communications

Knowledge of the blood supply and venous drainage of a flap is essential to reduce loss of the explant or transfer by partial or complete necrosis. Therefore an in-depth regional knowledge of the anatomy (including blood vessels) in the nasal and forehead areas is critical to reduce the incidence of flap necrosis.

Shumrick et al, 1992, from the University of Cincinnati (Ohio) and Cincinnati College of Medicine have emphasized the importance of the vascular and regional anatomy regarding forehead flaps for nasal reconstruction. However, these researchers and accomplished clinicians have pointed out that there are very few detailed studies addressing vascular and regional anatomy, regarding the application of forehead flaps. Also, there has been few prospective human cadaveric dissection studies focused on the vasculature of midline pedicled forehead flaps. They have, however, made major contributions to our understanding of the arterial vascular pattern in this region by die application of angiography (Shumrick et al, 1992). For instance, this group have demonstrated rich anastomoses between the arteries of the forehead region (supra-trochlear, supra-orbital, ophthalmic and superficial temporal). This angiographic, including dissection, work shows that minute arterial-arterial communications exist

(Shumrick et al, 1992). Furthermore, they have shown hemifacial and transmidline communications at the nasal, superior, middle and inferior regions of the forehead (Shumrick et al, 1992). This anatomical detail is critical for the design of para-median and median forehead flaps. They have shown that the forehead region contains an intricate system of anastomosing arterioles, allowing flow in a prograde and retrograde fashion (Shumrick et al, 1992). Drawbacks of these angiographic studies are that they are two-dimensional. What about the medial canthal area and the relevance to pedicled forehead flaps and nasal rhinoplasty? Their work also shows that **inter-arterial** anastomoses exist between the angular, supra-trochlear (STrA) and supra-orbital arteries. In addition they have demonstrated the anatomical course of the STrA in relation to the corrugator muscle, orbicularis and frontalis muscle (Shumrick et al, 1992). Therefore the intra-arterial anastomoses or communications (vascular anatomy) in the region of the nasal arcade is important to the clinician. However, it is unknown if small *arterio-venous* shunts exist in the forehead or medial canthal area. In the pilot study, we demonstrated a small collection of latex at the posterior aspect of the central forehead vein (not extravasation) and this raises the possibility that small A-V shunts may occur in the face and forehead.

Venous return of the face is by the following named branches:

1. Supra-orbital and supra-trochlear veins (unite to form the angular vein)

2. Facial vein (communicates with the retro-mandibular vein)

3. Superficial temporal vein

4. Maxillary veins (from pterygoid plexus), retromandibular vein

5. External jugular vein and joins with the subclavian vein

6. Deep venous connections: cavernous sinus, ophthalmic veins, deep facial vein. This communication is relevant to clinical practice: "the danger area" of infection of the upper lip and nearby cheek (Mc Minn 1994).

Lymphatic drainage of the face (After Romanes 1989)

Lymph nodes of the head and neck are numerous and traditionally divided into a *superficial* and *deep group* (Romanes 1989). Lymph from the forehead, orbital region, cheek and side of the nose drain to superficial parotid nodes, submandibular nodes and deep cervical nodes (Romanes 1989:91, Mc Minn 1994: 453).

Structure of skin (micro-anatomy) relevant to forehead flaps and reconstructive surgery:

Histological aspects: After Ham and Kessel 1964

Knowledge of the components of the skin and deeper structures is essential for the understanding and application of reconstructive flaps. The basic histological components of the skin from superficial to deep is well described in standard works on Anatomy (Mc Minn 1994, Gray's Anatomy 1995, Moore and Dalley 2006). The components are briefly summarized below:

1. Epidermis (stratum corneum, lucidum, granulosum, spinosum, basale); Langerhans cell.

2. Dermis (papillary and reticular layer: see Kessel 1998)

    a. Rete subpapillare (sub-papillary plexus)

    b. Sebaceous glands

    c. Arrector pili muscles

    d. Sweat glands (and association with sebaceous glands)

    e. Hair follicles

    f. Rete cutaneum (cutaneous plexus) (Kessel 1996)

    g. Sensory mechanoreceptors

3. Subcutaneous tissue (superficial fascia): This layer contains the important arteries, veins, lymphatics and nerves (also referred to as the hypodermis).

4. Deep fascia

5. Skeletal Muscle (See Coetzee et al 1997)

Specialized structures within the skin include hair and hair follicles, arrector pili muscle of hair, collagen and elastic fibres, sebaceous glands, fat, *L. retinaculum cutis* and sweat glands. The epidermis consists of a keratinized epithelium; the dermis is composed of interlacing collagen, extracellular matrix (ECM) and elastic fibers. Important histological features worthy of note include:

a) Papillae

b) *Rete subpapillare, cutaneum*

c) Melanocytes

d) Sensory receptors (Merkel's disks, free nerve endings, Pacinian corpuscles, Meissner's corpuscles, Ruffini cylinders or corpuscles, Krause end bulbs).

e) Glands: eccrine, sebaceous, apocrine (Kessel 1998, Coetzee 1997, Ham 1964).

<u>Angiosomes and venosomes</u>

Taylor et al, 1990, from the University of Melbourne coined a new term that is not used in conventional anatomy nomenclature or described in *nomina anatomica*. These are not traditional terms. The importance and relevance of the use of the term "angiosome" in flap reconstruction is discussed shortly below:

“In 1987, a series of total body studies revealed that anatomically, the arterial framework of the body is structured in such a way that composite blocks of tissue are supplied by named source (segmental or distributing) arteries. These composite blocks of tissue are termed *angiosomes*. They span between skin and bone and fit together, like the interlocking pieces of an intricate jigsaw puzzle. Their perimeters are defined usually by zones of reduced-caliber arteries that link adjacent angiosomes”. In addition to this, this group introduced a second term not traditionally used in the anatomy literature. This is the term “*venosomes*” and apparently refers to “venous territories” in the human body. This excellent study is important to the current doctoral dissertation. Key aspects regarding the Australian study are briefly summarized below:

1. “The venous architecture is arranged as a continuous network of vascular arcades”. This occurs in all tissues and between adjacent tissues. This group believes that, “each angiosome consists of matching arteriosomes and venosomes”.
2. “The venous network consists of linked valvular and avalvular channels that allow equilibration of flow and pressure”.
3. “The veins follow the connective tissue framework of the body”. “This concept is fundamental to the design of flaps in general and to the fasciocutaneous and septocutaneous flaps in particular”. Therefore, few vessels, whether arteries or veins, have mobile tissue planes.
4. “Veins converge from mobile to fixed areas”. “Veins hitch-hike with nerves”.

5. “The muscles are the prime movers of the venous return” (i.e. importance of a “muscle pump”).

<u>Flap arterial inflow and venous outflow according to type: Cadaveric study</u>

<u>Conventional forehead flap</u>:

The blood supply (or pedicle) of a large forehead flap based on a temporal axis is from the frontal branch of the superficial temporal artery. The superficial temporal joins the middle temporal vein at the root of the zygomatic arch to form the retromandibular vein (Romanes 1989, Gray’s Anatomy 1995, McMinn 1993, Grant 1964).

a. <u>Inflow</u>: from terminal branches of the external carotid artery.
b. <u>Ouflow</u>: via the retromandibular vein to the internal jugular vein.

<u>Newly proposed forehead flap methodology based on central vein</u>: cadaveric study

<u>Arterial inflow</u>: Branches from the dorsal nasal artery (**origin ophthalmic artery**) and angular artery **(facial artery**).

<u>Venous return</u>: Nasofrontal, superior ophthalmic vein *en route* to the cavernous venous sinus. Angular vein drains into the facial and internal jugular vein.

TABLE III: ARTERIAL AND VENOUS RETURN OF FOREHEAD FLAPS*		
Vessel	Conventional	Forehead flap based on central vein
Arteries	Superior temporal artery	Branches of angular-, supratrochlear artery
Veins	Superior temporal vein	Nasofrontal vein, ophthalmic veins, angular vein, facial vein, cavernous vein

***Anatomy source**: Gray's Anatomy 1995; Clemente Anatomy 4th Ed.

Comment:

The newly proposed midline forehead flap methodology in this doctoral study, based on the central vein, therefore also drains via the superior ophthalmic vein to the cavernous venous sinus. This drains via the superior and inferior petrosal sinus to the sigmoid sinus and internal jugular vein. **This is true when a person is lying. In the upright position (approximately 16 hours a day) the venous blood is transported to the heart mainly by the vertebral venous plexus (Epstein et al. 1970).** It needs to be re-emphasized that infections of the central face "danger area" can spread along the ophthalmic veins to the cavernous venous sinus and result in thrombosis thereof (Romanes 1986, Gray's Anatomy 1995).

<u>Communications of the cavernous sinus are described as follows:</u>

1. <u>Anterior</u>: Ophthalmic veins, sphenoparietal sinus.
2. <u>Posterior</u>: Superior and inferior petrosal sinus (Romanes 1986).

3. Medial: Intercavernous sinus communication via the hypophysial fossa.
4. Superior: Superficial middle cerebral vein.
5. Inferior: Pharyngeal and pterygoid plexus.

The cavernous sinus therefore forms an important route of communication between the veins of the face, cheek, brain and internal jugular vein (Romanes 1986, Gray's Anatomy 1995).

CHAPTER 4

CADAVERIC STUDY

MATERIAL AND METHODS

- **Nomenclature utilized**
- **Ethical aspects (Promulgated Health Act 2004)**
- **Embalming aspects (University of Stellenbosch Protocol)**
- **Aspects of latex instillation: technique**
- **Instruments needed for dissection**
- **Anatomical terminology: "Anatomical Position"**
- **Dissection program: structures identified**
- **Histological analysis**
- **Terminology of arterial branches**
- **Mapping**

NOMENCLATURE UTILIZED IN THIS STUDY

The following resources were utilized when referring to detailed *arterial and venous anatomy* regarding design and implementation of forehead flaps in nasal reconstruction (including cadaveric dissection nomenclature):

1. *Mosby's Medical Dictionary*: **3rd** edition: C.V. Mosby Company, St. Louis, 1990, pp A-12.

2. *The Faber Medical Dictionary*: Faber and Faber Limited, London, 1953 (Edited by Sir Cecil Wakeley), pp 1-471.

3. *Dorland's Illustrated Medical Dictionary*: 30th edition, Saunders, Philadelphia 2003, pp 75.

4. *Metanalysis of original articles* in the surgical literature: see metanalysis of published works in peer-reviewed literature, Table 1 (14 authors).

5. *Oxford Dictionary of Biology*: 4th edition, 2000. Anatomy is "the study of the structure of living organisms, especially of their internal parts by means of dissection and microscopical examination".

6. *Nomina Anatomica*: Authorized by the Twelth International Congress of Anatomists in London, 1985. Together with *Nomina Histologica*, 3rd ed., *Nomina Embryolica*, 3rd ed., Revised and prepared by sub-comittees of the International Anatomical Nomenclature Committee, 6th ed., Edinburgh: Churchill Livingstone, 1989. ISBN0443040850. The authorative standard nomenclature for anatomy, embryology and histology is currently out of

print. Portions of the *Nomina Anatomica* are, however, available on the web.

7. <u>*Standard Anatomy Text books*</u>: Gray's Anatomy (1995)., Cunningham's Anatomy (1964)., Last's Anatomy (1964)., Clementé's Anatomy (1993)., Grant's Method of Anatomy (1955) and Moore's Clinically Orientated Anatomy (2006).

Anatomical terminology in standard anatomy text books regarding the superficial, temporal, supra-orbital, supra-trochlear, dorsal and angular arteries are *consistent*. Descriptions of anomalies or variations in text books are very poorly recorded and *inconsistent*. No standard anatomy text book gives a "normal pattern" of the peripheral fine branches or ramifications of the above named arteries. Terms used in the published literature, including attempts to standardise facial artery anatomy *terminology,* have not been entirely consistent (Tolhurst et al, 1990: "The surgical anatomy of the scalp"). This is evident when the metanalysis (Table 1) of the publications regarding vasculature terminology, is studied. Much is still debated and conjecture. This terminology dilemma was taken into account when planning this study and naming the small branches of the arteries found at dissection. There seems to be some overlap regarding terminology in the literature. These are no absolute guidelines regarding the "naming" of the small branches of the superficial temporal, supra-orbital, supra-trochlear, dorsal and angular arteries. "Descriptive statistics" could also not be applied to the dissection findings.

Ethical aspects:

The morphological clinical study was approved by the Human Ethics Committee of the University of Stellenbosch (2004). The dissection protocol falls within, The National Health Bill 2003, Government Gazette, Chapter 8, Section 74, 76, Vol 437, N°22824: Surveillance is by the Director General of the Western Cape Government, The Superintendent and Inpector of Anatomy.

<u>Metanalysis of Literature (regarding vascular anatomy)</u>

Details by author, university, cadaveric/ clinical study are reflected in Table VII.

<u>Metanalysis of forehead arteries according to authors and number of cadavers studied</u>

Details include authors, year of study, number of cadavers dissected (in comparison to this study) and general comments are reflected in Table IV.

TABLE IV: RECONSTRUCTIVE RHINOPLASTY METANALYSIS DETAILS OF VASCULAR ANATOMY OF PEDICLE FOREHEAD FLAPS AND OTHER MODIFICATIONS FOR NASAL RECONSTRUCTION*										
Author	University	Cadaveric study	SOA	STA	Angular artery	DNA	Histo	Doppler	Veins	**Vasc anatomy**
Shumrick 1992	Cincinnati	√: (barium sulphate) X-rays	√	√	√	√	√	√ (5)	-	√
Millard 1976	Miami	Patients/ vascular pedicle	-	-	-	-	-	-	-	√
Burget 1989	Cincinatti	Patients/ septal flaps	-	-	-	-	-	-	-	√
Corso 1961	New York	√: M. methacrolate	-	-	-	-	-	-	√	√**venous study**
Maris 1981	Bratislava	Patients/ clinical	√	√	-	-	-	-	-	√
Vural 2000	Arkansas	√: and patients latex	-	√	-	-	-	+	-	√**Doppler study**
Tolhurst 1990	Virginia	√: cadaveric (comment)	-	-	-	-	-	-	-	√ **Discussed**
Potparic 1996	Eastern Virginia	√: coloured Ink/latex	√	√	√	-	√	-	-	√
Fukuta 1994	Nagoya	√ Dye, X-rays	√	√	√	√	-	-	√	√
Conway 1960	New York	Patients/ clinical	-	-	-	-	-	-	√	√
Mangold 1980	Hamburg	√: silicone	√	√	√	√	-	-	√	√
Carstens 1990	Pittsburg	Patients/ clinical	-	-	-	-	-	-	-	√
Hayreh II 1962	London	√: neoprene latex	√	√	√	√	-	-	-	√ **ophthalmic artery**
Hayreh III 1962	London	√: neoprene latex	√	√	√	√	-	-	-	√
Taylor 1989	Melborne	√: Lead oxide Chlorocresol	-	-	-	-	-	-	-	**venous study**

*Terminology Comparison: Gray's Anatomy, 38th edition, 1995, Churchill-Livingstone (pp 1526-1527)

SOA: Supra-orbital artery, STA: Supra-trochlear artery, DNA: dorsal nasal artery

Statistics: Cadaveric studies (N = 10)

Doppler studies (N = 2)

Venous anatomy (N =4)

LATEX ENHANCEMENT OF MINOR AND MAJOR FACIAL ARTERIES: UNIVERSITY OF STELLENBOSCH PROTOCOL

All cadavers utilized in this Gross Anatomy study, resort under the Anatomy Act (Health Act 1994: revised) and the usage thereof were approved by the Inspector of Anatomy (Dr. David Bass). The majority of persons were unclaimed and embalmed 4 – 6 weeks after death. In almost all cases the carotid arteries were used as access site for embalming. In a small percentage of cases the femoral artery (<5%) was used, if access through the neck was technically difficult.

INSTRUMENTS AND INFRASTRUCTURE REQUIRED FOR EMBALMING (UNIVERSITY OF STELLENBOSCH PROTOCOL)

1. Well ventilated room in basement with extraction fan and high air-flow (minimum regulatory requirements under the Industrial Act).
2. Formalin level monitoring (badges).
3. Running water, basins for washing hands; hose-pipe for washing down excreta.
4. Linen cloth, plastic covering (extremities, hand and torso).
5. Stainless steel dissection table.
6. Embalming fluid (formalin (10%), phenol, alcohol, pine oil): 20-40 litres/ cadaver.
7. Embalming fluid injection (pressure driven).

8. Identity tag on cadaver (for registration, control and identity).
9. Scissors (blunt tip).
10. Scalpel and number 21 scalpel blade (Swann-Morton or equivalent).
11. String or surgical cord for vessel ligation.
12. Forceps, cotton wool, Raytex gauze swabs.
13. Overhead light.
14. Protective clothing: gloves, protective helmet and visor, apron, coat, rubber boots.
15. Special epoxy-coated flooring and drains.
16. Outside windows and double-doors.

EQUIPMENT NEEDED FOR LATEX INFUSION (UNIVERSITY OF STELLENBOSCH PROTOCOL)

1. Two 15-gauge plastic Leuer lock catheters (15-20 cm in length).
2. 50 ml Leuer-lock disposable plastic syringe.
3. Arterial clamps, to seal back-leakage of Latex from dermal and other vessels.
4. Acetic acid (optional: to facilitate sealage of Latex leakage).

5. Latex: Rubber products and Mouldings (PTY), Ltd. Mouldtex® liquid Latex Maitland, Republic of South Africa (ICC. International Chemical Corporation).
6. Colouring: Xeracolour (Universal colourants for decorative paints: contents ethylene di-ethylene glycol). Choice of yellow, red or blue.

STEPS IN LATEX INFUSION: UNIVERSITY OF STELLENBOSCH PROTOCOL

1. A cervical approach is utilized (both sides simultaneously): 4 catheters and 2 syringes must be available. Fifty to 70 ml of Latex should be available.
2. Cadaver is placed supine. Optimal illumination is needed to visualize dissection of carotid vessels.
3. Cervical regions are exposed. A wooden block is placed under the shoulders.
4. Dissection should be facilitated in a well ventilated dissection hall (2nd floor in the Division of Anatomy and Histology, University of Stellenbosch).
5. Avoidance of skin flap raizing is recommended to reduce latex leakage.

6. 10 cm incision placed just medial to anterior border of *M. sternocleidomastoideus*.

7. Incision is deepened posteriorly into deeper structures and the carotid sheath is identified after palpation of *V. jugularis internus.* This structure may be resected before latex infusion.

8. Carotid bifurcation is identified together with the following structures:

    a. Common carotid artery

    b. Internal carotid artery

    c. External carotid artery

9. Common facial vein and internal jugular vein can be excised.

10. Three vessels in the carotid sheath are mobilized and taped. All vessels must be freed to as high a level as possible. This facilitates arteriotomy and canalization of the carotid artery with the catheter for latex infusion. The vagus nerve lies posterior and is not in the route of intervention.

11. A 10mm anterior incision is made in the common carotid artery, just inferior to the bifurcation. Thereafter, all blood clots in the lumen are extracted. All 3 lumens are carefully washed out and irrigated with tap water or saline. Both ostia of carotid arteries are selectively catheterized and the vessels secured with linen tapes or string. Both

arteries are flushed again with saline or water. Distal common carotid artery is controlled and sealed to prevent leakage or back flow of latex.

12. Latex is injected independently (by gentle hand pressure) into both catheters. Instillation is terminated when approximately 50-70ml is inserted and resistance is encountered. This is a blind end-point. The procedure is carried out on the opposite side as well. Therefore, all 4 carotid systems are theoretically filled. It is important to first flush with saline and to remove obvious debris in lumens. Failure to do so, results in incomplete filling of the arterial tree. Sufficient latex is instilled until leakage of latex is observed oozing out the cut surface of small arteries in the skin. This is the experience of this unit, but is a crude and relatively inaccurate end-point.

13. Vessel tapes are tightened and the vessels secured after the catheters are removed (to prevent extrusion of latex).

14. Dissection may take place comfortably after 10-14 days when the latex has formed a firm cast in the vessel lumen and network (Grant 1964, 1958). Previous pilot studies performed in various experimental models (rats, rabbits, monkeys, penguins, gazelles, whales and dolphins), including man, in this department, indicate that this is a very suitable technique to fill small arteries including those in the dermis. Arteries are easily identified by the red, yellow or blue colour depending on the latex selected. Veins do not fill if the latex is injected

into the arteries and are identified by clotted, dark blood. However, veins can be studied by the infusion of latex. This department has shown that this approach is very useful for studying the **internal vertebral** venous plexus (IVVP). Arteries and veins are identified by sharp and blunt dissection and the fat and superficial fascia is discarded, thus exposing the vessels.

15. Magnification is recommended for optimal dissection and vessel identification (10 x).
16. Digital photo's are taken to map and record the dissection (and progress thereof: Canon®) and the images are stored on a computer for later analysis, comparison and statistical processing.

GENERAL PROPERTIES AND FACTS REGARDING LATEX

- Latex is obtained from the tropical rubber tree, *Hevea brasiliensis*.
- Good quality latex is exported from Malaysia and Thailand.
- Latex is a natural elastomer and the chemical name is cis-poly-isoprene.
- During harvesting or collection from the stem (bark) of the tree, ammonia is added to the raw latex, thus preventing the liquid latex from curdling (ammonia counteracts acid production of waste products from local bacteria that feed on the latex and make it curdle).

- Fresh, raw latex consists of 70% water and 30% rubber cells.
- During manufacturing and processing of latex, other chemicals, including anti-oxidants, are added (for more details see www.fhi.org)
- Today, industry can supply latex as a pre-vulcanized emulsion that will air dry and can be utilized to make moulds in which wax, plaster or resin parts can be cast.
- This unit has found the use of Moultex® and Xeracolour very suitable for filling either the arterial or venous system for dissection purposes and display of fine morphological structures.

ANATOMICAL TERMINOLOGY: AFTER DANIEL JOHN CUNNINGHAM 1850-1909*

- Anatomical position: "Position used as though the body were standing upright, with the upper limbs hanging by the sides, but so rotated that the palms of the hands are directed forwards."
- Superior: part nearer the head
- Inferior: part nearer the feet
- Anterior: part nearer the front of the body
- Posterior: part nearer the back of the body
- Ventral and Dorsal: may be used instead of anterior and posterior (*Venter* = the belly; *dorsum* = the back)
- Median plane: imaginary plane dividing the body into a right and left half
- Median: position of a structure that is bisected by the median plane
- Medial: means nearer the median plane
- Lateral: means farther away from the median plane
- Superficial: means nearer the skin
- Deeper: means farther away from the skin
- Sagittal: plane parallel to median plane
- Coronal: vertical plane at right angle to the median plane
- Superficial fascia: "fibrous, fatty covering that underlies the skin and is attached to it by fibrous strands". Contains cutaneous blood vessels, lymph vessels and nerves.
- Principles of human cadaveric dissection:
    a. Instrumentation: scalpels, forceps
    b. Care of cadaver: covered with cloth, soaked in embalming preservative fluid and closed entirely with waterproof material (plastic cover).
    c. Skin removal
    d. Reflection of skin flaps
    e. Dissection of the superficial fascia, nerves, arteries, veins

f. Deeper dissection: piecemeal removal of fascia: nerves, arteries, veins
g. Identification of the structures and relations (veins, arteries, nerves)
h. Identification of variations and anomalies (critical knowledge needed for flap planning and execution).
i. Appreciation of surface anatomy and landmarks.

* Cunningham's Manual of Practical Anatomy, Oxford University Press, London, 1986.
* Moore K.L. Dalley A.F., Clinically Oriented Anatomy, Lippincott, 2006, pp 5-11.
* Terminology utilized in this thesis.

GROSS ANATOMY OF FOREHEAD AND NOSE RELEVANT TO FLAP RECONSTRUCTION; STRUCTURES IDENTIFIED (AFTER GRAY'S ANATOMY 1995 AND LAST'S ANATOMY 1994)

General: Goals of dissection and identification of structures-

- Skin, superficial fascia, arteries, veins, nerves
- Facial artery and branches
- Superficial temporal artery (terminal branch of the external carotid artery)
- Supra-orbital and supra-trochlear branches of the ophthalmic arteries (from the orbit); appropriate side branches of the supra-trochlear-, angular-, dorsal nasal arteries.
- Supra-orbital and supra-trochlear veins
- Angular vein; central vein
- Facial vein
- Superficial temporal artery, vein
- Vessels of orbit (ophthalmic artery and veins)
- Inferior ophthalmic vein

Specific: Goals of dissection and identification of-

- Frontal branch of the superficial temporal artery (FBSTA)
- Supra-trochlear artery (STrA)
- Supra-orbital artery (SOA)
- Dorsal nasal artery (DNA)
- Central artery (CA)
- Angular artery (AA)
- Para-central artery (PCA)
- Central vein (CV)
- Oblique vein (OV)
- Supra-orbital nerve (SON)
- Supra-trochlear nerve (STrN)
- Trans midline communication

* Other Anatomial references: Clementé Anatomy, 435-576, 1997

HISTOLOGICAL PROCESSING OF FULL THICKNESS FOREHEAD AND NASAL SKIN BIOPSIES

Full thickness skin biopsies (including epidermis, deep fascia and muscle) were obtained from cadavers of varying ages (28-85 years), genders and races to identify the deep dermal network of vessels (small arteries and veins). A standard departmental histological protocol was utilized to stain skin and dermal sections with Haematoxylin and Eosin (H & E). The histological processing and staining technique as used in the Division of Anatomy and Histology, Faculty of Health Sciences, is as follows:

After Harris 1900, Mallory 1938.

- De-wax sections, rinse in alcohol; rinse in water.
- Stain with Harris' haematoxylin – 10 minutes.
- Wash and blue, in running tap water – 1 minute.
- Differentiate in acid alcohol (1% hydrochloric acid in 70% alcohol) – 10 seconds.
- Wash and blue, in running tap water – 5 minutes.
- Stain with eosin – 4 minutes.
- Wash in tap water.
- Dehydrate, clear and mount.
- Examine on the light microscope at low and high magnifications (x 100, x 40).

Anticipated results: as confirmed in this histology laboratory

Nuclei: - blue

Other tissue components - shades of red and pink.

Harris'Hhaematoxylin: contents

Contents:

- Haematoxylin 5g
- 100% alcohol 50ml
- Potassium alum 100g
- Distilled water 1 litre
- Mercuric oxide 2.5g
- Glacial acetic acid 40ml

Eosin

1% eosin Y (yellowish); dissolve in tap water. Add a crystal of thymol to prevent the growth of moulds.

Method of preparing Haematoxylin

Dissolve the potassium alum in the water by warming and stirring. Dissolve the haematoxylin in the alcohol and add. Bring rapidly to the boil, then remove from heat and add the mercuric oxide. Cool, add the acid and filter. Ready for use immediately.

Structures identified under the microscope: Full thickness skin biopsies

1. Outer epidermis (ectodermal origin: Kierszenbaum 2002)
2. Deeper dermis (mesodermal origin)
3. Hypodermis or subcutaneous layer (also referred to in Gross Anatomy as the *superficial fascia*). Regarding the epidermis, the following layers were sought: stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum and stratum basale (Kierszenbaum 2002). Other aspects

studied included the adipose tissue, dermal papilla and muscles. The luminal area (diameter) of the deep dermal arterioles was measured on a Zeiss Microscope (Image Analyser) with a specially written macro-statistical package. Adjacent veins and nerves were documented. The blood supply of the skin at microscopic level was classified after Kierszenbaum 2002.

1) Sub-papillary plexus (adjacent to papillary layer).
2) Cutaneous plexus (adjacent to the reticular layer of the dermis).
3) Subcutaneous plexus sited in the hypodermis (All three vessel arcades are in communication with each other by the tiny arterio-venous anastomoses).

1. CADAVERIC STUDY: Summary

1. 1 CADAVER PREPARATION:

The cadavers were embalmed at the Department of Anatomy and Histology of Stellenbosch University (previously discussed). Ethical approval for this study was granted by the Inspector of Anatomy of the Provincial Administration of the Western Cape (PAWC), Dr. David Bass. A departmental mixture of formalin, alcohol, pine oil and phenol of 20 litres was used for the embalmment of the cadavers.

1.2 LATEX PREPARATION AND INJECTION: Previously discussed and not repeated here.

2. HISTOLOGY: FOREHEAD AND CENTRAL GLABELLA: Histology previously discussed and not repeated here.

3. METHODOLOGY OF FACIAL ARTERY MAPPING:

According to the methodology of Shumrick and Smith, the source arteries of the forehead were injected with a latex solution (Shumrick and Smith, 1992). A pilot study was completed previously for the M.MED (Plast Surg) degree at Stellenbosch University in 2003 using the same methodology. After the latex solution had set (usually two weeks, and sooner if the cadaver was cooled down), cadaver dissection of the forehead proceeded from superficial to deep, identifying the latex coloured arteries and observing the associated venous drainage and nerve patterns and their anomalies. The central glabella and nose bridge as well as the lateral forehead areas, where the supplying arteries enter the forehead was considered vitally important during the dissections. Magnifying lenses were used to assist with the dissection of smaller vessels. Thirty randomly selected adult cadavers were prospectively studied with the latex technique and twenty control non-latex filled cadavers. No chemical agents were used to dissolve the soft tissue (Corso, 1956). No flaps were dissected beforehand or after latex infiltration (Fukuta et al, 1994). Emphasis was placed on observing the planes of the vessels, their diameters, their variations, midline communications, and the associated venous and nerve patterns. Details of the cadaver demographics and previous cadaveric studies are portrayed in Tables 3, 4 and 5.

4. DOPPLER MEASUREMENT OF ARTERIAL FLOW IN FRONTAL NASAL FLAPS: Principles of application in this thesis.

Preservation of vascular pedicles during flap reconstruction is important to reduce ischaemia. This has been stressed by Vural et al, 2000, from the University of Arkansas, regarding the preservation of the supra-trochlear pedicle during fashioning and application of the para-median forehead flap. Although this pedicle can be determined in most cases by the aid of a Doppler apparatus, they indicated that 8% of the supra-trochlear arteries could not be detected by Doppler examination (Vural et al, 2000). This may be due to variations or absence of the artery. This group have stressed that this percentage may increase when the patients are under hypotensive anaesthesia, if the location of the vascular pedicle is searched after the anaesthetic is given (Vural et al, 2000). They have advised that when Doppler examination cannot reveal the artery, a surface landmark should be used to avoid compromizing pedicle vasculature (i.e. medial eye brow). Landmarks are also problematical. In vascular surgery, blood flow in an individual artery can be detected and measured with an ultrasonic flow meter, using the Doppler effect. This methodology relies on the shift in frequency of sound waves when the distance between the sound wave generator and reflection is changing (see Surgery, Scientific Principles and Practice, 1993, Lippincot, pp1515). The same authors state, “A Doppler probe detects the shift in frequency of its emitted sound waves, which is proportional to the velocity of blood flow which the sound waves reflect”. In this study, the arterial supply was located by the aid of a Doppler detection (model 811-B; Parks Medical Electronics Inc., Aloha).

GENERAL ABBREVIATIONS, FOREHEAD ARTERIAL SIDE BRANCHES AND TERMINOLOGY (duplicated for convenience of the reader):

AA……………………………………Angular Artery

AFA..Ascending Frontal Artery

ATA..Ascending Temporal Artery

CA..Central Artery

CV..Central Vein

DNA..Dorsal Nasal Artery

DTA..Descending Temporal Artery

FBSTA..Frontal Branch Superficial Temporal Artery

ITT..Inferior Transverse Third

LORB..Lateral Orbital Rim Branch

LORV..Lateral Orbital Rim Vertical **Line**

MB..Medial Branch

MCH..Medial Canthus Horizontal **Line**

MCV..Medial Canthus Vertical **Line**

MTT..Middle Transverse Third

OB..Oblique Branch

OV……………………………………Oblique Vein

PCA…………………………………Paracentral Artery

SOA...Supra-Orbital Artery

SOL...Supra-Orbital Ligament

SON..Supra-Orbital Nerve

SPA...Superior Palpebral Artery (medial)

STrA...Supra-Trochlear Artery

STrV………………………………… Supra-Trochlear Vein

STrN……………………………….. Supra-Trochlear Nerve

STT...Superior Transverse Third

TFA...Transverse Frontal Artery

VB..Vertical Branch

5. TECHNIQUE OF ILLUSTRATIONS:

The arteries have been numbered for identification and photographic appearance. Digital photography was used with a 4 mega pixel camera. Needles with numbered red flags were used for pointing out various structures.

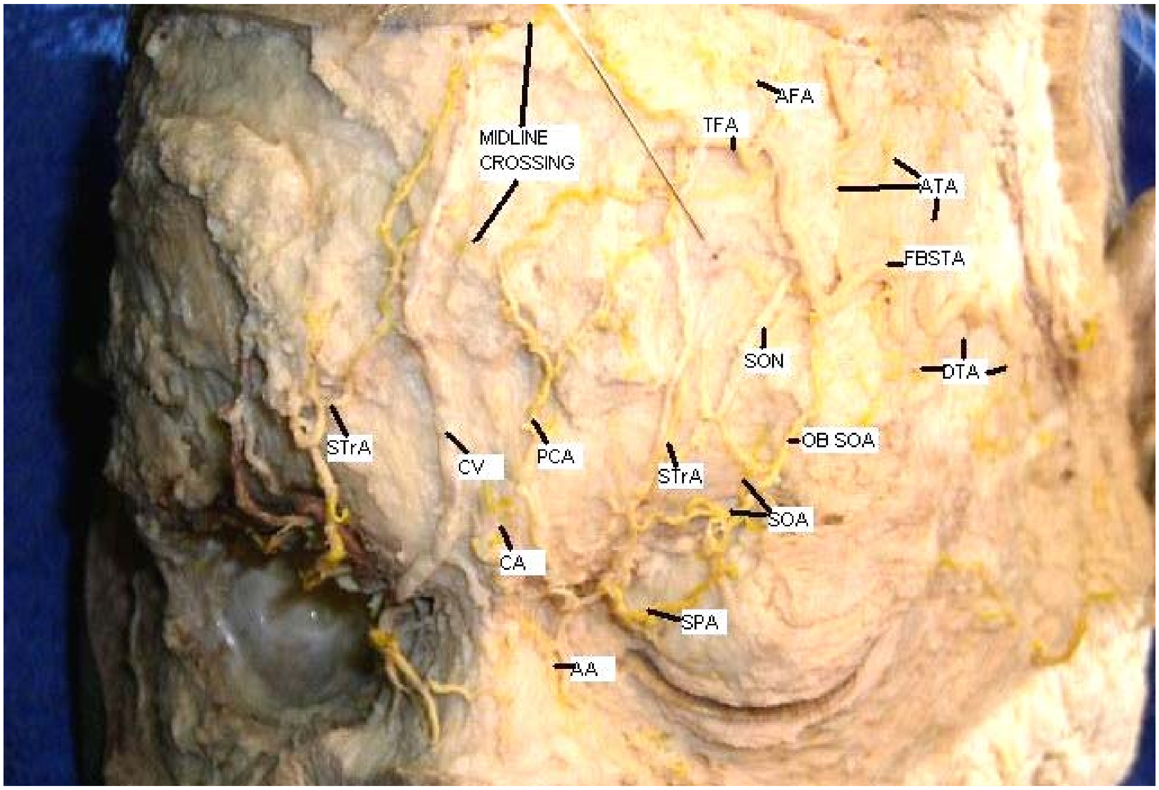


Fig 1. <u>Latex filled cadaver study</u>. Arteries of the forehead and the central vein with its bifurcation at the glabella. Note the vein is positioned between the right STrA and the midline. STrA= supratrochlear artery; CV= central vein; CA= central artery; AA= angular artery; PCA= paracentral artery; SPA= superior palpebral artery; SON= supraorbital nerve; OBSOA= oblique branch supraorbital artery; DTA= descending temporal arteries; SOA= supraorbital artery; ATA= ascending temporal arteries; FBSTA= frontal branch of the superficial temporal artery; TFA= transverse frontal artery; AFA= ascending frontal artery.

6. HISTOLOGICAL STAINS:

SUPERFICIAL AND DEEP FASCIA, SUBDERMAL VASCULATURE

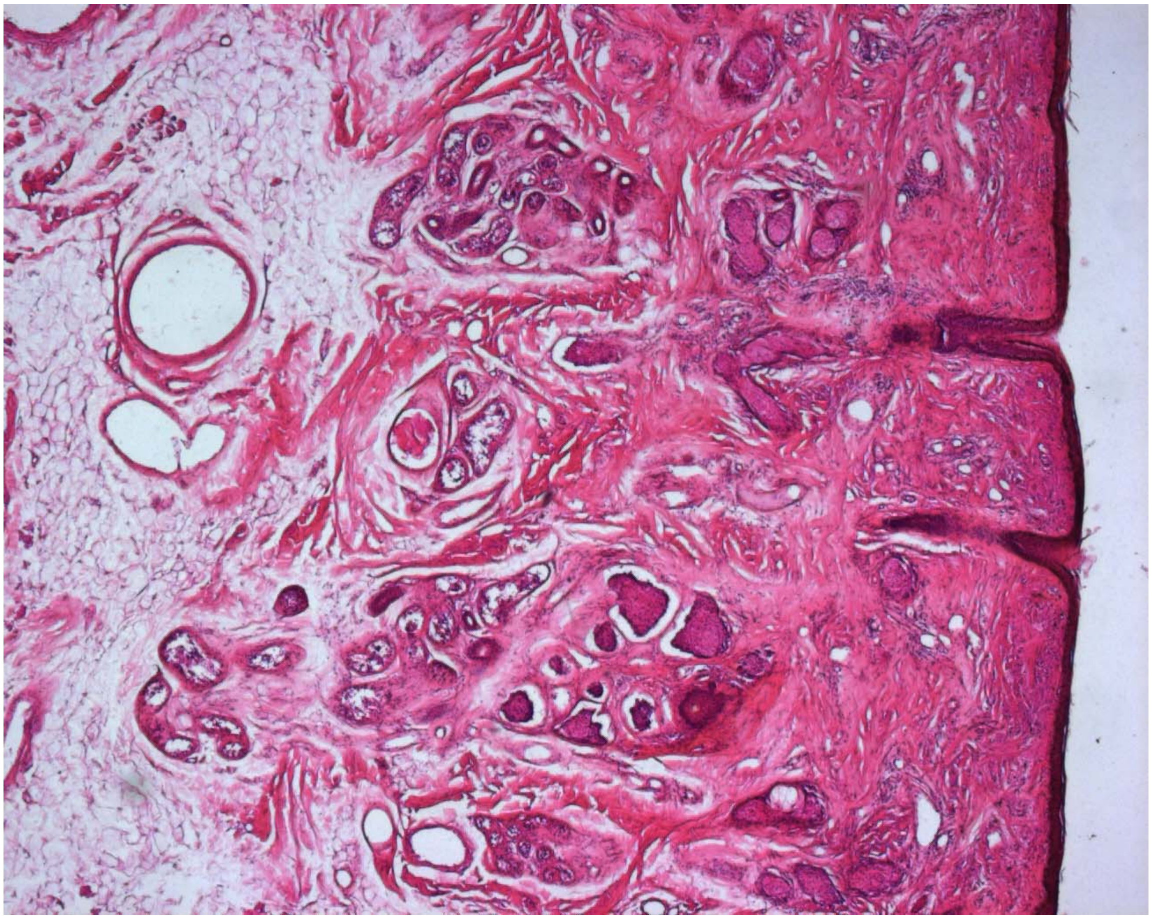


Fig 2. Histology section of cadaveric skin harvested from the forehead and showing epidermis, dermis and superficial fascia (from right to left). Mean luminal diameter of arterioles was 93.3µ (19 readings). Permission of Dr. C.J. F. Muller.

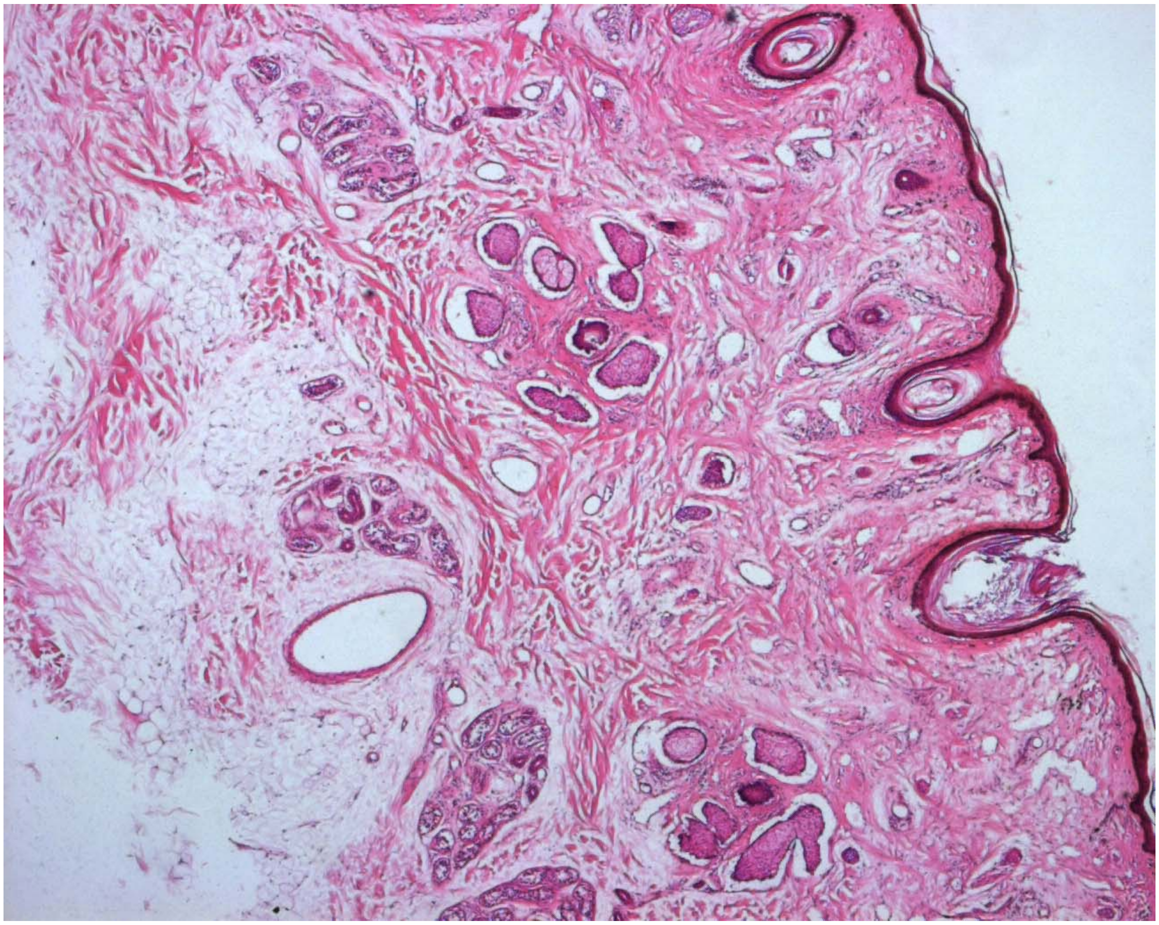


Fig 3. Cadaveric skin (full thickness biopsy) showing histological characteristics of superficial and deep components. Note muscle fibers of M. procerus in the deep dermis. Compared to the forehead, the mean luminal diameter of arterioles was 170.1µ (21 readings). Permission of Dr. C.J. F. Muller.

CADAVERIC STUDY

RESULTS

Details of the demographics are displayed in Table V.

TABLE V: DEMOGRAPHICS AND STATISTICS OF 30 ADULT CADAVERS USED IN THIS STUDY: PERIOD 2003 – 2006 AT THE UNIVERSITY OF STELLENBOSCH
• Males: 25 • Females: 5 • Average: 26 – 76; mean age: 42 years • Race: Caucasian, mixed ancestry, black (negro) • Period of death before dissection: 3 months to 12 months • Children: none • Common causes of death: Pulmonary tuberculosis, cardiac disease, stroke, exposure, unknown Average time of death to embalming: 3 weeks (need for identification)

RESULTS OF CADAVERIC STUDY:

Variable filling of the arteries with latex solution was encountered, but on the whole, it was satisfactory. Details of each individual dissection are given in appendix (1-30). Three cadavers had almost no filling and only the larger vessels could be dissected. Often only one hemi-forehead had good latex filling. Asymmetry of the vascular patterns between the two hemi-foreheads was encountered in practically every cadaver. Landmarks of 30 (60 hemi-foreheads) randomly selected adult cadavers were utilized for investigating the arterial patterns of the forehead over a period of three years (2003 to 2005). The following **vessels and nerves were identified and described (vessel nr's 5, 7, and 8; 9 were previously unnamed)**:

1. Frontal branch of the superficial temporal artery (FBSTA).
2. Supra-trochlear artery (SrTA)
3. Supra-orbital artery (SOA)
4. Dorsal nasal artery (DNA)
5. **Central artery (CA)**
6. Angular artery (AA)
7. **Para-central artery (PCA)**
8. **Central vein (CV**)
9. **Oblique vein (OV)**
10. Supra-orbital nerve (SON)
11. Supra-trochlear nerve (STrN)
12. Trans-midline communication.
13. **Other vessels given new names in this thesis: Ascending temporal artery (ATA); descending temporal arteries (DTA), Median artery and median vein.**

Fig 4. Cadaver maintainance. After dissection, each cadaver is soaked with embalming fluid and tightly wrapped in plastic sheeting to avoid drying out of the tissue. Permission of the University of Stellenbosch and Superintendent of Anatomy.

FOREHEAD LANDMARKS:

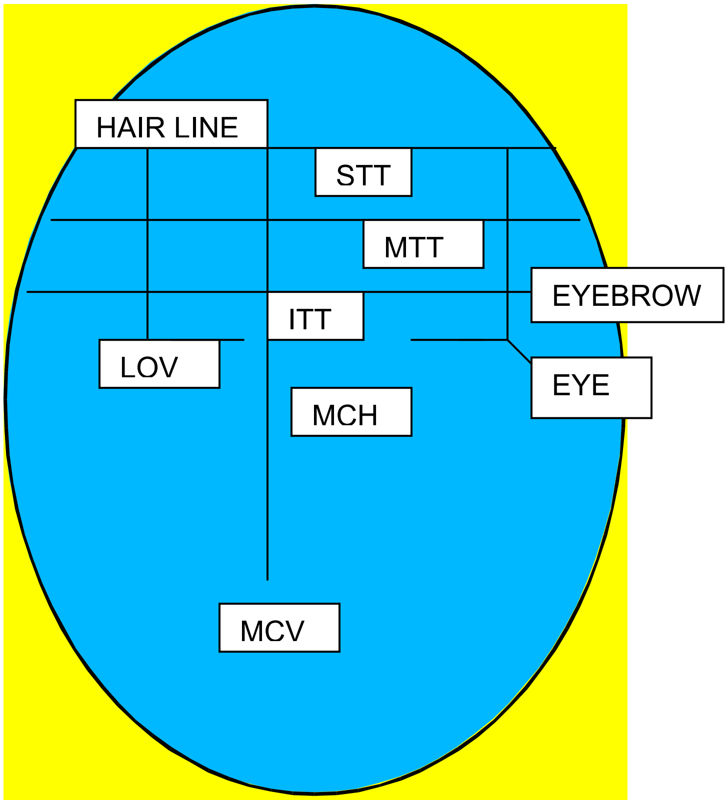


Fig 5. Landmarks for artery identification. STT= superior transverse third. MTT= Middle transverse third. ITT= Inferior transverse third. LOV= Lateral Orbital Vertical line. MCH= Medial Canthus Horizontal line. MCV= Medial Canthus Vertical line (These landmarks are not described in standard Anatomy texts).

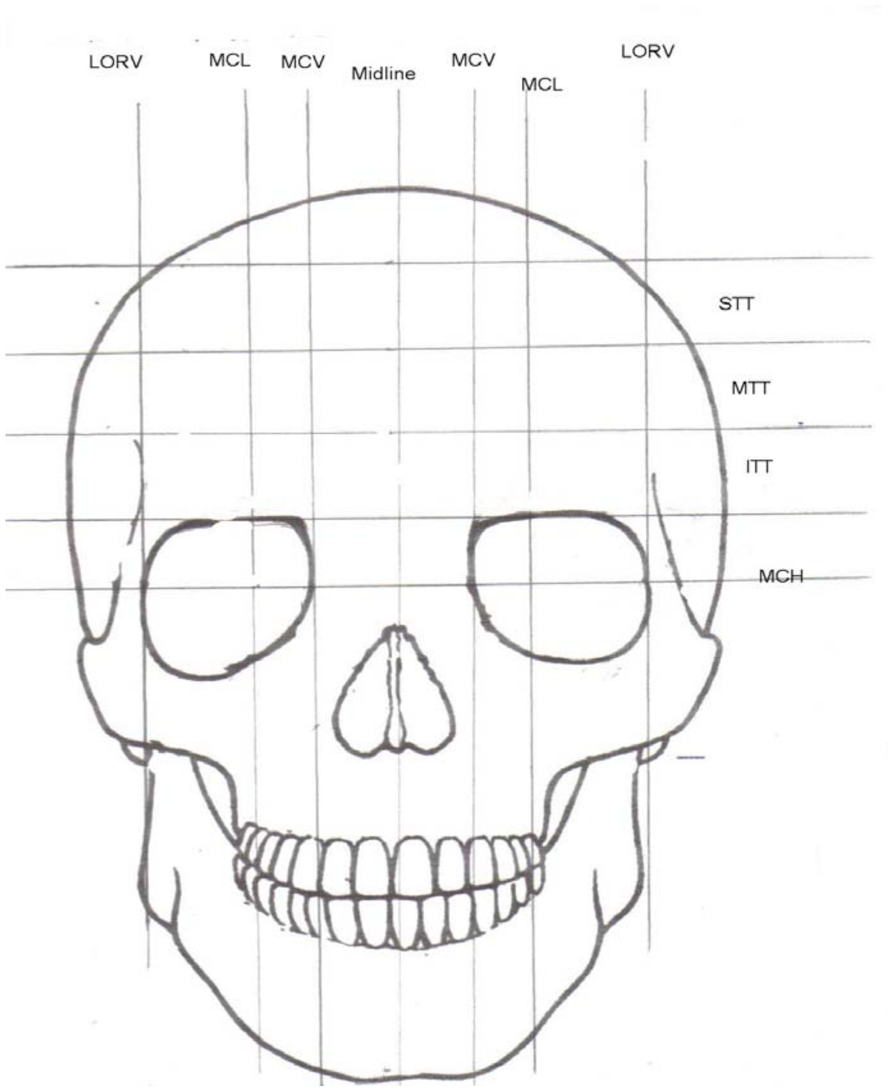
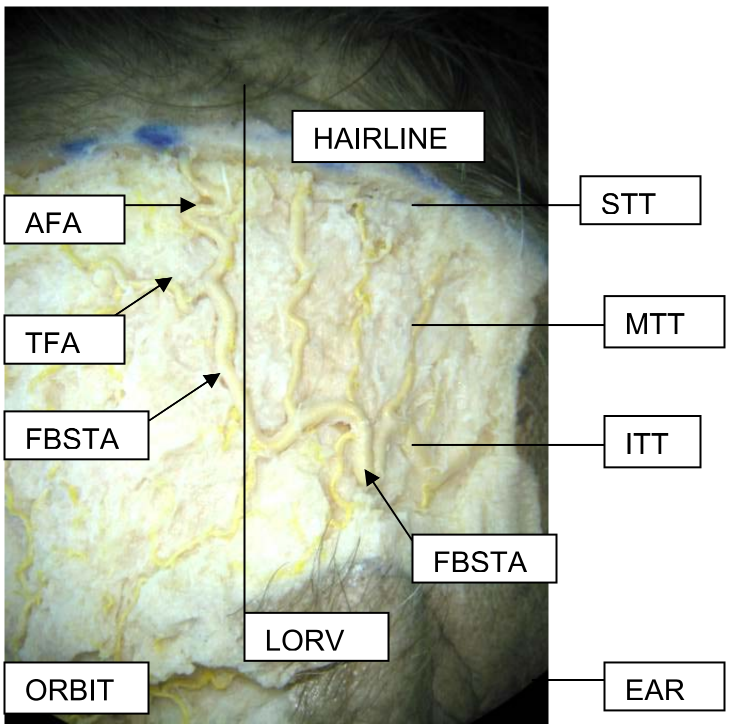


Fig 6. Landmarks of the forehead. Division of the forehead into equal thirds: STT= superior transverse third; MTT= Middle transverse third; ITT= Inferior transverse third. MCL= Medial cornual limbus vertical line. LORV= Lateral orbital rim vertical line.

THE FRONTAL BRANCH OF THE SUPERFICIAL TEMPORAL ARTERY (FBSTA):

The FBSTA was found to enter the forehead at varying transverse levels at the lateral orbital rim vertical plane (LORV).



1 cen

Fig 7. Left temporal view. The frontal branch of the superficial temporal artery (FBSTA) and its division into the ascending (AFA) and transverse frontal arteries (TFA). LORV= lateral orbital rim vertical line. 1 cen = scale for one centimetre.

At or close to the LORV the FBSTA usually divided into an ascending branch (usually the main continuation with a similar diameter to the FBSTA) and a transverse branch of smaller diameter. Because the transverse branch and the ascending branch are poorly delineated in the anatomical literature, the terms Transverse Frontal Artery (TFA) and the Ascending Frontal Artery (AFA) have been introduced. This distinction is necessary to accurately describe the arterial variations associated with the FBSTA. The FBSTA and its TFA branch were found to be superficial to the frontalis muscle. As the arteries progressed medially they gradually became more superficial up to the sub dermal level. The average diameter of the FBSTA, at the LORV, was 2mm. The FBSTA was identifiable in 42 hemi-foreheads. In 33 the, branching into the TFA and AFA at the LORV was seen. In two, there was no TFA to the forehead. In two, the FBSTA did not reach the forehead. It coursed to the scalp a few centimetres lateral to the LORV. In two the FBSTA was poorly definable. The FBSTA entered the forehead 23 times at the inferior and middle transverse third (MTT) junction and five times in the superior transverse third (STT). The TFA originated mostly in the MTT (20 times). It originated from the STT 13 times. There was more than one TFA in eleven hemi-foreheads (11/ 31). The arterial variations of the FBSTA seen in 42 hemi-foreheads were:

1) A more medial branching of the TFA from the FBSTA at the lateral corneal vertical line.

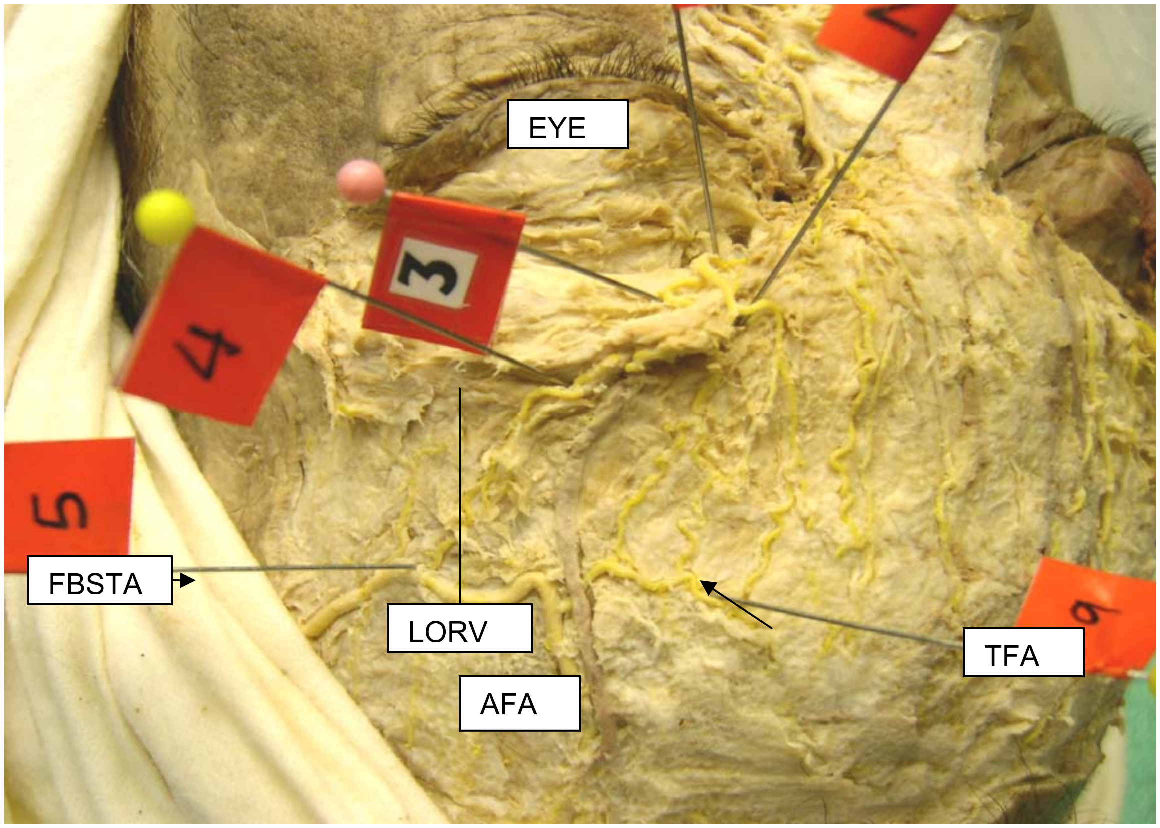


Fig 8. The division of the frontal branch of the superficial temporal artery (FBSTA) into a transverse frontal artery (TFA) and ascending frontal artery (AFA) is a few centimetres medial from the lateral orbital rim vertical line.

2) A Z- pattern of the TFA (FBSTA-TFA-AFA-TFA).

Fig 9. The frontal branch of the superficial temporal artery (FBSTA) is seen dividing into a transverse frontal artery (TFA) and ascending temporal artery (ATA), then

CV

AA

from the TFA, the ascending frontal artery (AFA) originates at the lateral orbital rim vertical line.

3) An absent TFA. (The dominant axis was from the angular artery to the oblique branch of the SOA). The FBSTA was a minor branch off OBSOA).

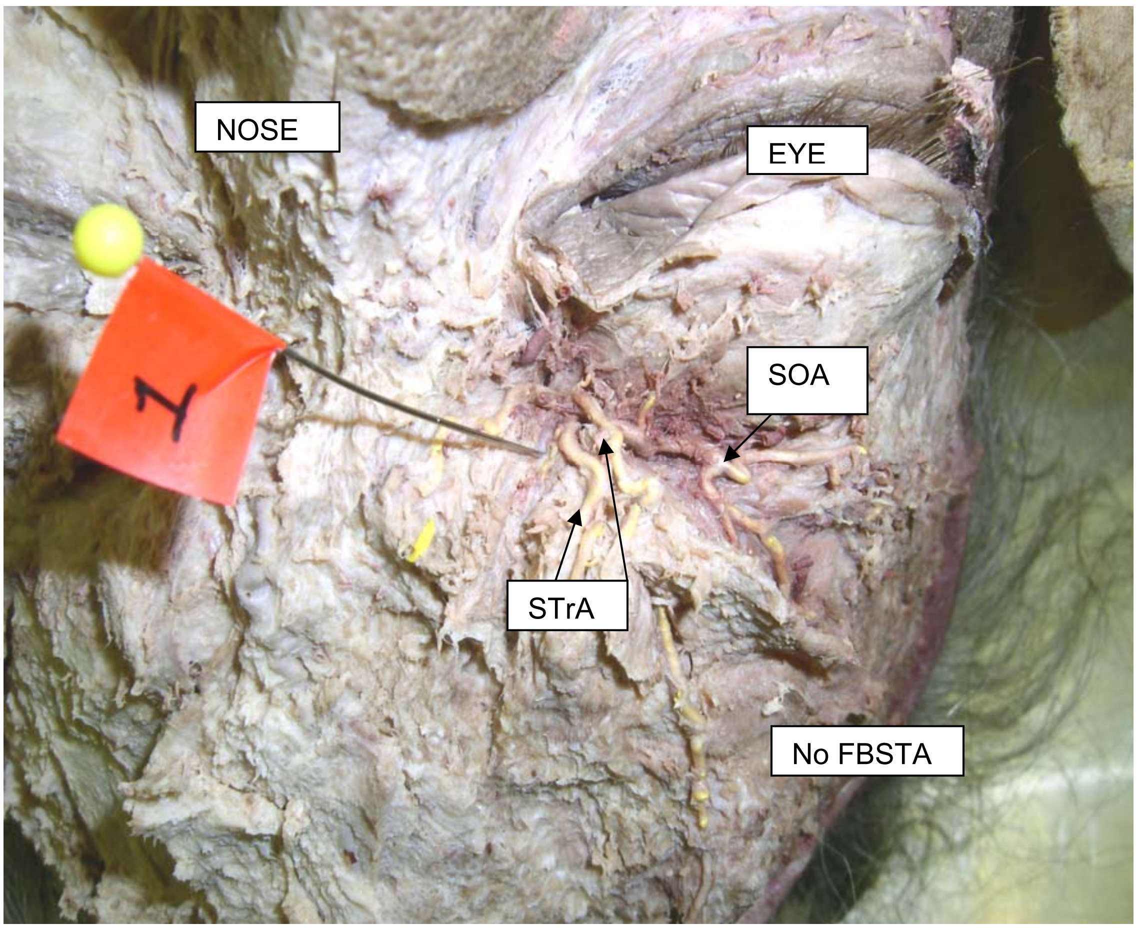
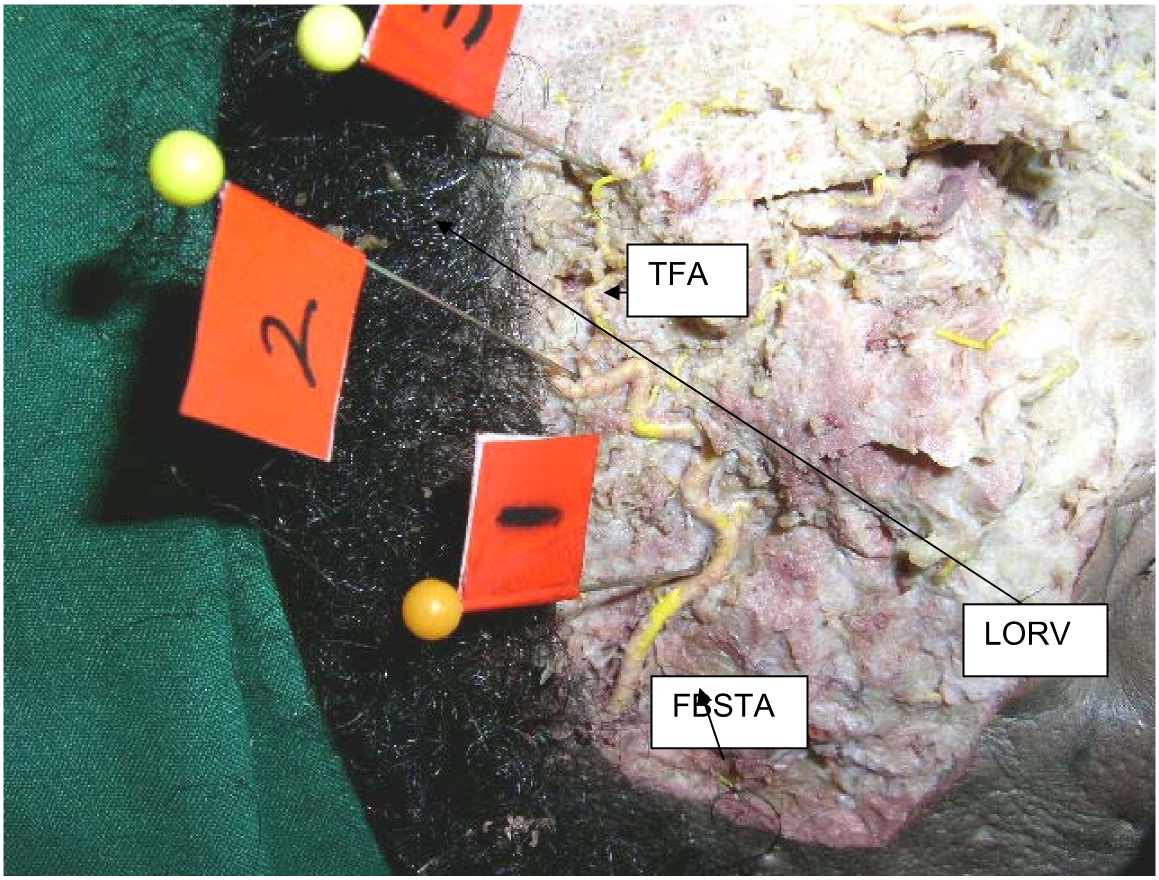


Fig 10. <u>The supra-trochlear artery (STrA) and supra-orbital artery (SOA)</u> is shown by the arrows. No frontal branch of the superficial temporal artery (FBSTA) is seen in the forehead.

4) No clear branching of the FBSTA in the forehead. The FBSTA went from the inferior transverse third (ITT) towards the STT with no TFA.

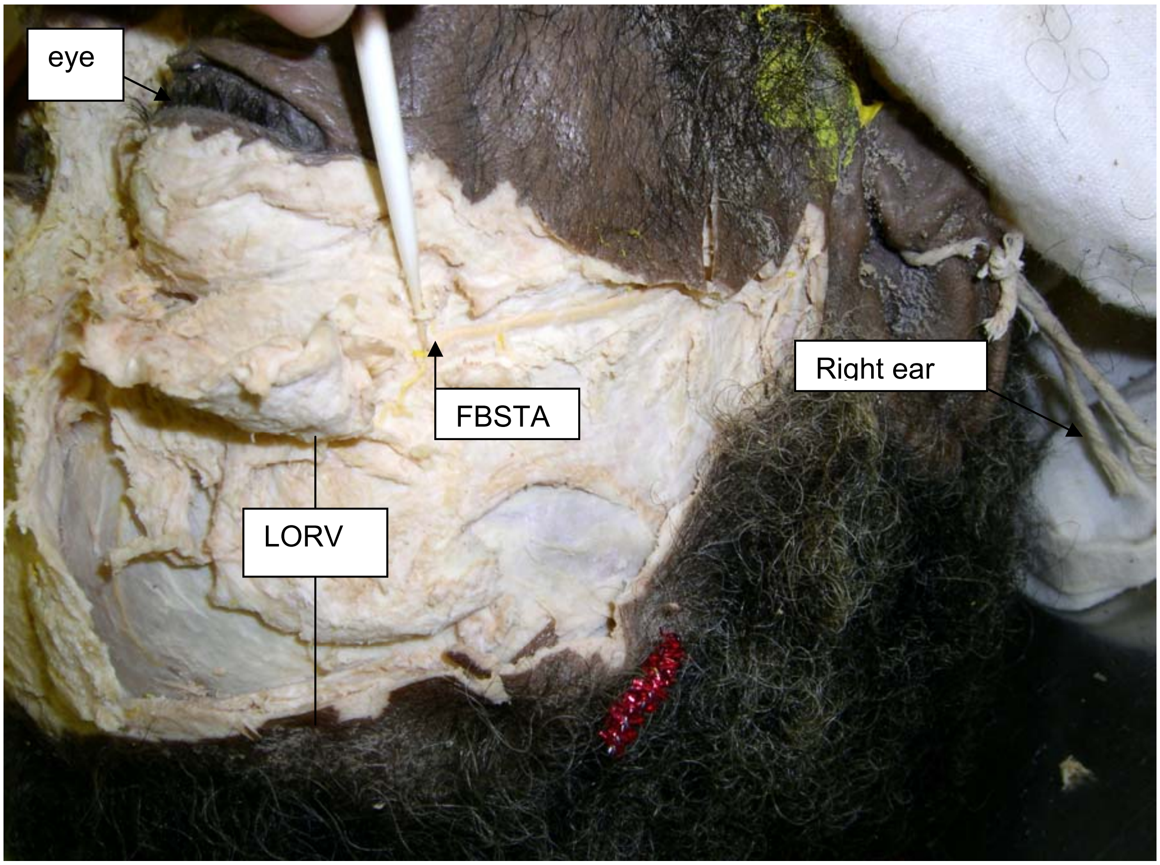


1 cen

Fig 11. The frontal branch of the superficial temporal artery has a high lateral course and the transverse frontal branch is seen entering the superior transverse third of the forehead. 1 cen = scale for one centimetre.

5) No branch entering the forehead across the LORV. In this case there was a transverse branch from the superficial temporal artery (STA) at the SOR

level communicating with the lateral end of the lateral branch of the SOA. This artery has been referred to as the zygomatic-orbital artery.



1 cen

Fig 12. Low frontal branch of the superficial temporal artery is shown. The entry at the lateral orbital vertical line is seen close to the supra-orbital rim and the typical pattern of the transverse frontal artery (TFA) and ascending frontal artery (AFA) is absent. 1 cen = scale for one centimetre.

A variation where the TFA and AFA arose from the zygomatic-orbital artery was seen in one hemi-forehead where a normal FBSTA was absent in the temporal area.

THE SUPRA-TROCHLEAR ARTERY (STrA):

The STrA was found to be relatively constant around the medial canthal vertical plane (MCV), appearing from the supero-medial orbit. It never deviated more than five millimetres from this vertical plane in the inferior transverse third of the forehead and was mostly medial to the MCV. The STrA pierced the corrugator supercilii muscle and became subcutaneous from 15 to 25 mm above the SOR. It was difficult to distinguish between the orbicularis oculi and the corrugator muscle just above the SOR. In the corrugator muscle the artery usually made sharp deviations. **This genu has not been emphasized previously, especially in forehead flap planning and applications**.

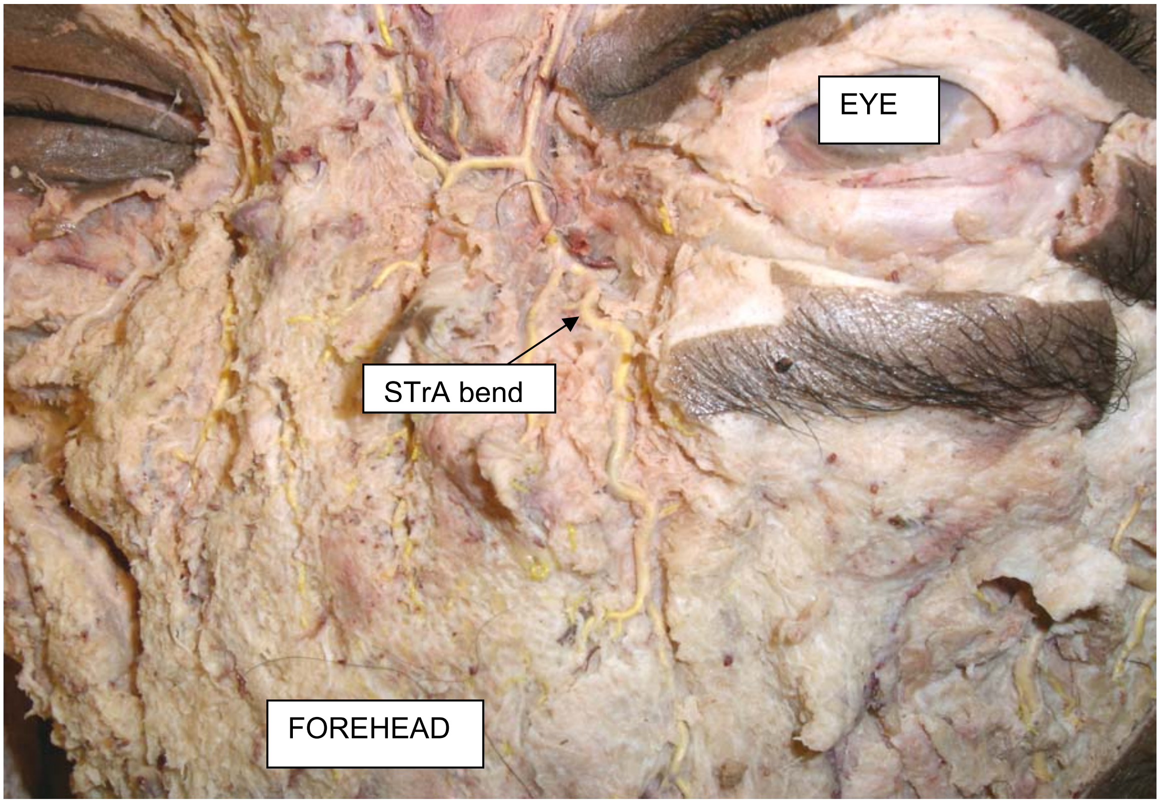
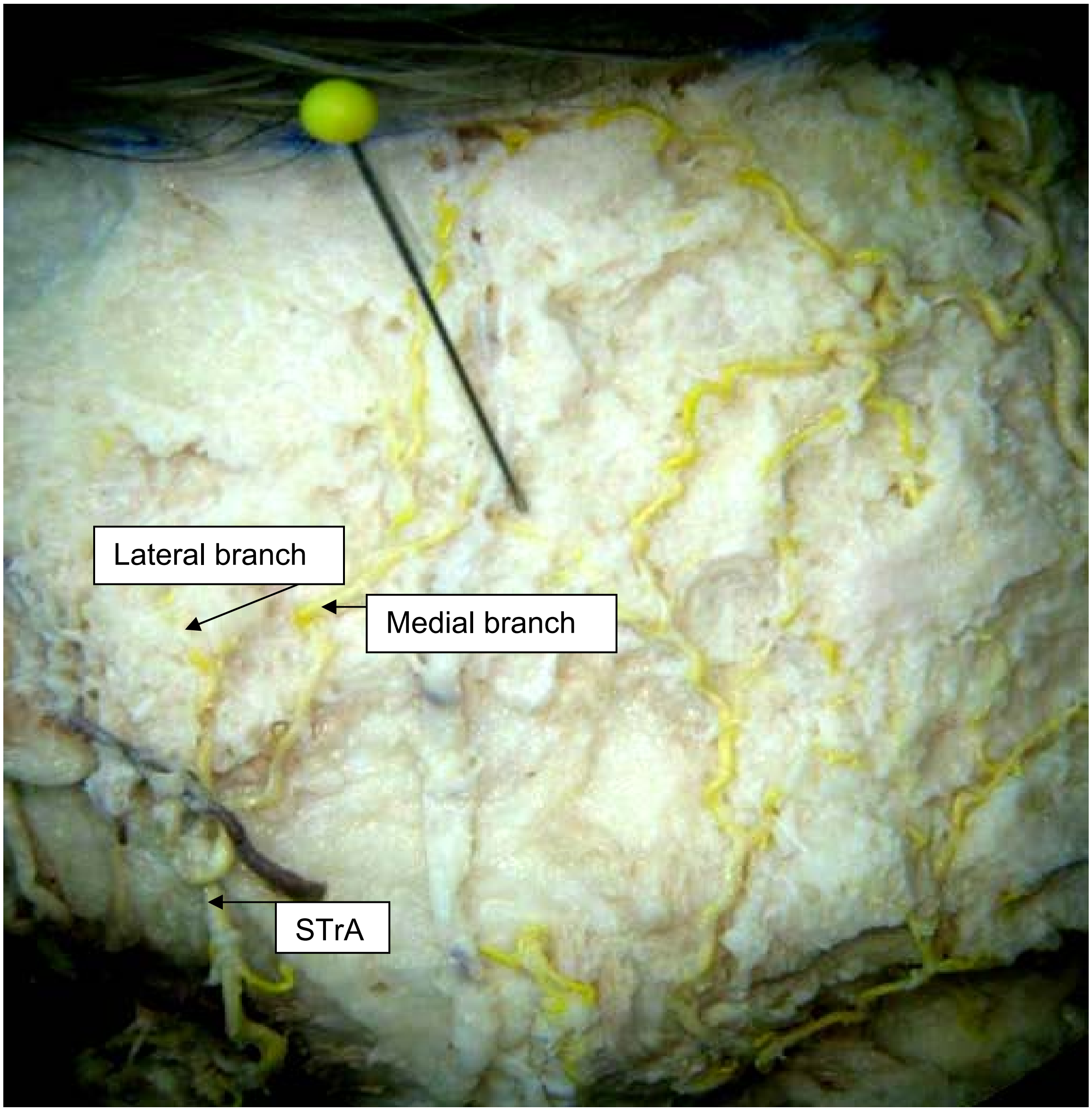


Fig 13. Supra-trochlear artery intra-muscular bend or genu as it leaves the supra-orbital rim.

The artery in almost all dissections was relatively superficial within the muscle layers (only one to two millimetres deep or posterior). The average diameter of the STrA was one millimetre (n=37).

Some variations of the STrA were found. The STrA was identifiable in 43 hemi-foreheads. The STrA had a medial and lateral vertical branch in 23 hemi-foreheads. The division into a medial branch and a vertical continuation or lateral branch, occurred mostly at the junction of the inferior and middle third.



1 centi

Fig 14. The medial and lateral branches of the supratrochlear artery (STrA).

In one cadaver the STrA originated as two equally sized, but separate branches at the level of the supraorbital rim. 1 centi = one centimetre.

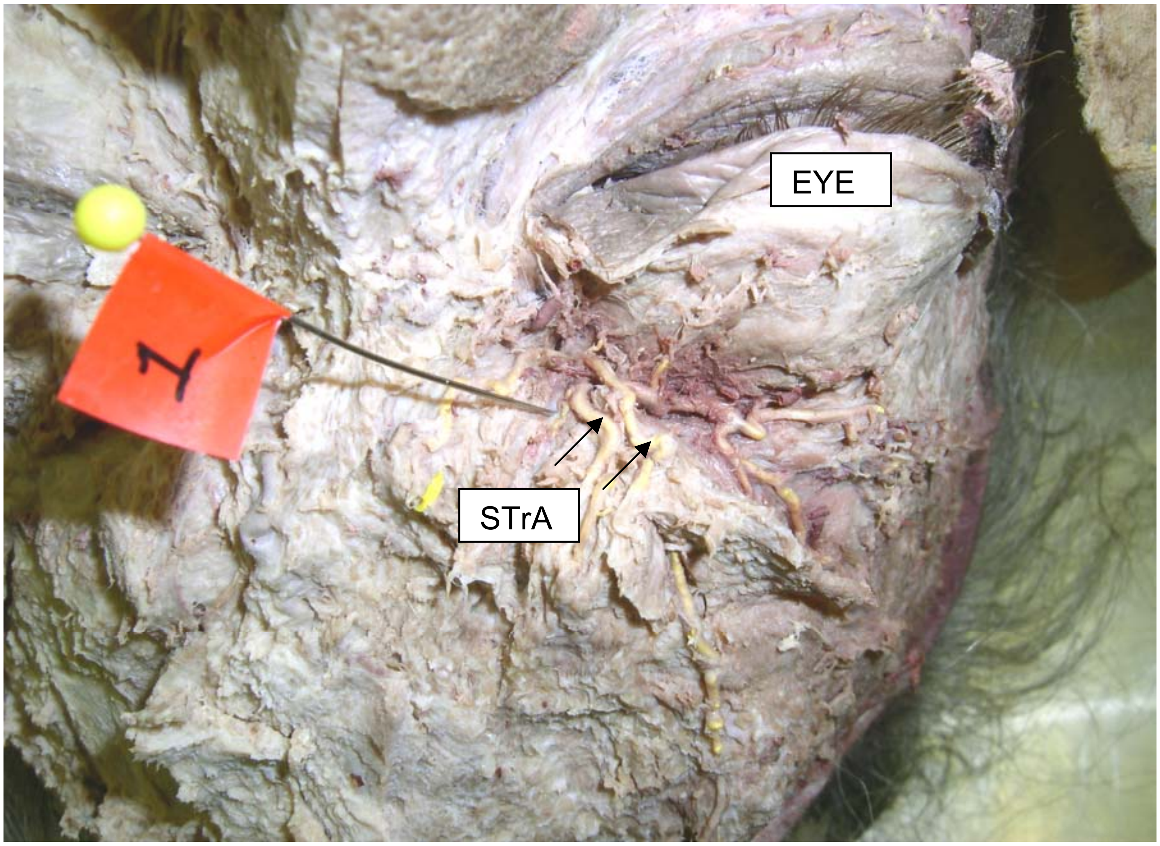


Fig 15. Two supra-trochlear arteries are shown by the arrows.

In 20 hemi-foreheads, the STrA consisted of a single branch. The STrA branches ran towards the midline usually from the level of the middle transverse third (MTT) of the forehead superiorly. Two variations were seen where the STrA was absent. In the first case a branch from the angular artery (AA) extending into the forehead, which I have termed the “para-central artery”, gave off a lateral branch to take over the para-median forehead arterial inflow associated with the STrA. In the second instance, a lateral branch from the “para-central artery” was given off. This branch had a lateral transverse course and joined the transverse branch of the FBSTA (TFA).

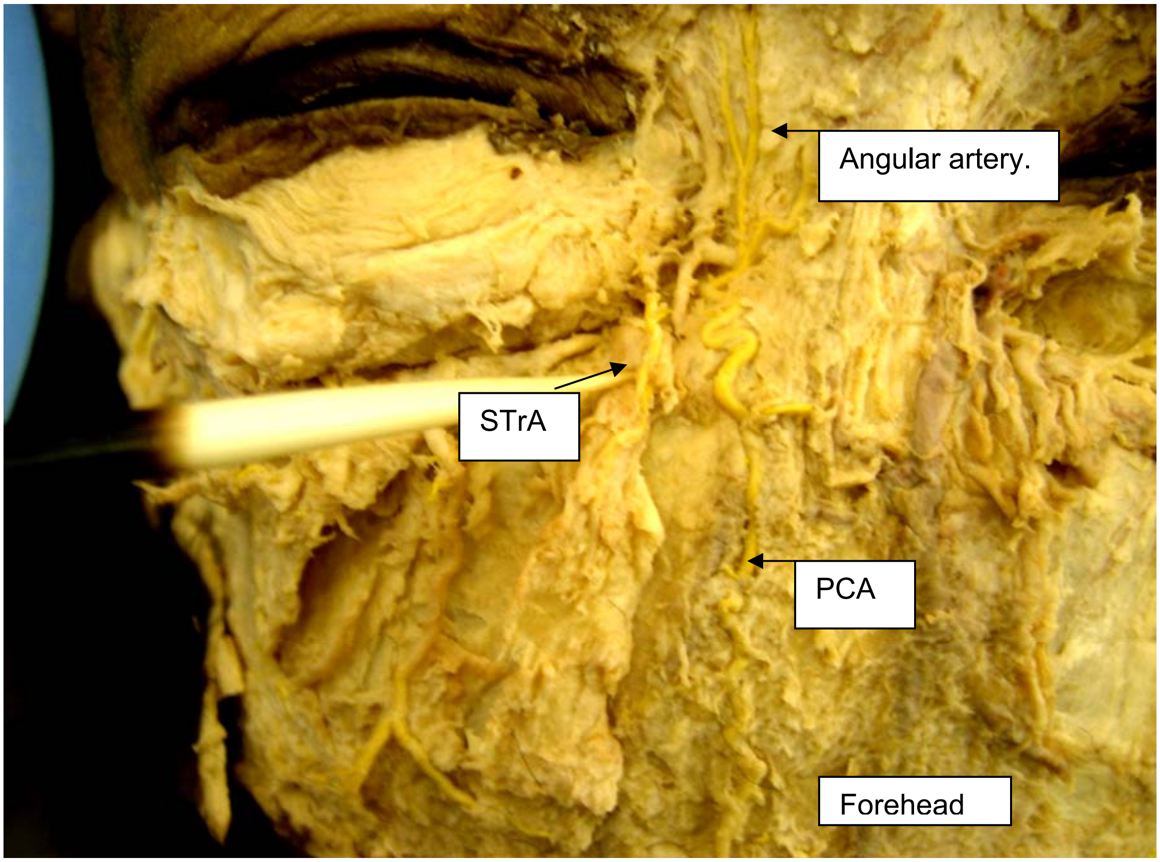


Fig 16. The para-central artery (PCA) is seen adjacent to a small diameter supra-trochlear artery (STrA).

Another interesting variation of the STrA was seen in one cadaver where the STrA in the middle transverse third (MTT) of the forehead descended posteriorly to the frontalis muscle.

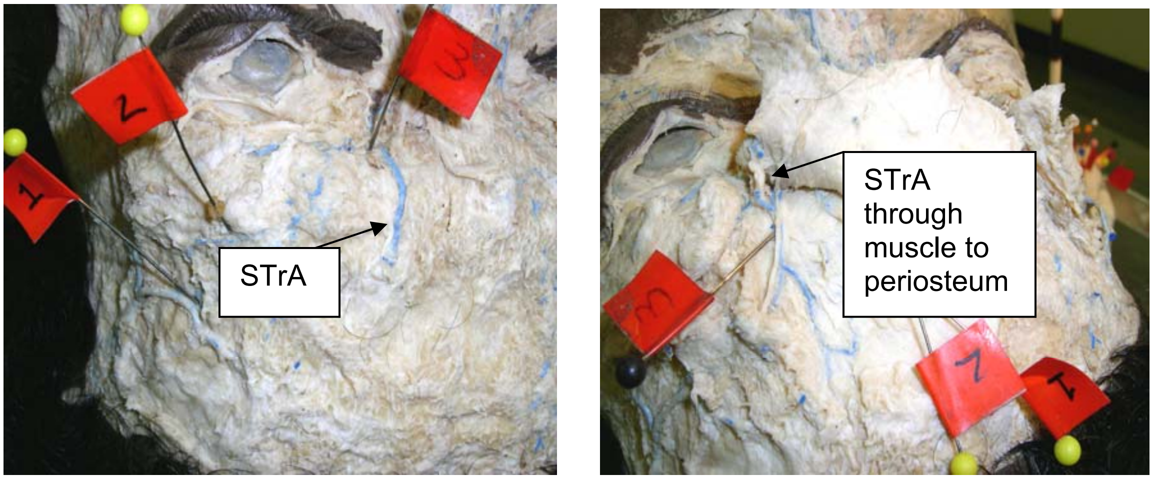


Fig 17. Posterior variation of the supratrochlear artery (STrA)

The following branches of the STrA were identifiable: a medial communicating branch (MCB) with the AA at the SOR (26/43), a lateral communicating branch (LCB) with the supra-orbital artery (SOA) at the SOR (10/43), superior palpebral artery (SPA) (11/43) at its origin, a superficial brow artery (BA) (2/37), periosteal branches (PB) posterior or medially close to the SOR (3/43), medial and lateral muscular branches (MB), cutaneous branches (CB) communicating medially with the PCA or central artery (CA) and laterally with the SOA or the TFA, an oblique branch (OB) (8/43); division into medial and lateral vertical branches (MVB;LVB).

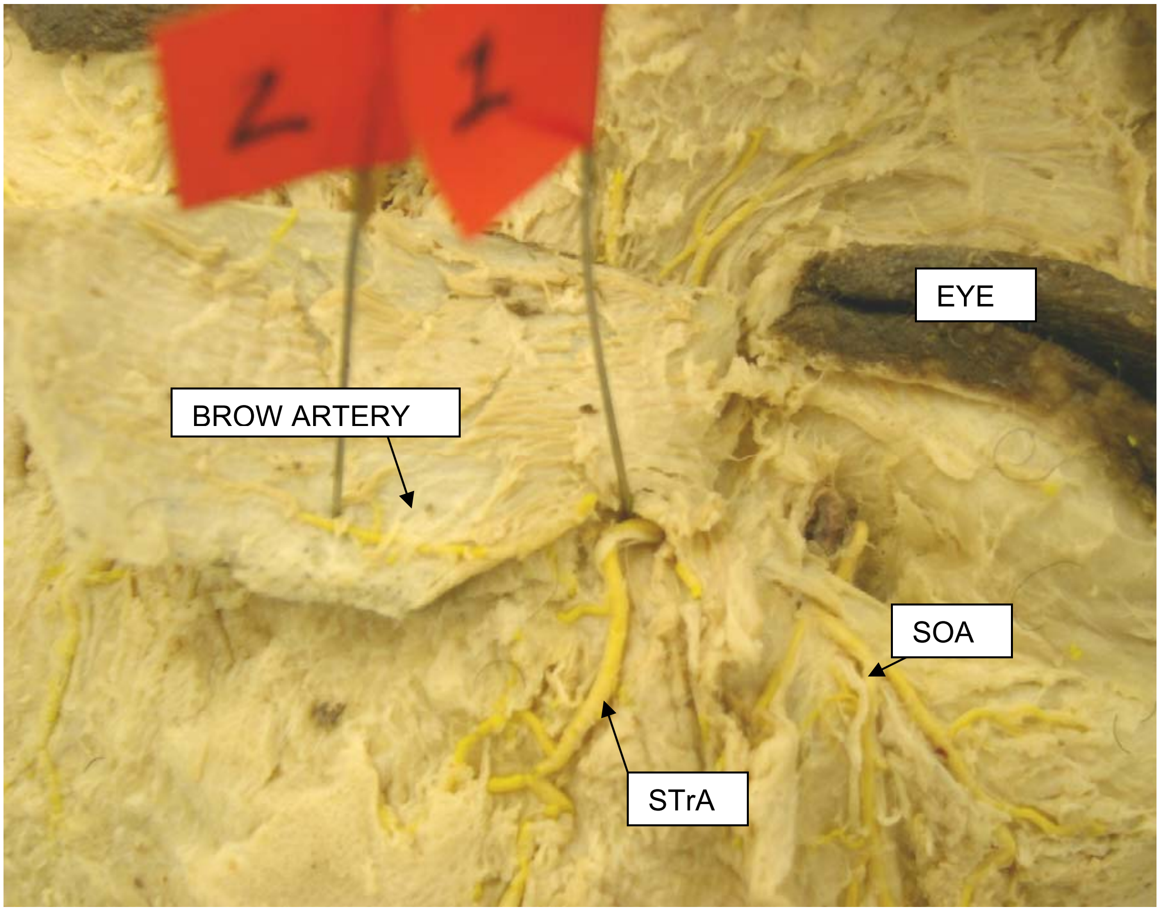


Fig 18. The brow artery is shown by reflecting the right brow skin medially with flagged needles. STrA= supra-trochlear artery; SOA= supra-orbital artery.

TABLE VI: MACROSCOPIC IDENTIFIABLE NUMBER OF SIDE-BRANCHES OF THE ARTERIES OF THE FOREHEAD (N = 30 CADAVERS).

Artery	Branch numbers	Side branch terminology and names
StrA	9	CB/m+L, SPA, BA, PB, MB1, CB, OB, MB, LB
SOA	6	LRB, VB, MB2, OB1, BB, SB
FBSTA	4	TFA, AFA, ATA, DTA
DNA	4	DB, AB, CA (IN2)
AA	3/ 4	DMA, PCA, CB, ±ITA
CA	2	Medial and lateral branch
PCA	2	Medial and lateral branch

Abbrev: SOA supra-orbital artery, STrA supra-trochlear artery, FBSTA frontal branch of the superficial temporal artery, DNA dorsal nasal artery, AA angular artery, CA central artery, PCA para-central artery.

Branches: CB (communicating branches), SPA (superior palpebral artery), BA (brow artery), PB (periosteal branch), MB (muscular branch), CB (cutaneous branch), OB (oblique branch), MB + LB (medial and lateral branches), LRB (lateral rim branch), VB (vertical branch), BB (brow branch), SB (superficial branch), TFA (transverse frontal artery), AFA (ascending frontal artery), ATA (ascending temporal artery), DTA (descending temporal artery), DB (descending branch), AB (anastomosing branch), CB (communicating branch), ITA (infratrochlear artery).

TABLE VII. AVERAGE DIAMETER OF THE ARTERIES OF THE FOREHEAD (SUPERIOR ORBITAL RIDGE AT POINT OF ENTRY)	
Artery	Diameter Average in Millimeters (mm)*
FBSTA	2mm
STrA	1mm
SOA	1mm
DNA	1mm
AA	1mm
CA	< 1mm
PCA	< 1mm

* Figures rounded off to millimetres (mm)

Abbrev: See Table VI for terminology.

TABLE VIII: BRANCHES OF THE STrA		
Branches	Incidence (n = 43)	Percentage (%)
MCB	26	60%
LCB	10	23%
SPA	11	26%
BA	2	5%
PB	3	7%
CB	1	1%
OB	8	19%
M; L VB	23	53%
Single VB	20	47%

Branches of the STrA. MCB= Medial communicating branch; LCB= Lateral communicating branch; SPA= Superior palpebral artery; BA= Brow artery; PB= Periosteal branches; CB= cutaneous branches. These numerous branches were present, but not counted; OB= Oblique branch; M & L VB= Medial and lateral vertical branches; Single VB= Single vertical branch.

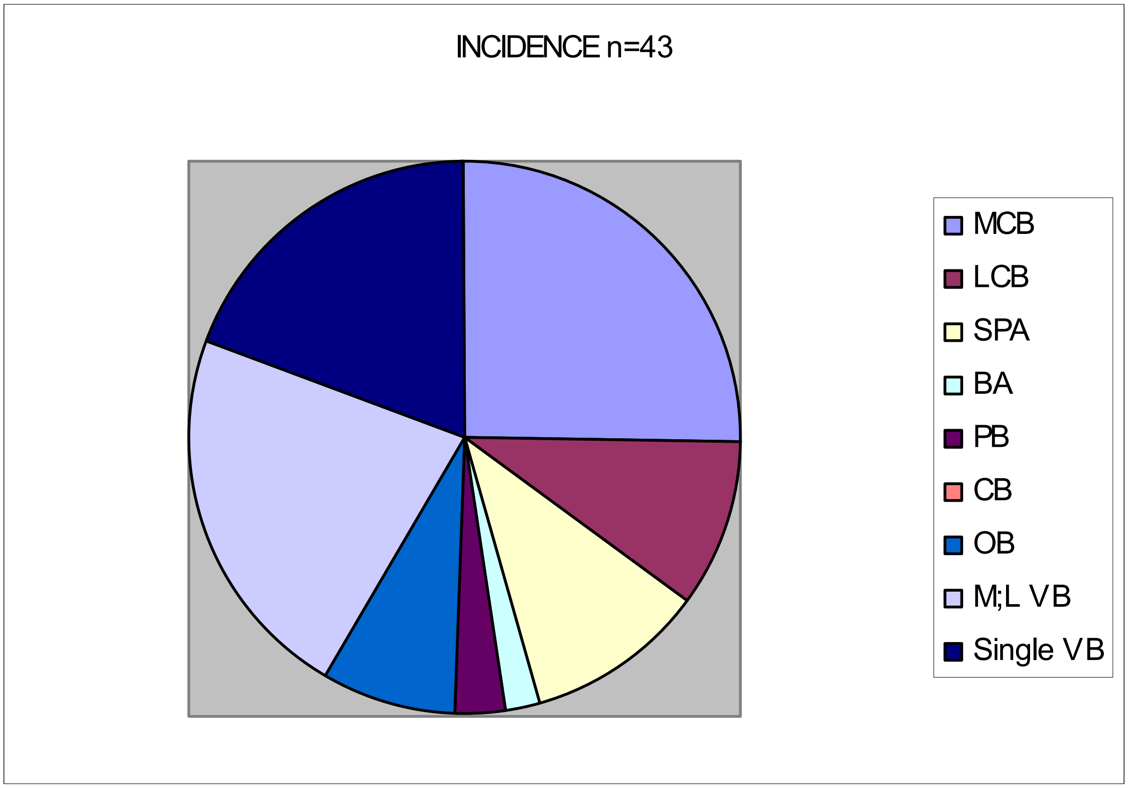


Fig 19. Graphic presentation of the incidence of the branches of the STrA.

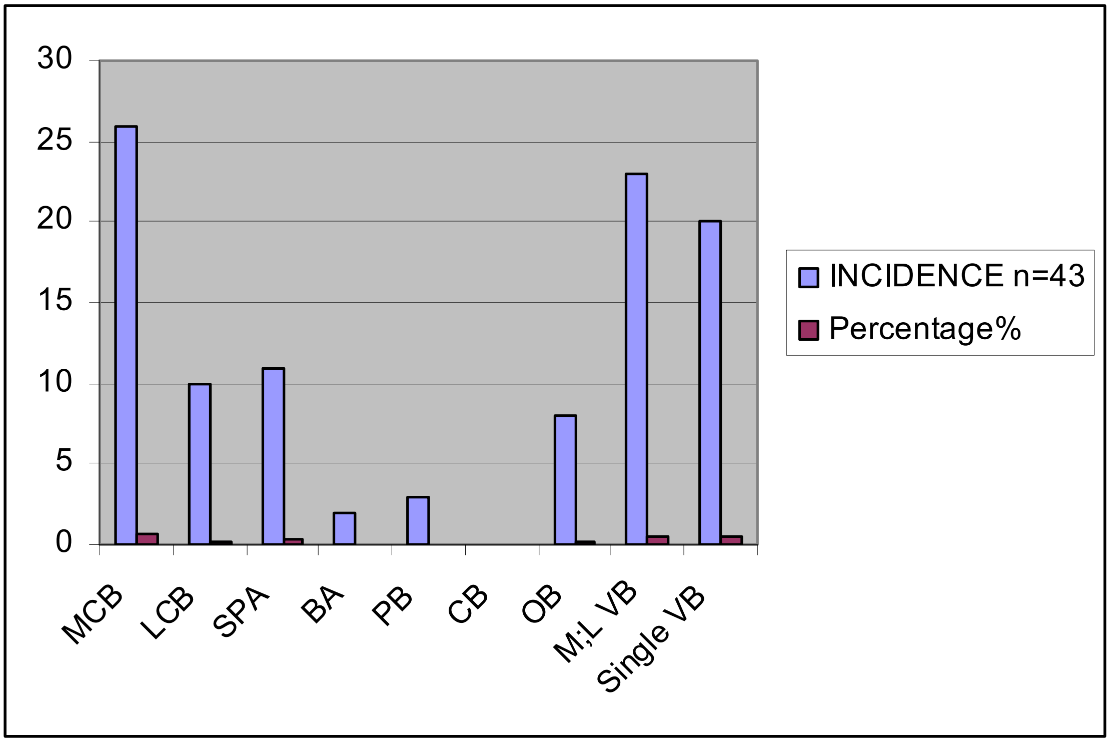


Fig 20 Bar graph illustration of the incidence of the branches of the STrA.

THE SUPRA-ORBITAL ARTERY (SOA):

The SOA appears over the SOR on a vertical line corresponding to the medial limbus of the cornea. It runs from medial to lateral over the SOR. At the SOR it is surrounded by a ligament, the supra-orbital ligament (SOL), as it exits the orbit.

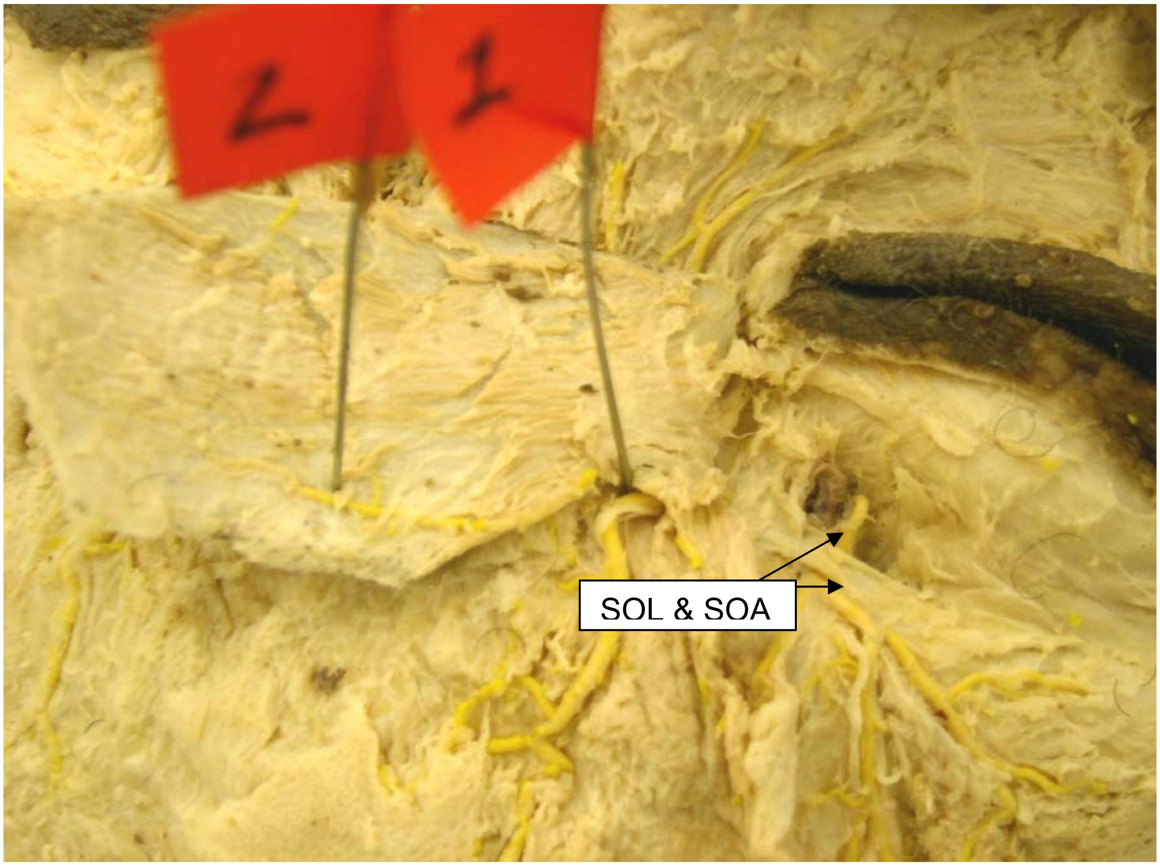


Fig 21. The supra-orbital artery (SOA) is shown as it exits the orbit and the supra-orbital ligament (SOL) compressing it firmly against the supra-orbital rim (SOR).

The SOL was present in all cases where the artery coursed over the SOR (58/60). It was absent when the artery passed through a foramen (two out of 60 hemi-foreheads). The SOA is accompanied by the supra-orbital nerve (SON) and supra-orbital vein (SOV). The SOV is anterior to the SOA and the frontal bone is posterior. The SOA had an average diameter of 1mm. The SOA branches were seen in 46 hemi-foreheads (46/60) and the SOA was absent in one filled ophthalmic artery. Five branches of the SOA were identifiable: 1)

Lateral rim branch (LRB) (39/46). 2) Oblique branch (OB) (39/46). 3) Vertical branch (VB) (43/46). 4) Medial branch (MB) (19/46). 5) Brow Branch (BB) (2/46).

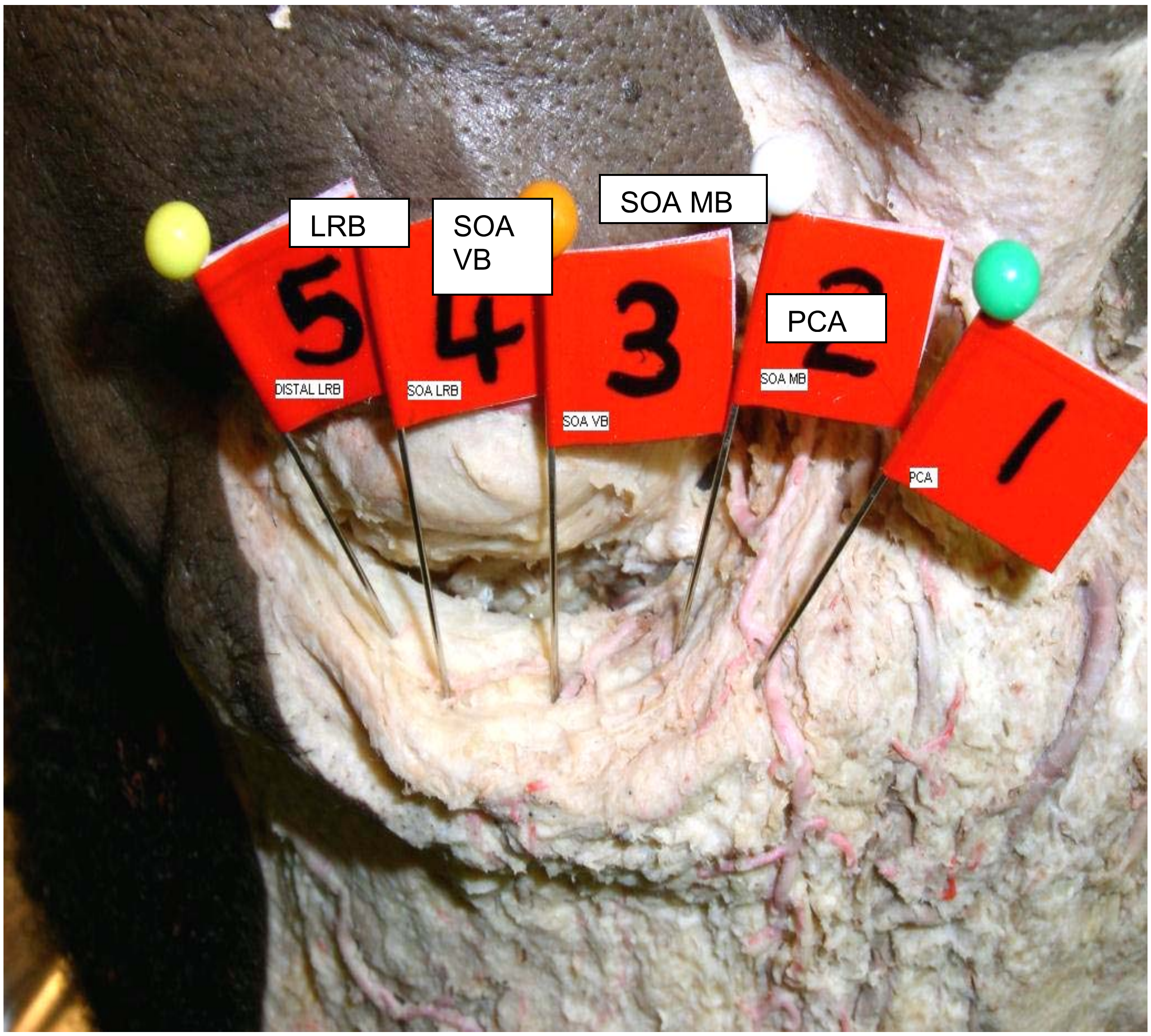
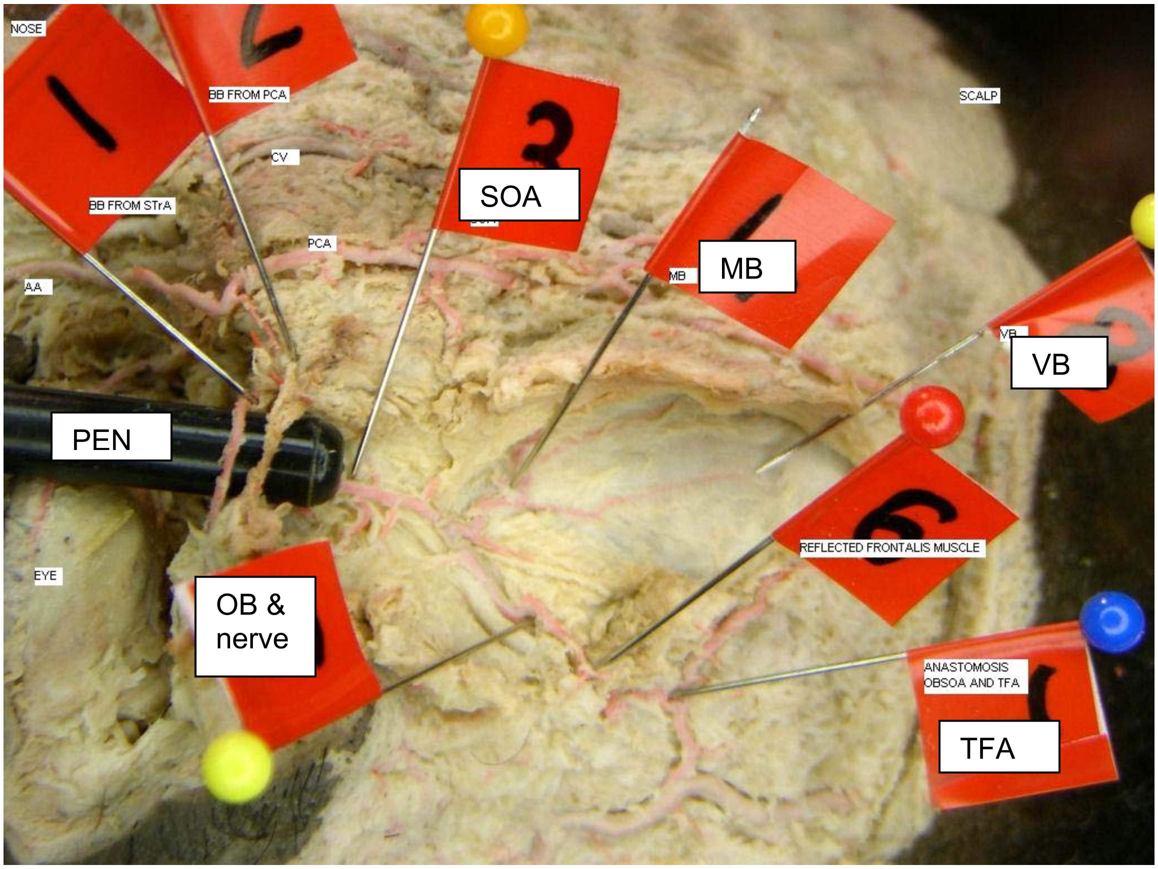


Fig 22. <u>The left supra-orbital artery (SOA)</u> and its medial branch (MB), vertical branch (VB) and lateral rim branch (LRB) is shown.



<u>1 centi</u>

Fig 23. The deep (posterior) nature of the supra-orbital artery (SOA) is shown. A black pen demonstrates the depth at the supra-orbital rim. VB= vertical branch; MB= medial branch; OB= oblique branch; TFA = transverse frontal artery. 1 centi = one centimetre.

The MB, OB and LRB were always deep (periosteal/ sub muscular). The VB was often duplicated or branched soon after its origin. It was mostly periosteal/deep (26/30 cadavers). Superficial and deep VB's were present in four cadavers. In two cadavers only superficial VB's were seen. When the superficial VB was present, it had a similar course to the STrA entering the subcutaneous forehead

15 to 20 mm above the SOR after a short intra-muscular course. The superficial VB had anastomoses with the TFA in the MTT and STT superiorly. Low take-off FBSTA and TFA in the forehead were associated with shorter VB's from the SOA. The OB ran on the periosteum toward either the FBSTA or TFA at the LORV line at which point it sharply entered the frontalis muscle anteriorly to anastomose with either of the TFA or FBSTA. At this point the TFA or the FBSTA often makes a sharp deviation or 'genu'. This anastomosis is mostly at the junction of the ITT and MTT at the LORV. It can be higher though and the OB is then longer. The BB had a superficial course laterally and was similar to the one seen arising from the STrA in another hemi-forehead.

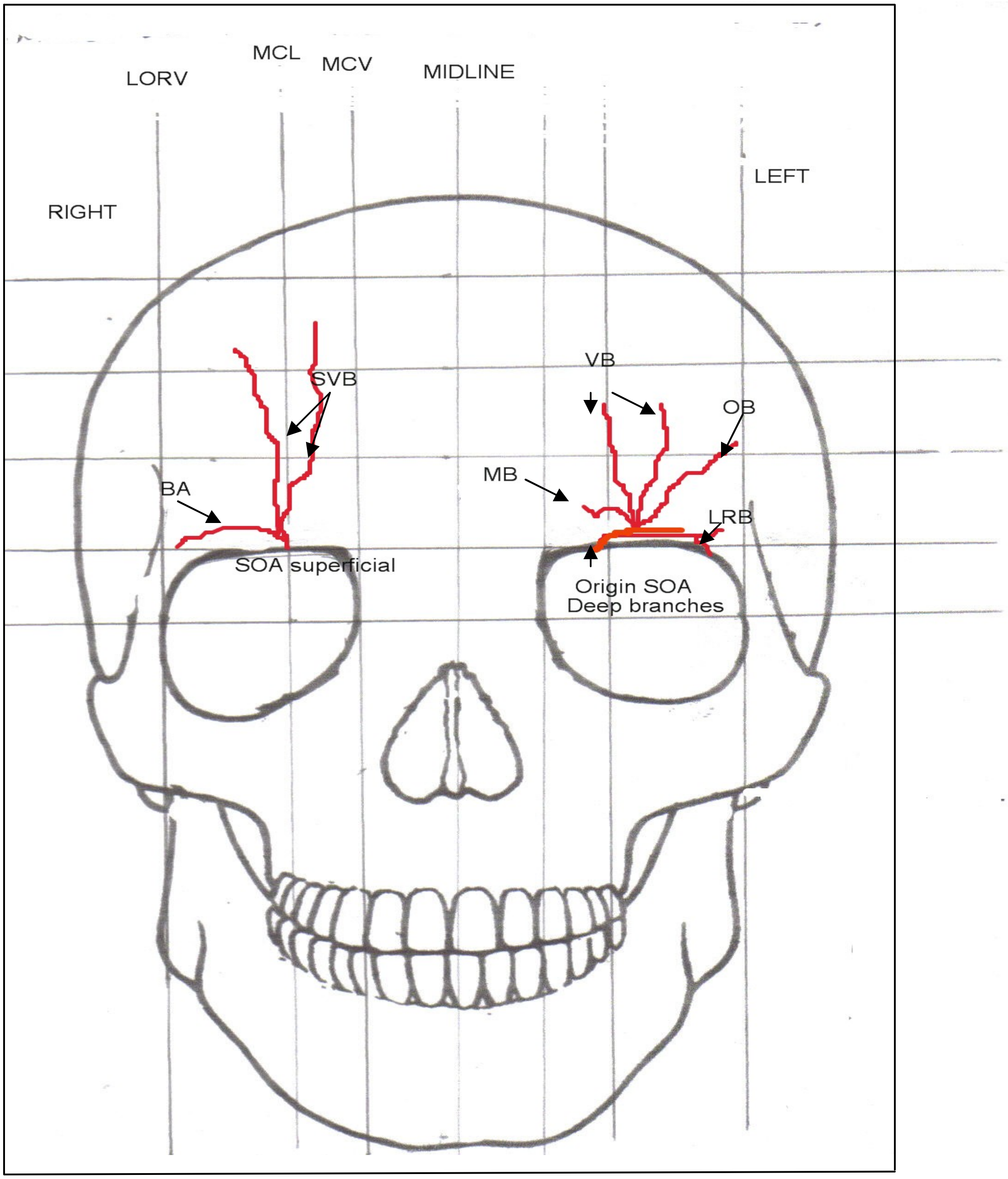


Fig 24. The right hemi-forehead shows the superficial branches of the supraorbital artery (SOA): BA= Brow artery; SVB= Superficial vertical branches. The left side shows the deep branches of the SOA: LRB= lateral rim branch; MB= medial branch; VB= vertical branches; OB= oblique branch.

TABLE IX: THE SUPRA-ORBITAL ARTERY (SOA) BRANCHES		
Branches	Incidence (n=46)	Percentage (%)
LRB	39	91%
OB	39	91%
VB	43	100%
MB	19	44%
BB	2	5%
SVB	4	9%

Abbreviations: LRB (lateral rim branch); OB (Oblique branch); VB (Vertical branch); MB (Medial branch); BB (Brow branch); SVB (Superficial vertical branch)

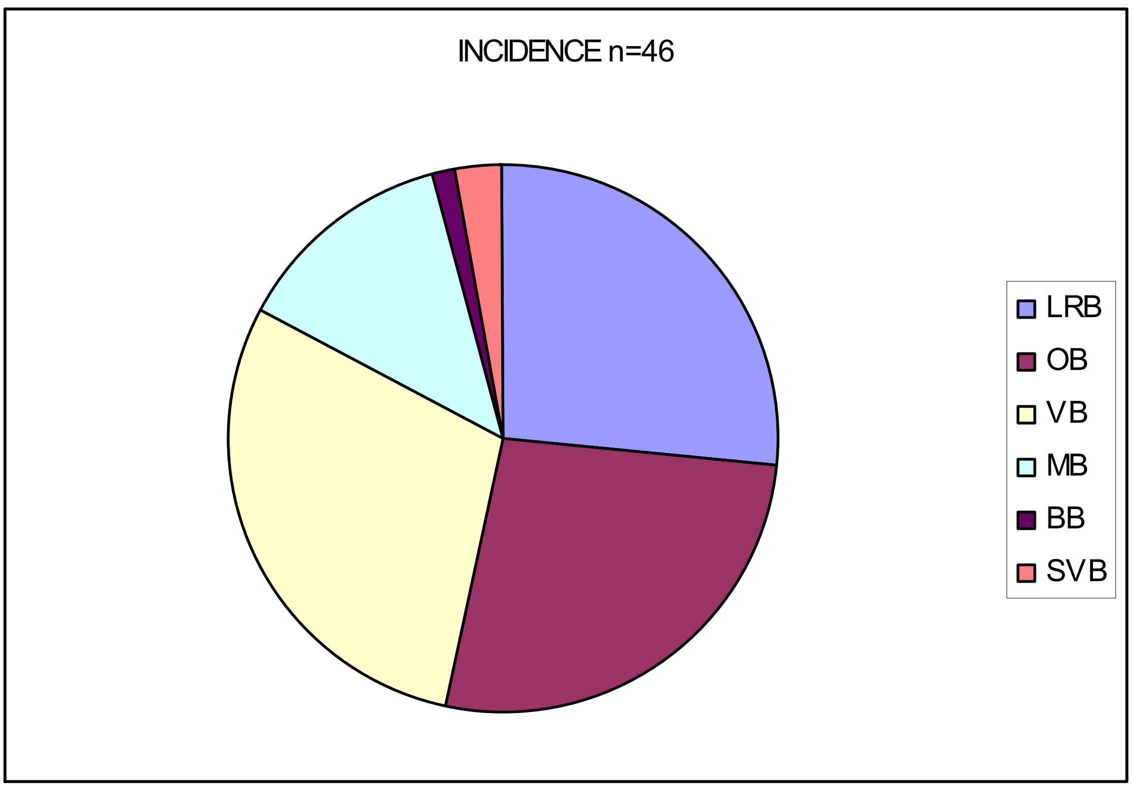


Fig 25. Graph illustration of the incidence of the branches of the SOA.

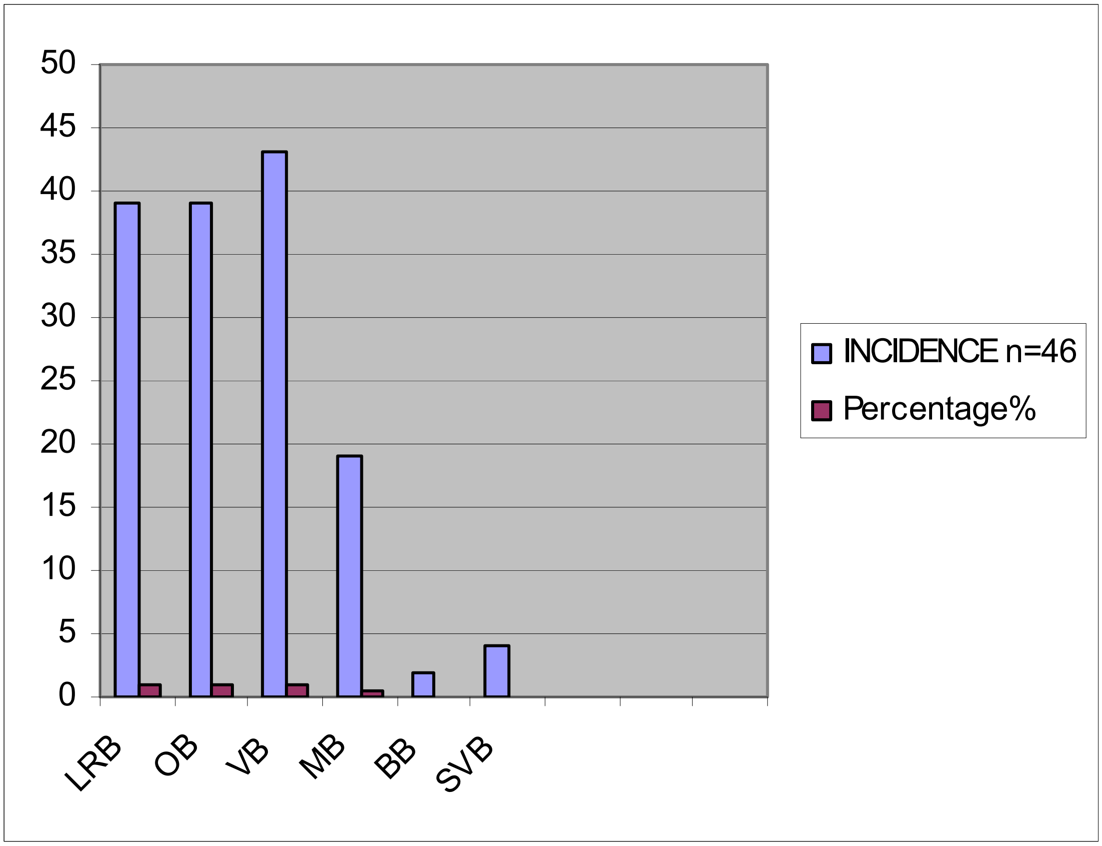


Fig 26. Bar graph of the incidence of the SOA branches

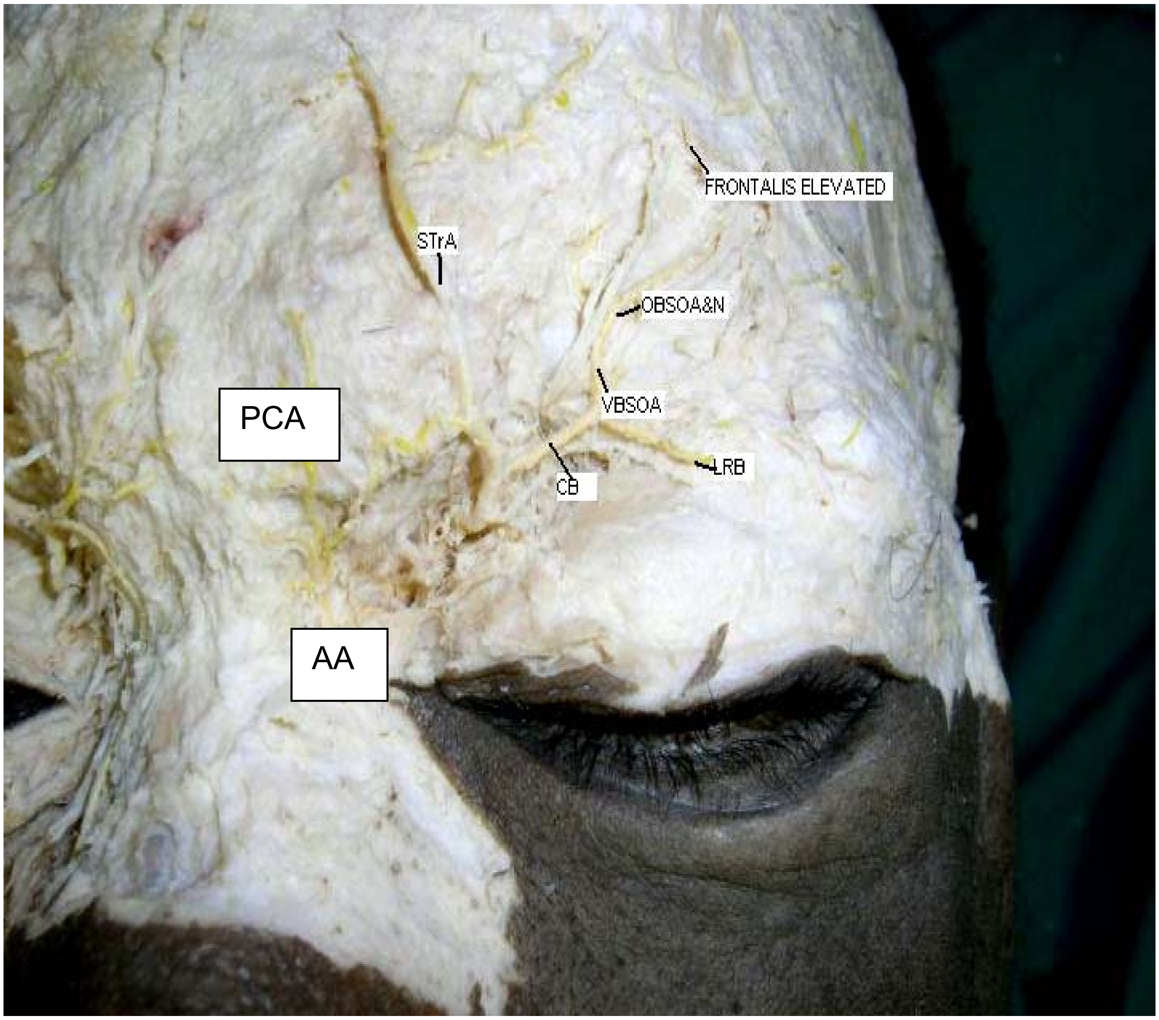


Fig 27. The supra-orbital artery (SOA) and the branches: CB= communicating branch; VBSOA= vertical branch; OBSOA & N = oblique branch supra-orbital artery and nerve; STrA= supra-trochlear artery; PCA= Para-central artery.

THE DORSAL NASAL ARTERY (DNA):

The DNA had an average diameter of 1 mm. It took origin from the AA 42 times (42/45). The DNA can usually be identified usually 5 mm above the medial canthal horizontal (MCH) line. It was not present in three cases where the angular artery (AA) was present (3/45) and this may well have been a result of poor latex filling of the vessels. The DNA gave off a superior central artery (CA) 3 to 5 mm after its origin and the main branch continued inferiorly. A variation of minor significance was the presence of an occasional CA, given off superiorly a few millimetres after the "first" CA. Another variation of lesser significance is that a sporadic inferior (descending) branch might be given off distal to the CA origin.

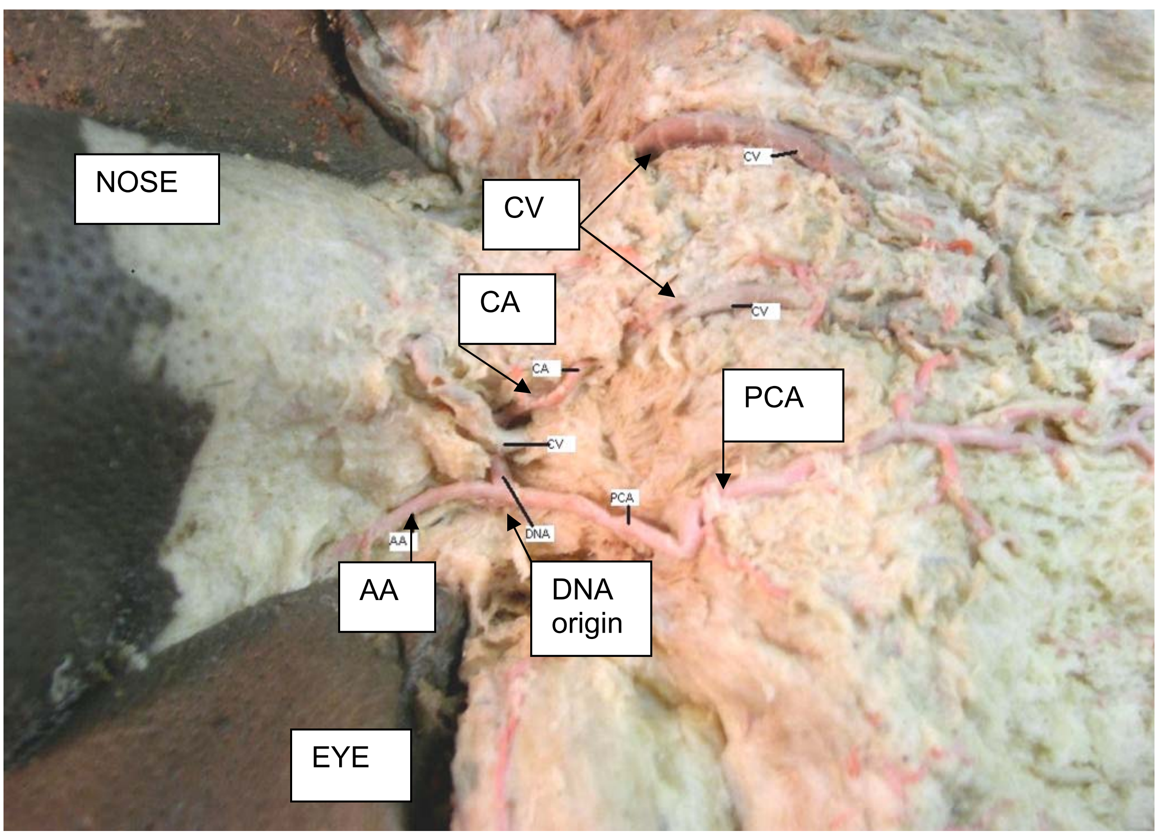


Fig 28. The origin of the dorsal nasal artery (DNA) from the angular artery (AA) is shown.

THE CENTRAL ARTERY (CA):

The CA supplies the glabella and ITT and MTT of the central forehead. The central STT is supplied by the STrA and indirectly by the TFA. The CA's from the two hemi-foreheads anastomose in the ITT to form an imaginary triangle. The CA also has lateral anastomoses with the STrA. The CA has an average diameter of 1 mm. The CA origin is not directly visible when dissecting from superficial to deep as the distal end of the central vein (CV) is anterior to it. It runs superiorly on the medial aspect of the ipsilateral CV.

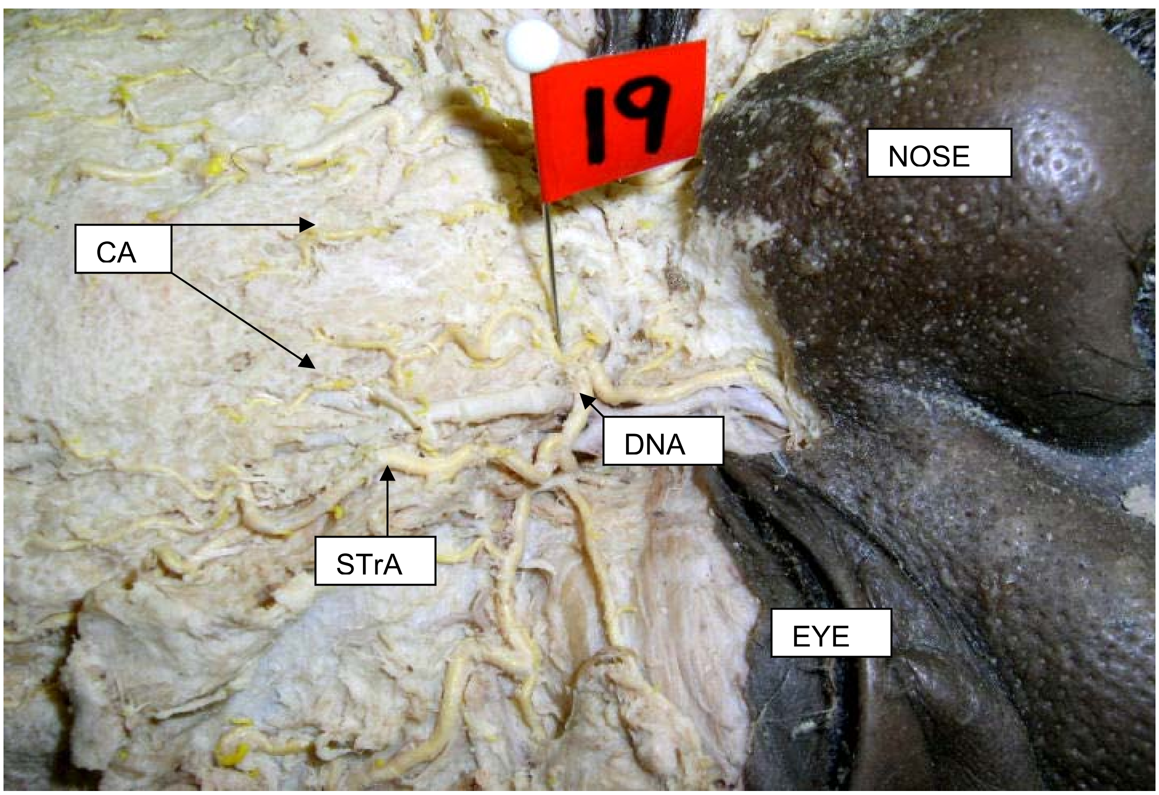


Fig 29. Duplication of central artery (CA). DNA= dorsal nasal artery; STrA= supra-trochlear artery.

THE ANGULAR ARTERY (AA):

The AA is easily identifiable on a vertical line about 5mm medial from the MCV line. The average diameter of the artery was 1, 5 mm and it runs on the deep muscle fascia. The angular vein is medial to the artery. The AA was identifiable in 45 hemi-foreheads. Its branches were the DNA (42/45), communicating branch (CB) and the para-cenral artery (PCA) (21/45).

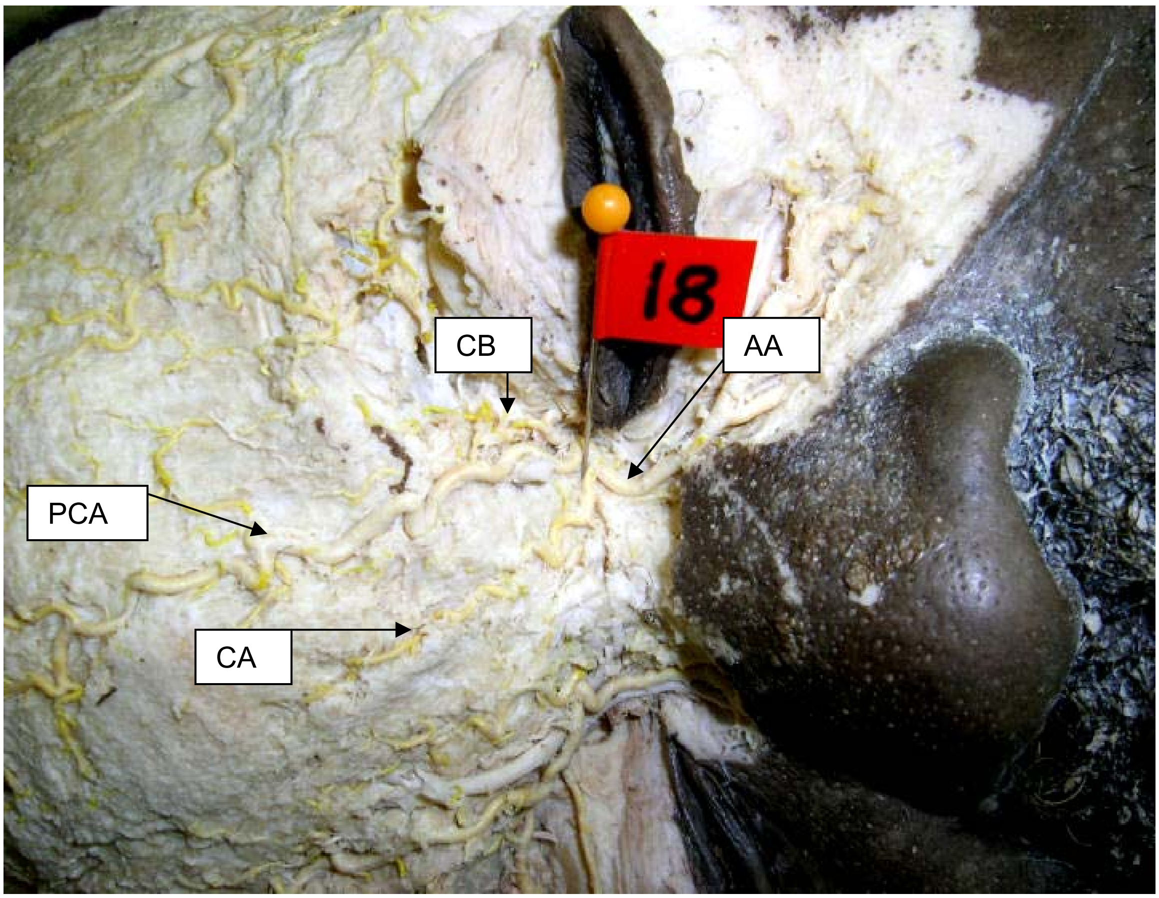


Fig 30. The Angular artery. PCA= paracentral artery; CB= communicating branch; CA= central artery.

TABLE X: BRANCHES OF THE ANGULAR ARTERY (AA)		
Branches	Incidence n=45	Percentage%
DNA	43	96%
CB	30	67%
PCA	21	47%

Abbreviations: DNA (Dorsal nasal artery); CB (communicating branch); PCA (Paracentral artery).

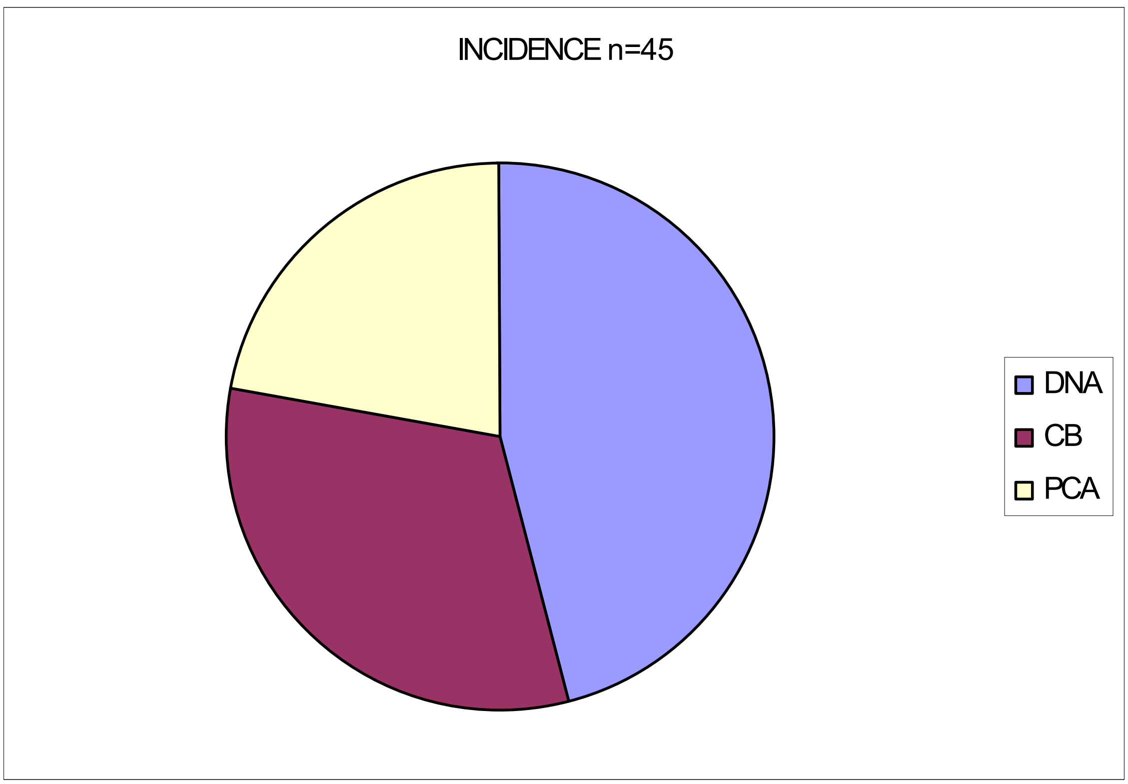


Fig 32. Graph of the branches of the angular artery (AA): DNA= Dorsal nasal artery; CB= Communicating branch with the supratrochlear artery; PCA= Paracentral artery.

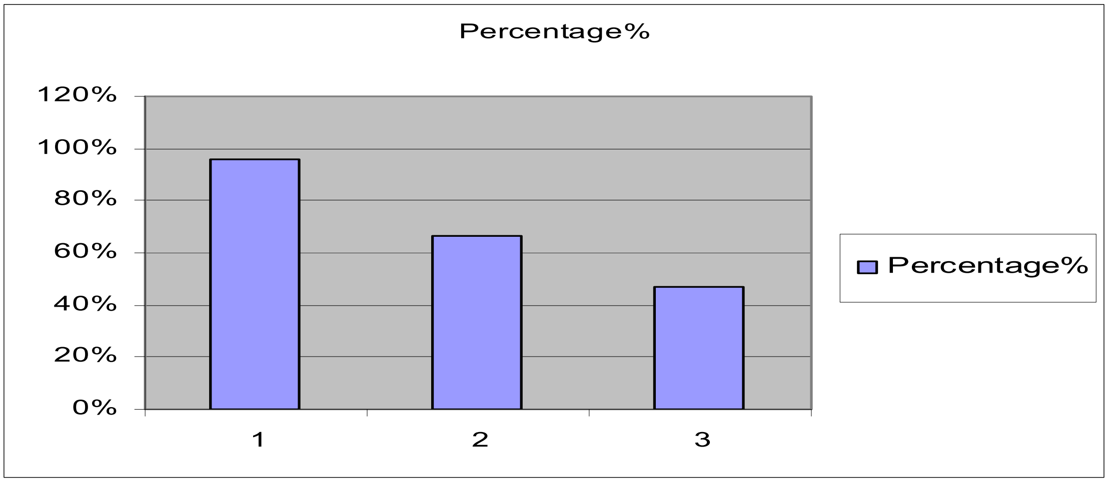


Fig 32. Bar graph of the branches of the AA: DNA (1); CB (2); PCA (3).

THE PARACENTRAL ARTERY (PCA):

The PCA was present in 21 hemi-foreheads. The PCA originated from the AA as its main continuation into the forehead (15/21) or from the CB with the STrA (6/21). When the PCA originated from the CB, a STrA variation was present in two thirds (4/6). The STrA was absent in 3 hemi-foreheads. In the other hemi-forehead, the STrA gave off two vessels from the SOR. The PCA was on the lateral side of the CV in the lower central forehead with the CA medially. It had medial and lateral anastomoses with the adjacent arteries in the forehead.

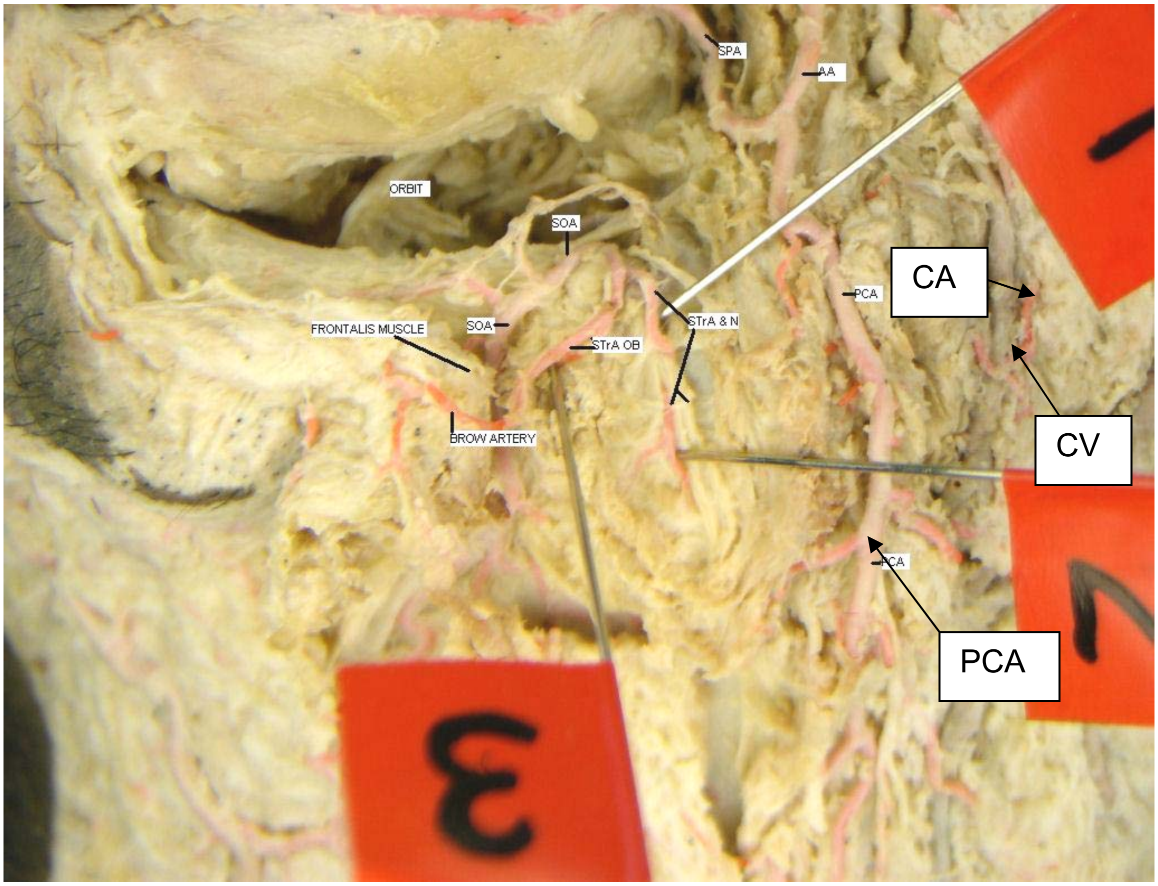


Fig 33. <u>Note the relationship of the central artery</u> (CA) and para-central artery (PCA) to the central vein (CV)

TABLE: BRANCHES OF THE PARACENTRAL ARTERY

TABLE XI: ORIGIN OF THE PCA		
Origin PCA	Incidence (n = 21)	Percentage (%)
AA	15	71%
CB STrA	6	29%

<u>Abbreviations</u>: AA (Angular artery); CB STrA (communicating branch with supra-trochlear artery)

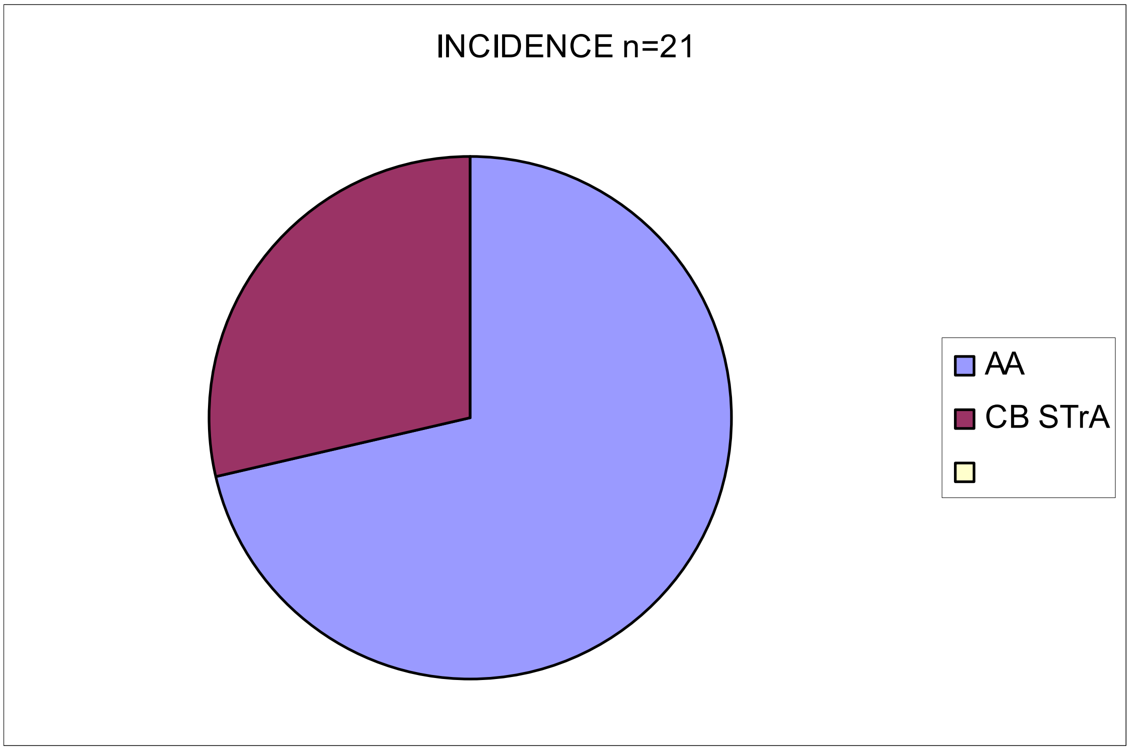
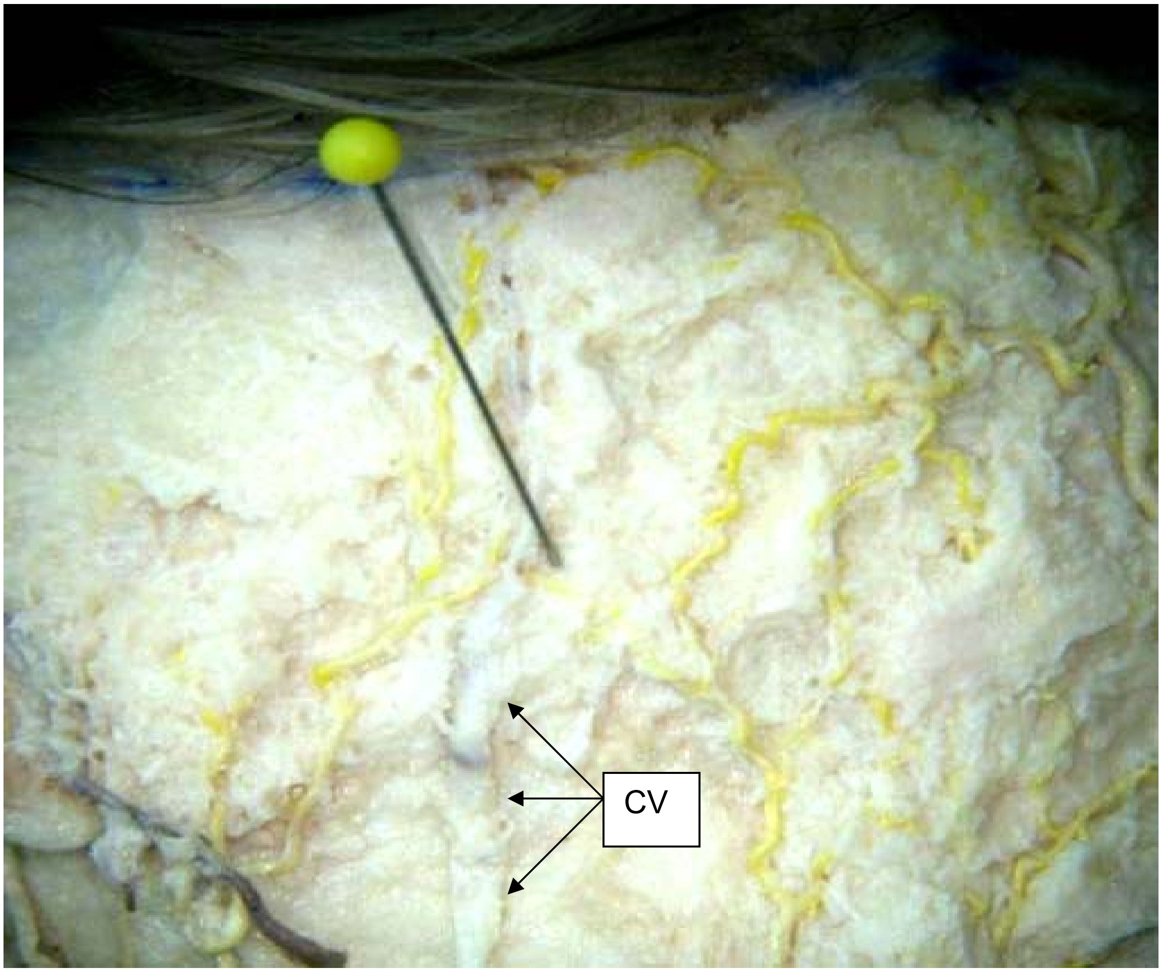


Fig 34. Graph illustration of the origin of the PCA

THE CENTRAL VEIN (CV):

The CV is often larger on one side of the forehead midline. It usually has a bifurcation in the ITT or inferiorly and drains to the supero-medial orbit. In the lower forehead and glabella, it is usually accompanied by the CA medially and the PCA laterally. If the CV is in close proximity to the STrA, then usually, the PCA is absent and the vein can be in close proximity to the STrA. A duplicated CV was present in a few cadavers, in which case the veins may have transmidline connections.



1 centi

Fig 35. The central vein (CV). 1 centi = scale for one centimeter

OBLIQUE VEIN (OV):

An OV was present in the lateral forehead often sited medial to the OBSOA in which case the vein was usually superficial to the arteries. It coursed towards the SOA origin and then in the direction of the supero-medial orbit. The OV was occasionally joined by a lateral orbital rim vein branch at the SOR level.

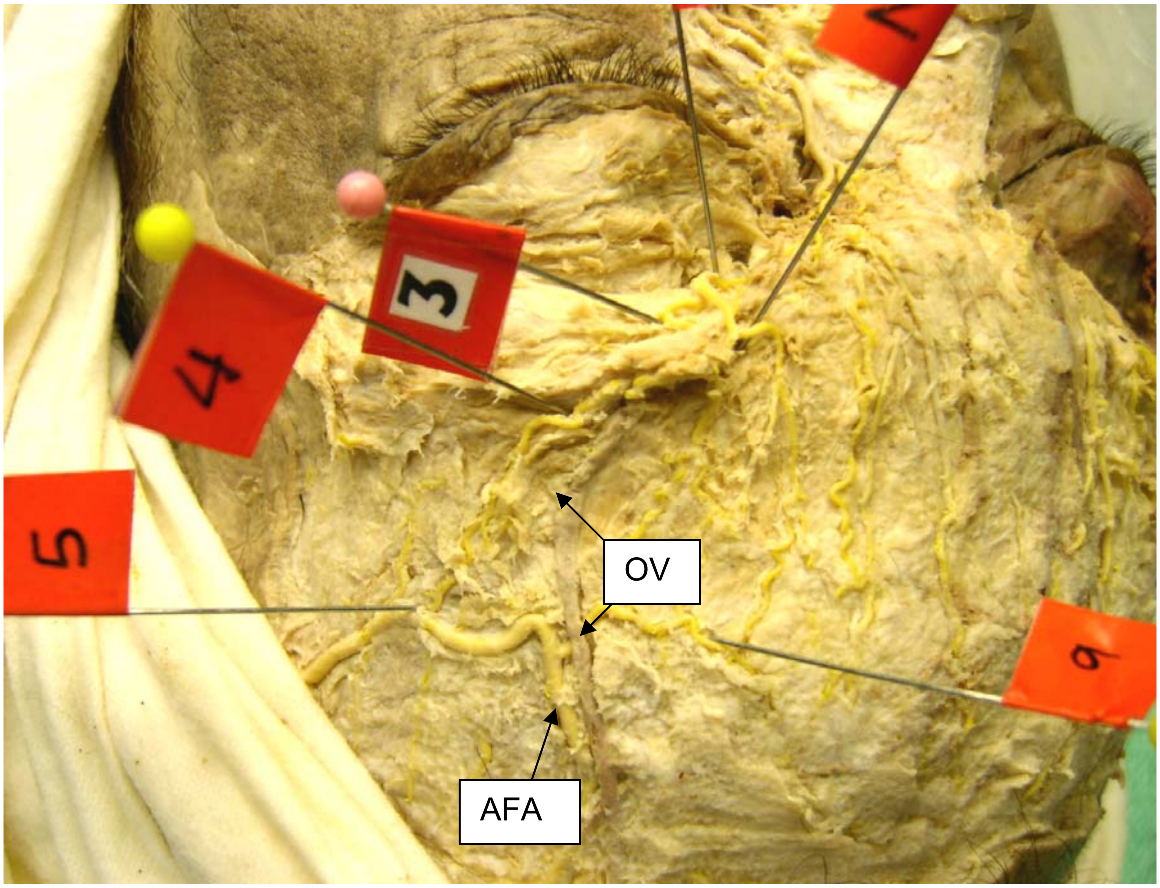


Fig 36. The oblique or lateral vein (OV) adjacent to the ascending frontal artery (AFA).

THE SUPRA-ORBITAL NERVE (SON):

The SON has several branches and they were observed to accompany the arteries. These nerves like the arteries were mostly related to a periosteal level. Since naming the branches of the arteries, it follows logically that the corresponding nerves would have the same name to avoid confusion. Several vertical branches (VBSON) were seen accompanying the VBSOA. The OBSOA was similarly accompanied by an oblique branch of the SON (OBSON). This nerve was often detectable lateral to the artery and in most cadavers the largest nerve. In some specimens it was duplicated and situated medial and lateral to the artery. No significant SON was seen with the MB and LRB of the SOA.

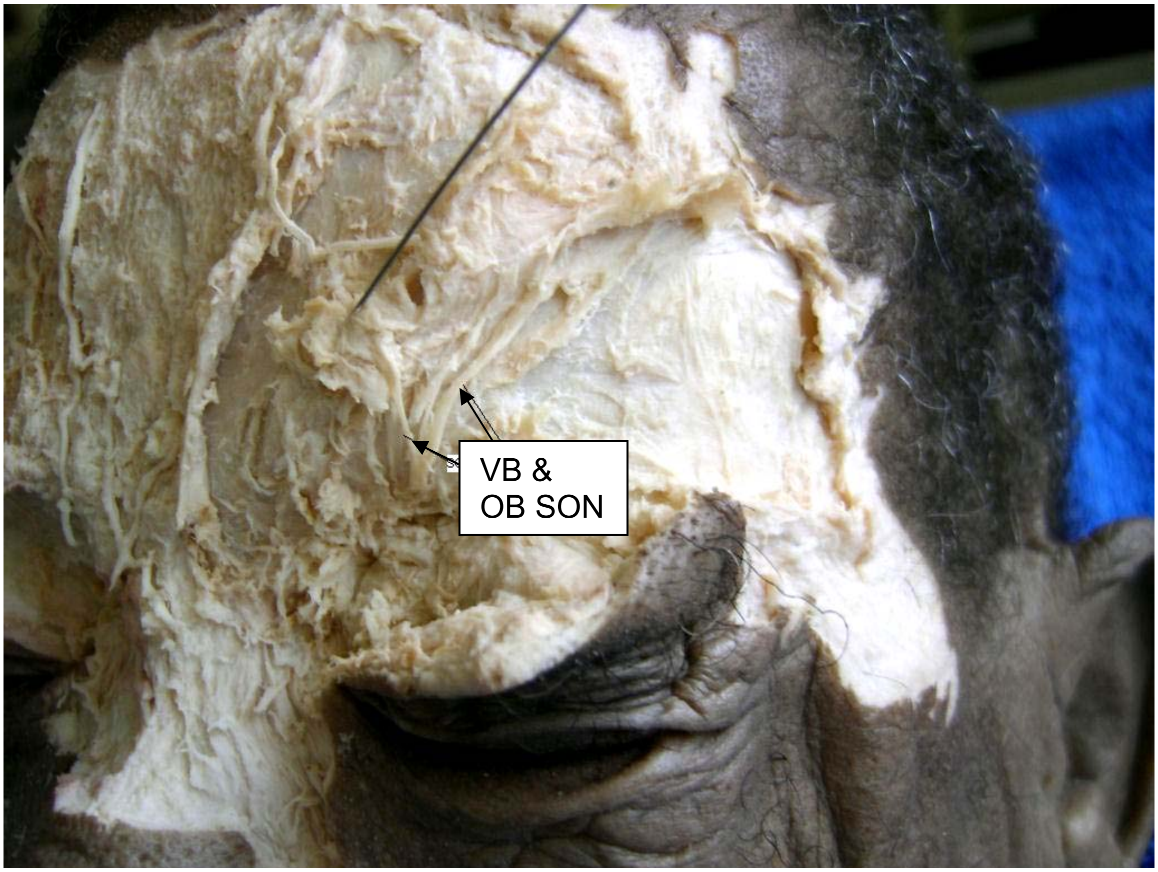


Fig 37. Supraorbital nerve (SON): vertical (VB) and oblique branches (OB)

SUPRA-TROCHLEAR NERVE (STrN):

The STrN was detectable accompanying the STrA in the forehead of almost all cadavers.

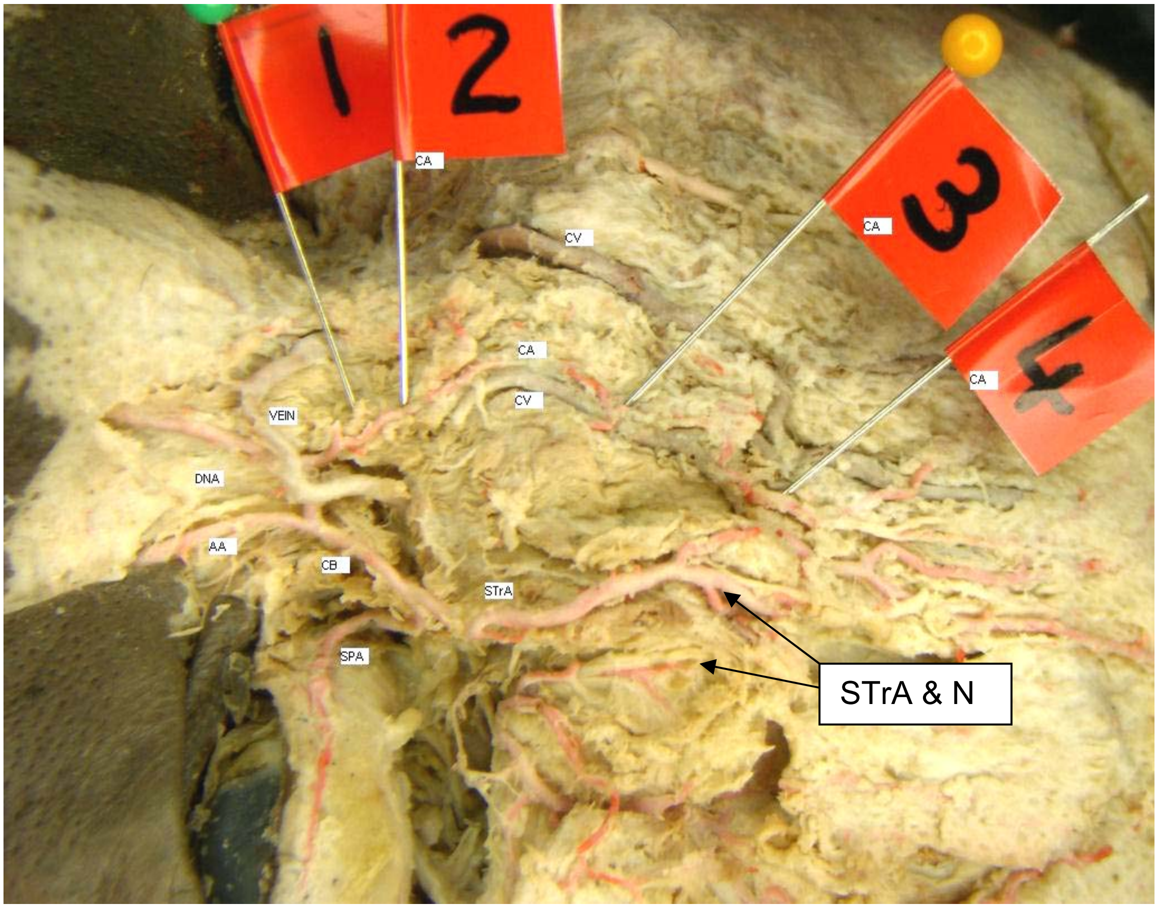


Fig 38. The supratrochlear artery and nerve (STrA & N)

TRANS MIDLINE COMMUNICATION:

This was visible in all thirds (ITT, MTT; STT), in the subcutaneous tissue but was absent on a periosteal level. The TFA or FBSTA and had indirect communication across the midline in a zigzag pattern with the STT anastomosing branches from the ipsi-lateral STrA, then indirectly with the opposite STrA.

Fig 39. Trans midline communication of the supra-trochlear artery medial branches are seen in the middle and superior third of the forehead as indicated by the red flag needles. These anastomose with the contralateral vessels.

TABLE XII: METANALYSIS OF FOREHEAD ARTERIES ACCORDING TO AUTHORS AND NUMBER OF CADAVERS STUDIED*			
Author	Year	Cadavers	Comments
Conway	1952	6	Arterial vascularization of soft tissues
Corso	1961	9	Described 9 cadavers Studied supply in 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th} and 9^{th} decades Described hazards of flap surgery based on arterial supply Used corrosion specimens (p163) Emphasized importance of veins Utilized methacrolate
Mangold	1980	10	Emphasized arterial arcades
McCarthy	1985	6	Blue dye study to show arteries. Angular contributions
Fatah	1991	10	Only veins studied
Shumrick	1992	5	Radiographic study
Fukuta	1994	12	General anatomy
Potporic	1996	12	Radiographs. No variations
Vural	2000	8	STrA position variability
Park	2000	1	Noted angular artery contributions

*The current doctoral study is the largest prospective cadaveric study consisting of 30 latex filled cadavers and 10 controls. Little supporting data is available from other cadaveric studies, because the focus is different. Also, many of the studies have a small cohort of cadavers compared to the current study of 40, making it the largest study at the moment.

HISTOLOGICAL RESULTS:

Biopsies stained with H & E and Masson Trichrome, and obtained from the forehead and

glabella region showed:

i. Epithelium and hair follicles (n=10)

ii. Dense compact dermis, individual nerve fibres.

iii. Absent stratum lucidum (only found in the palms and soles of the feet)

iv. Large arterioles and complex venous connections.

v. Skeletal muscle (muscles of expression)

vi. Surrounding adipose tissue and sweat glands.

vii. Blood vessels in the glabella region more prominent than in the forehead region. The mean luminal diameter was 170.1 micron (glabella) and 93.3 micron (forehead); p = 0.21

Comment: New information that has been forthcoming from this study is the arterial luminal sizes, which are not unexpected. There is however nothing reported in the anatomy or histological literature referring to arteriolar diameter in the glabella region.

CADAVERIC STUDY

DISCUSSION

DISCUSSION ON CADAVERIC STUDY:

Controversies in the blood supply of the central forehead areas

The description of the arterial supply of the medial forehead has evolved from ill-defined and non-specific to detailed single vessel descriptions (Ahn et al 1998, Lascaratos et al 1998, Millard 1976, Shumrick et al 1992, Daver et al 1975). Sawhney (1979) described a technique of maximising the contribution of the arteries of the DNA and STrA to the midline forehead flap by blunt dissection close to the vessels and referred to previous work by Brown and McDowell (1951). Blandini et al (1994) documented that the DNA originated from the ophthalmic artery, just above the medial canthal ligament. Further, the DNA had numerous anastomoses with the AA, STrA, alar branch of the facial artery and superior labial artery. They mention the presence of two constant longitudinal branches from the DNA that communicate freely across the midline. Some similarities were recorded in this study. From these dissections it is clear that the DNA is a constant branch of the AA. The infra-trochlear artery was consistently (except in one from 54 hemi-foreheads, where the AA did not fill or was absent) of a very smaller calibre diameter than the AA, whereas the DNA and AA were more or less of similar diameter. The para-median branches they refer to we have selected to refer to as the CA.

In 2001, Wild and Hybarger injected 10 cadavers with blue dye to define the anatomical position of the DNA and found it to be roughly 7, 4 mm superior to the medial canthal tendon. In 2000, Fan stated that the blood supply of the medial forehead is primarily derived from the STrA and SOA, possibly ignoring the important contribution from the AA (DNA, CA and PCA).

In 1994, Fukuta et al. evaluated 12 cadavers by an intra-arterial dye injection technique to demonstrate the blood supply of the *galea frontalis* flap. They describe the superficial and deep branches of the STrA and SOA, but did not specify the branches by names. They described the course of the OBSOA but omitted to name it. A point not highlighted by them adequately is that the OBSOA is deep (posterior) almost right up to the level of TFA or FBSTA at the LORV. It penetrates the muscle almost at 90 degrees to anastomose with the TFA or FBSTA posterior and inferiorly. These authors “correctly” found that the SOA branches are periosteal and that the STrA supply was not as significant as the SOA to the periosteum. Based on the inconsistent presence of the superficial branches of the SOA, we would not recommend these branches as a sound vascular basis for any planned flap. The consistent presence of the deep branches of the SOA and the area that they supply make them suitable for consideration for SOA based flaps (inconsistent and small STrA contribution) (Carstens, 1991).

The findings of Whetzel and Mathers in 1992 that the deep branch of the SOA anastomosed with the superficial temporal artery (STA), whereas the superficial branch entered the sub dermal plane directly, is vague or non-specific, but may have some value (Fukuta, 1994). There is an “inaccurate” description of the termination of the superficial branches of the SOA, as compared to our dissections, by Fukuta et al. The FBSTA and TFA are almost always anterior to the frontalis muscle. Therefore the superficial branches of the SOA don’t have to penetrate the muscle to anastomose with these arteries. Leonard (1983) proved by meticulous dissection and histological analysis that the FBSTA was positioned anterior to the frontalis muscle and this was our experience in all the dissected specimens.

In 1987 it was believed that the midline forehead island flap had a random circulation (Field, 1987; Savage, 1983). Our study removes all doubt that the central forehead blood supply is indeed axial. The brow artery originating from either the STrA or SOA has also been described previously for application in a transverse orbicularis oculi myocutaneous flap (Capizzi, 1999). Dzubow (1986) also described horizontal and vertical cutaneous arterial supply in their study.

SIMILAR CADAVERIC STUDIES:

Whetzel and Mathes (1992) studied a total of 21 cadavers using different techniques to evaluate the vascular territories and perforating cutaneous vessels of the face. They used eight cadavers for latex dissection studies, 15 cadavers for ink injections and radiography and one cadaver for lead

oxide injection. Houseman et al. (2000) studied 30 cadavers in total, 24 retrospectively and 6 fresh specimens to define the 'angiosomes' of the head and neck. Definitions of "angiosomes and "venosomes" have been given in previous chapters. Their focus was not on the arterial variations, but on the areas supplied by the different arteries. Herbert in 1978 studied 45 fresh cadavers radiographically and by dissection to demonstrate the blood supply of the naso-labial region. Unfortunately, no results of the forehead vasculature were presented even though the forehead arterial patterns were visible on the radiographs published. The only draw back of radiographic studies is that they are *uni-dimensional* and that's a possible explanation for the misconceptions of the SOA blood supply and the few arterial and venous correlative studies of the face. Shipkov et al. studied ten cadavers over ten years, investigating the blood supply of the forehead flaps. They describe that the STrA and SOA pierces the frontalis muscle and runs 'over' it. Unfortunately no mention is made of the SOA deep branches and no arterial variations are presented, or mentioned of the AA contribution (DNA, CA, and PCA). Fatah in 1991 presented his results of ten cadaver dissections looking at the nerves of the forehead. No arterial or venous relationships were described.

McCarthy et al. (1985) studied the median forehead blood supply on six cadavers using a blue dye injection technique and found that the AA supply stretched to the hairline. Unfortunately no arterial variations were documented or presented and some inaccuracy in the picture description of the DNA is presented. Park (2000) from a single cadaver dissection found significant contributions from the

AA to the median and para-median forehead flap. Shumrick and Smith (1992) studied 9 cadavers roentgenographically to determine the location of the STrA and omitted to document any arterial variations or arterio-venous associations. They reported that the STrA was 1, 7 to 2, 2 cm from the midline at the SOR. **This study also included anatomical dissection of injected cadaver heads as well as Doppler study of normal subjects.** Thereafter, the vessel passed superficial to the corrugator muscle and deep to the orbicularis and frontalis muscles. Then the course was more subcutaneous in the rest of the forehead.

Vural et al. (2000) studied eight cadavers to determine the relationship between glabella frown lines and the position of the STrA. The STrA was detectable at the glabella frown lines in about 50 % of cases and at an average of 3.2 mm laterally in the other 50 %.

Potparic et al. (1996) studied the arterial supply of 12 cadaver foreheads by dissection and radiographs, three by direct STrA and SOA injection and eight more by sectional histology. They emphasised deep and superficial branches of the STrA, SOA and FBSTA. From the 12 cadavers that the STrA entered in a subcutaneous plane: the average distance from the SOR was 35 mm superior and for the SOA 56 mm.

NEW ANATOMIC TERMINOLOGY:

New anatomic terminology can become quite a controversial issue. The paramedian forehead flap has the supratrochlear artery supplying it. Therefore if the paracentral artery was called the para-median artery it would have been confusing to learn. Also if there was a median artery instead of a central artery, one would expect to have a para-median artery. Since there was speculation and mention of some central arteries in the past, the word central is favoured above median for both the artery and vein.

Whether it is necessary to name the transverse frontal artery is another debate, but less controversial in the authors mind than the ascending frontal artery which is the superior continuation of the frontal branch of the superficial temporal artery. The anastomosis of the oblique branch of the supra-orbital artery is clinically significant and warrants accurate description of its termination and therefore the distinction between the transverse frontal artery and frontal branch of the superficial temporal artery is important.

The supra-orbital ligament (SOL) has not been accurately named previously. In 1991 Fatah described the presence of one or two canals of periosteal condensations at the supra-orbital groove where the nerves emerged from the orbit towards the forehead. The presence of this ligament may be of little clinical value but it needs to be highlighted for anatomic accuracy. When palpating over the supra-orbital rim often the

supra-orbital artery, supra-orbital nerve and supra-orbital vein can be felt as an elevated round ridge on the rim. This is true mostly for cases where there's no supra-orbital foramen. This palpable ridge over the supra-orbital neurovascular bundle was referred to as a notch previously and the associated supra-orbital ligament was not described.

Fatah proposed the terms medial, middle and lateral to describe the branches of the supra-orbital nerve in the forehead. The description of medial and lateral branches of the supra-orbital nerve was also used by later authors. These terms can be used, but since a distinction must be made between the lateral rim branch and oblique branch of the supra-orbital artery, it would more accurate and less confusing if the nerve descriptions follow their accompanying arteries. Fatah also accurately found that the most medial nerve branches change from a submuscular plane to a subcutaneous plane shortly after exiting the orbit and that the other lateral branches travel to a higher level before becoming subcutaneous. Although this is an over simplification, the described neural patterns correspond exactly to the branching pattern of the supratrochlear artery and the supra-orbital artery.

Branches of the Supratrochlear artery (STrA):

A possible explanation for the low incidence of visualization of the smaller branches (periosteal branches and the brow artery) of the STrA is that 1) the vessels were too small to preserve during dissection or 2) the smaller branches did not fill as well as the larger branches with the latex solution or 3) the actual incidence of these branches are low. Possibility one and two are the more likely answers. A possible explanation for the more or less 50% incidence of the medial and lateral vertical branches (M & L VB) versus the single STrA vertical branch is:

1) Good central blood supply from the central and paracentral artery are usually present when there is a single vertical branch of the STrA.
2) Good lateral blood supply from either the superficial vertical branches (SVB) of the SOA or the TFA/ FBSTA may be present.

When considering the blood supply lateral to the STrA, the *cutaneous* contribution from the TFA and FBSTA is more than that from the SVB of the SOA (the SVB was clearly identifiable in only 4 hemi-foreheads). A general pattern of compensatory enlargement of adjacent vessels in either size or branches is seen in the presence of a small or hypoplastic or absent artery.

Branches of the supraorbital artery (SOA):

The low incidence of the visualization of superficial vertical branches (SVB) of the SOA is quite surprising, since one would assume it to be the more common pattern. Possible explanations might be that:

1) The latex flow through the SVB could be met by resistance as it pierces the lower frontalis muscle to continue subcutaneously further superiorly. A large percentage of SVB could have been missed as a result of poor latex filling. This scenario is unlikely though, as the STrA also would then also

have had a low incidence related to poor latex filling, because it also has to travel through the corrugator and frontalis muscle.

2) The diameter of the vessels was too small to adequately fill or to dissect without damage.
3) The actual incidence of the SVB is low.

From the general arterial patterns seen, when the SVB was present, the FBSTA was high in the superior transverse third of the forehead. Since this pattern was seen only with the SVB present, it can safely be accepted that the actual incidence of the SVB are low. This finding is further supported by the difficulty of locating the SVB of the SOA with the use of a hand-held Doppler in the clinical setting.

The low incidence of the brow artery (BA) can be related to the small size of the vessel and possible poor latex filling and also inadequate visualization of the vessel during dissection. It is quite difficult to preserve this vessel when dissecting from superficial to deep, especially since the brow artery has an early subcutaneous course under the eyebrow.

The low incidence of visualization of the medial branches of the SOA could also be explained by three scenarios:

1) Small vessel diameter contributes to poor visualization
2) Poor latex filling also leads to poor visualization.
3) Actual low incidence of these vessels.

As the STrA periosteal branches were quite small and the medial branches of the SOA as well, one can come to the general conclusion that the median forehead periosteal blood supply is less prominent compared to the middle and lateral forehead.

VENOUS DRAINAGE:

TABLE XIII: STUDIES ON VENOUS DRAINAGE OF THE FACE: METANALYSIS*		
Author	Year	Details studied: comment
Corso	1961	“Venous drainage of forehead was more in the muscle layers”
Herbert	1978	Description unclear
Eiseman	1978	Emphasized that venous drainage was important for temporal flaps
Fan	2000	Forehead veins follow arteries
Houseman et al	2000	Veins often distant from arteries of the face (forehead scalp, nasolabial)
Taylor et al	1990	Described “venosomes”: areas of skin drained by veins

*Clinical and cadaveric impressions.

Misconceptions about the forehead anatomy and flap patho-physiology are common (Riggio, 2003). The occlusion of the venous drainage "kills flaps" quicker than arterial occlusion (Utley, 1998).

An explanation of why the venous drainage of the face has not been studied as in such detail as the arterial system was given by Herbert in 1978 : 'The veins are friable and thin walled and injection studies in fresh cadavers cause difficulties due to extravasation of the medium into the tissues.' The importance of venous drainage of temporal based flaps has been emphasized by Eiseman (Eiseman, 1978). A metanalysis is given in Table IX, highlighting the venous drainage of the face. **Literature** about venous drainage of the central forehead area is **almost non-existent**. Fan (2000) stated that the veins of the forehead usually follow the arteries. However Houseman et al. (2000) found that the veins are often at "a distance" to the major arteries of the face. This was mostly seen in the naso-labial area, forehead and scalp. Houseman et al. postulated that island flaps became engorged as a result of good inflow and poor outflow, because the flaps were isolated on a narrow arterial pedicle and thereby possibly occluding the venous outflow. This was also proposed to be the case with the transverse forehead flap. It was further proposed that the problems encountered with the full transverse forehead flap (FTFF) were related to the fact that the flap spanned 4 "angiosomes" (see definitions), but the problem is more often venous than arterial. In the superior third of the forehead it is possible that the angiosome of the FBSTA can almost reach the midline. Details on the definition of angiosomes have been given in earlier sections of the thesis. The location of the TFA can be of value in design of the flap. If it pursues a low course, then a hairline incision would be adequate for the FTFF. If it is situated higher in the forehead, one will have to make the superior incision (of the flap) in the hairline to capture the veins, which are more superior or posterior to the arteries, in order to avoid venous congestion in this flap. However this is not an absolute requirement for the FTFF to survive. The transverse level at which the TFA enters the forehead is often easily palpable and the FBSTA is often easily seen "waving tortuously" (**having a several up and down curves**) in the temporal area and lateral forehead.

One of the common problems with island flap surgery is venous obstruction with marginal or subtotal flap loss (Field, 1987; Converse and Wood-Smith, 1963). This problem in the central forehead can now be minimized by potentially using the CV method as the landmark for planning the flap and pedicle. The superficial temporal vein can either run alongside the artery or posterior to the artery and this clinically applicable information has been emphasized by Kobayashi (Kobayashi, 1995). Venous congestion is commonly observed after STA based forehead flaps. Park (2000) found an eight percent incidence of distal "epidermolysis" **(epidermal sloughing or epidermal necrosis**) in their 127 patients undergoing forehead flaps. An incidence of partial flap necrosis of 1, 7 percent from 532 forehead flaps was reported by Rohrich et al. in 2004. Others reported up to 14 percent incidence of flap necrosis. Twenty five percent (25%)

flap necrosis was experienced by Goncalves et al. in 2001 using a midline forehead flap design.

The importance of venous drainage in the temporal flap:

The inferior branch of the superficial temporal vein was seen anterior to the arteries and nerves over the supra-orbital rim, and posterior to the muscles over the supra-orbital rim in the specimens dissected in this study. This is quite low and an incision on the superior margin of the eyebrow is no guarantee of inclusion of this large vein.

From the anatomical study and results (including illustrations), it is clear that the vasculature of the midline forehead flap would be based on:

1. Angular artery (distal peripheral branch of the facial and external carotid artery).
2. Central vein (drains to orbit and cavernous venous sinus): This was demonstrated in the dissections.

Anatomically, the vasculature of the forehead flap based on the temporal artery then differs from the midline forehead flap. In the former, the arterial supply is from the temporal artery (a terminal branch of the external carotid artery) and the venous drainage is to the temporal vein. Therefore, in both flaps, the arterial supply is from ramifications, side-branches or terminal twigs of the external carotid artery. However, the venous drainage differs initially. In the midline forehead flap, venous outflow is to the orbit, cavernous venous sinusses and internal jugular vein. Temporal based flaps drain to the temporal veins. This subtle difference is important, as the midline forehead flap venous effluent is to the orbit, via an “intracranial route”. This is a unique concept, not emphasized adequately in the anatomical and surgical literature. Evidence from this study shows that it is safe to utilize this flap, although the venous drainage is via an intracranial route (see clinical results and data on flap necrosis). A very consistent finding in this study is the presence of the angular artery (this was also showed in the Doppler analysis: see clinical section). However, the cadaveric data shows that the central vein was poorly demonstrable in 7% of cadavers dissected. Possibly, some of the collapsed veins were unknowingly dissected away with the superficial fascia in the early part of the study. The results (see illustrations) showed the following interesting statistics regarding this view:

1. Bilateral drainage into both orbita (8/ 17; 47%)
2. Drainage into the left orbit (6/ 17; 35.2%)
3. Drainage into the right orbit (3/ 17; 17.6%)

This data is important clinically for various reasons. If the venous run-off of a flap is dual (as in the case of 47% in this study), then, theoretically, the flow through the flap is “high” and the potential risk of venous thrombosis and “flap loss” due to congestion, would be reduced. Why the venous drainage was predominantly to the left orbit (35.2% vs 17.6%; $p < 0.05$) remains a mystery and is not explained from the existing anatomical literature. Pre-operative venous Doppler assessment in flap planning may be important, given the findings of this study. This cadaveric study provides vascular information relevant in the clinic, theatre and practice of plastic reconstructive surgery.

Nerve injury and sensory disturbance of the forehead and scalp:

The dissection above the periosteum is more suitable if the inferior superficial temporal vein is to be included in the flap. Eiseman doesn't mention the sensory disturbance caused by raising the flap. The superficial sensory nerves (supra-orbital and supra-trochlear), that penetrate the inferior frontalis muscle and course superiorly with their arterial counterparts are severed. It is possible to preserve these nerves and sometimes arteries at the inferior border of the flap as shown by one of the clinical cases later in the study and supra-orbital nerve (medial, middle and lateral branches) preservation (Fatah, 1991).

The dissection plane and scoring of the galea through the frontalis muscle up to the subcutaneous fat:

The FBSTA is embedded on the anterior surface of the frontalis muscle. By scoring (making incisions through the galea and muscle) through the muscle up to the subcutaneous fat it is possible to damage this axial vessel, especially in the lateral forehead and temporal area. Branches of the FBSTA in the forehead have a subcutaneous course from about the lateral orbital rim vertical line. It should be emphasized therefore that the scoring should be limited to the area of the forehead medial to the lateral orbital rim vertical line.

OTHER CONSIDERATIONS:

i.INVERTED- KITE PEDICLE MODIFICATION

ii.V-PERIOSTEAL INCISION

iii. OBSOA ARTERIAL AXIS

1. THE INVERTED KITE PEDICLE MODIFICATION:

Five cadavers, not latex filled, were dissected to investigate the pedicle refinement that is necessary for a one-stage forehead flap for nasal reconstruction. The inverted kite pedicle base modification was found to be the best design applicable to the midline forehead flap. The paramedian forehead flap has a slightly lateral base and will always require pedicle division and inset, unlike the midline forehead flap where a one-stage flap design is possible. An important additional refinement of the midline forehead flap is to make its transfer a one-stage operation without later pedicle separation. This is not done as an islanded flap (Converse and Wood-Smith, 1963) or turnover flap (Guzel, 2003), but rather an inverted-kite modification of the base is necessary and exact measurements preoperatively (Park, 2002; Converse and Wood-Smith, 1963; Gupta, 2004; Guzel, 2003). This may be desirable in a subgroup of patients. Park (2002) proposed resection of the procerus

muscle, a narrow pedicle and wide undermining to decrease bulk at the nasal root. In his experience ten percent (1/10) of patients required surgical debulking. This does not exclude future flap refining operations which is the ultimate goal for the aesthetic reconstructive surgeon (Kaufman, 2003; Menick, 2004). Friduss et al. demonstrated that loss in flap length is sensitive to the pedicle width. At the medial canthus level, when incising the pedicle base, they would only cut through the skin close to the medial canthus and try to preserve all small arteries entering the base of the flap (Friduss et al., 1995). In order to avoid damaging the AA when doing incisions at the medial canthus for repair of naso-ethmoid-orbital fractures it would be wise to avoid W- or Zigzag incisions and to make it two millimetres from the inner canthus (Cruse, 1980). The AA is medial to the angular vein at this point.

APPLYING CADAVER FLAP TECHNOLOGY: DISSECTION LABORATORY

Fig 40. Exact pedicle and flap length measurement is done with a string. Based on central vein morphology.

Fig 41. The flap is outlined with the pedicle base just above the medial canthus. This denotes the donor flap area.

Fig 42. A nasal defect is created with a scalpel. This denotes the recipient area of the forehead flap

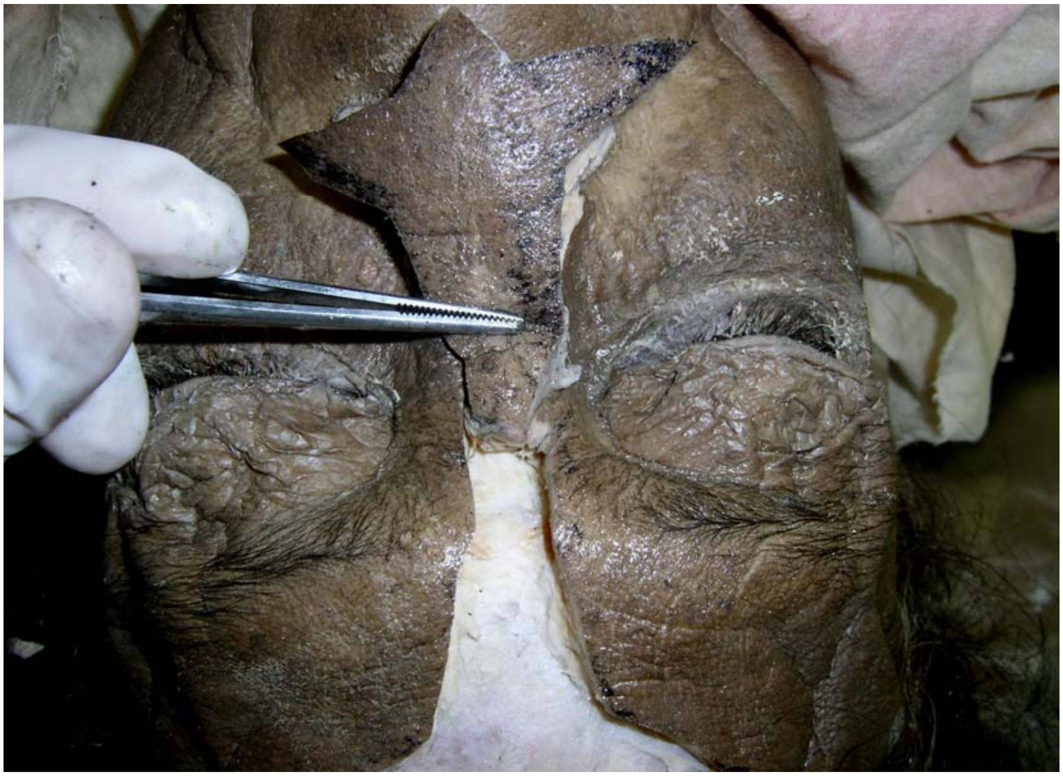


Fig 43. The midline forehead flap is elevated and transposed 180 degrees over the defect.

Fig 44. Excess tissue at the pedicle base is excised to allow the flap to be set in without a convex bulge at the nasal bridge.

Fig 45. The flap is returned and the pattern after excision of the excess bulk is inspected. An inverted 'Kite' design is seen and represents the desired refinement for the one-stage forehead flap.

2. V-PERIOSTEAL INCISION:

Based on the anatomy of the SON and STrN the technique of cutting through the periosteum at levels lower than 4 cm above the SOR for brow and forehead lifts is questionable (Mommaerts, 1994). Periosteal entry in the central area between the MCV lines can be as low as the SOR, but lateral to the MCV line where the SON branches travel higher in the periosteum the entry should be higher. At the LORV the OBSON is the highest at a periosteal level. Visualize a V-incision for this matter. Just above the SOR the deep branches of the SOA and SON are periosteal and the risk of neurosensory injury is likely. This should be a consideration in forehead lift operations (Rudolph, 1992; Knize, 1998; Marten, 1999; Park et al., 1998; Psillakis et al., 1988; Ramirez, 1994; Cheney, 1995). The height of the FBSTA or TFA across the forehead (in terms of the anatomical position) gives an indication of the height of the periosteal level of the SON. If one can preoperatively identify the FBSTA and TFA by either direct vision, palpation or hand-held doppler and use a dyed needle tip to mark the arterial level on the periosteum, then once the bicoronal flap has been turned over, the level of safely cutting through the periosteum is a few millimetres superior to the marked periosteal level. This approach may be valuable in decreasing sensory disturbance with any forehead periosteal techniques such as

forehead lifts, endoscopic forehead surgery, bicoronal flaps, etc (Adamson, 1986).

3. <u>OBSOA ARTERIAL AXIS:</u>

The OBSOA anastomosis with either the TFA or FBSTA is an arterial axis that can be exploited for additional safety of transverse based forehead flaps. Dr. Burget (1998) wrote: "Nevertheless, we should resist the impulse to plug the hole with a distant flap of gelatinous tissue that merely converts a concave deformity into a convex one" (Burget et al, 1998). If the FBSTA was previously injured or the arterial inflow is weak then additional arterial inflow can be guaranteed by preserving the OBSOA and its anastomosis with the FBSTA or TFA. In such a case where the FBSTA pulse is weak the variation where the FBSTA is a minor lateral branch off the larger OBSOA might be present.

THE CENTRAL VEIN METHOD OF PLANNING THE MIDLINE FOREHEAD FLAP:

During the pilot study dissection of cadaver-1, some latex was noticed at the posterior aspect of the central vein and there were no vessels to explain its presence. The question raised by this, was prospectively explored during subsequent dissections. The following sequence of observations from the cadaver dissections have been made and integrated into the *method of planning* the midline forehead flap in order to increase the robustness of the flap and guarantee flap survival (The arterial and venous patterns of all 30 cadavers are available in Appendix I).

CHARACTERISTICS OF THE CV:

Inspection of the patterns of the central vein (CV) and the (CA) in cadavers 1-30 can be used for descriptive purposes.

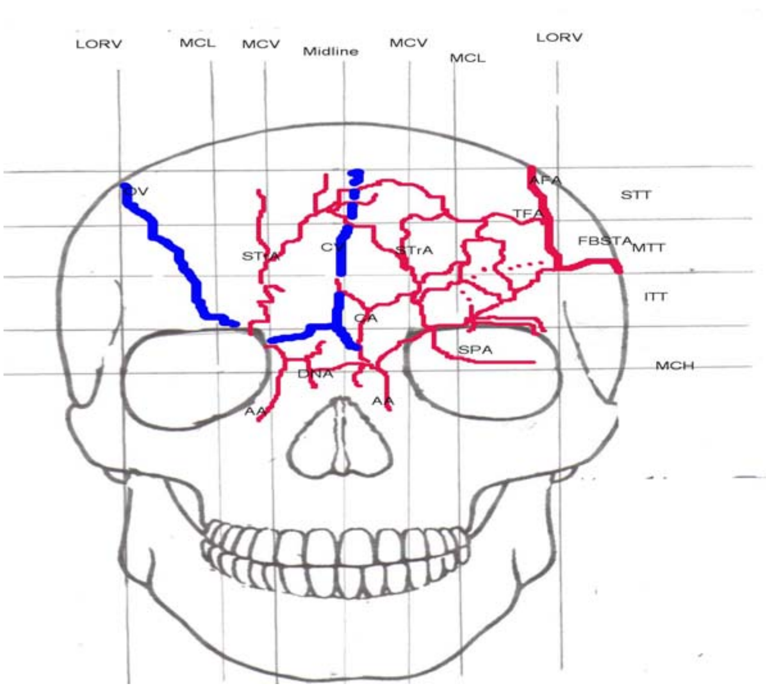


Fig Cadaver 1: The central vein is not associated with the STrA.

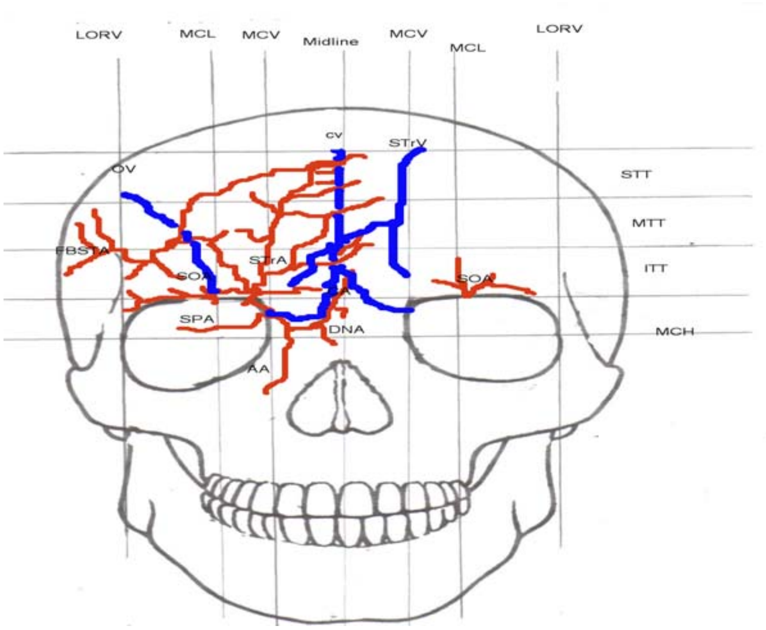


Fig Cadaver 4: This is the first cadaver evidence of an artery associated with the base of the CV. This arterial branch from the dorsal nasal artery (DNA) was unnamed at this stage and later termed the central artery because of its close association with the central vein.

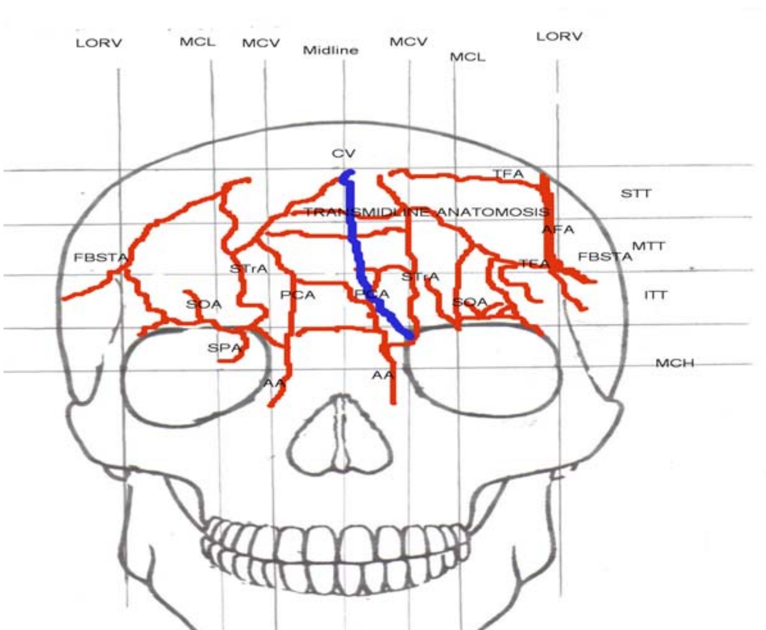


Fig CADAVER 6: This shows the CV for the fist time associated with an unnamed artery from the angular artery (AA). This artery tends to be in a vertical plane with the AA, and therefore more lateral to the CA. It was coined the paracentral artery (PCA).

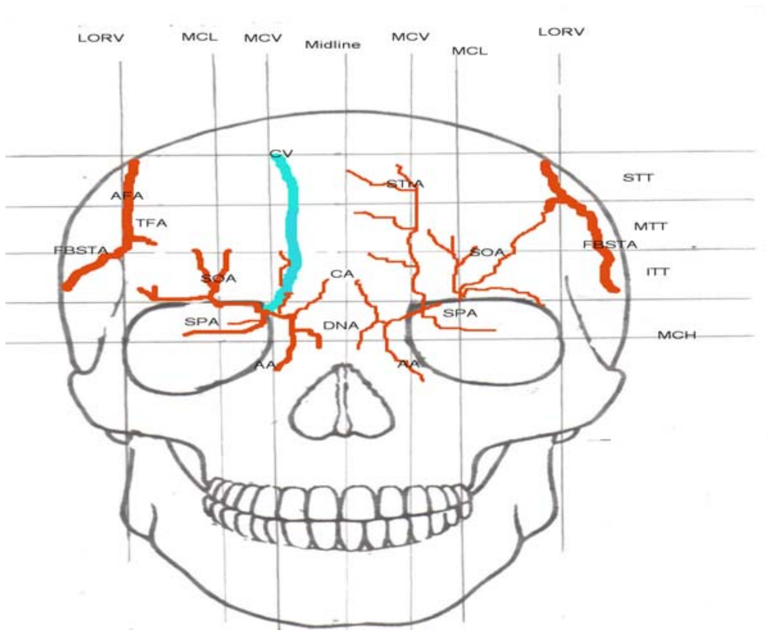


Fig CADAVER 10: A PCA originating from a communicating branch between the AA and the STrA is shown curling around the central vein. Note the absence of a normal STrA on the right hemi-forehead.

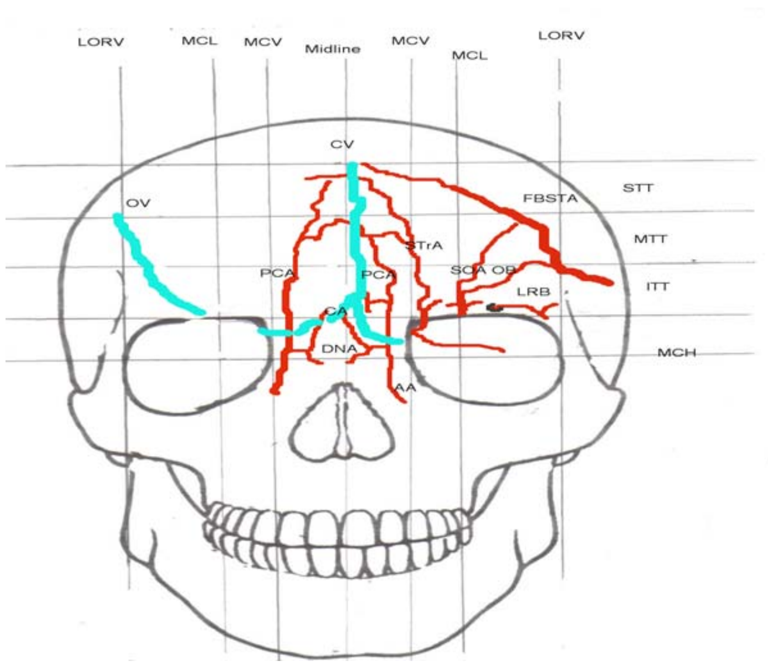


Fig CADAVER 15: The CV is shown with the PCA laterally and the ipsilateral CA medially. Note the STrA away from the CV and the ipsilateral tendency of the CV.

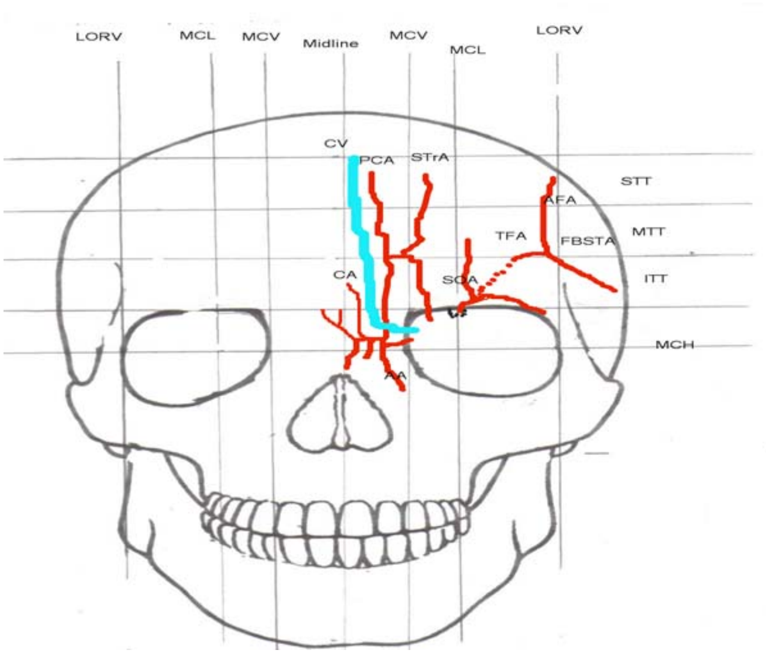


Fig CADAVER 21: A pattern similar to cadaver 15 is seen with the ipsilateral CA on the medial side of the vein and the PCA lateral to it.

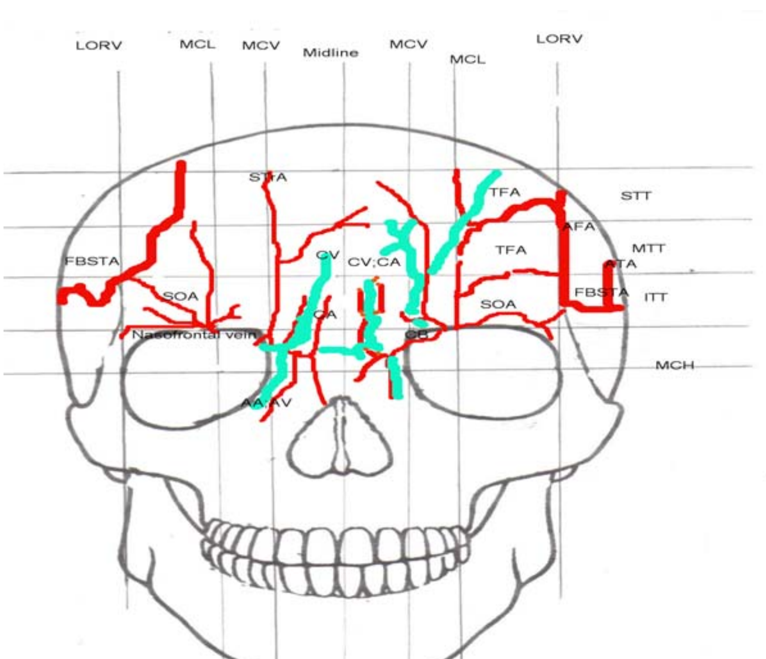


Fig CADAVER 26: Bilateral CV's are present and the recurrent pattern of the CA and PCA is seen.

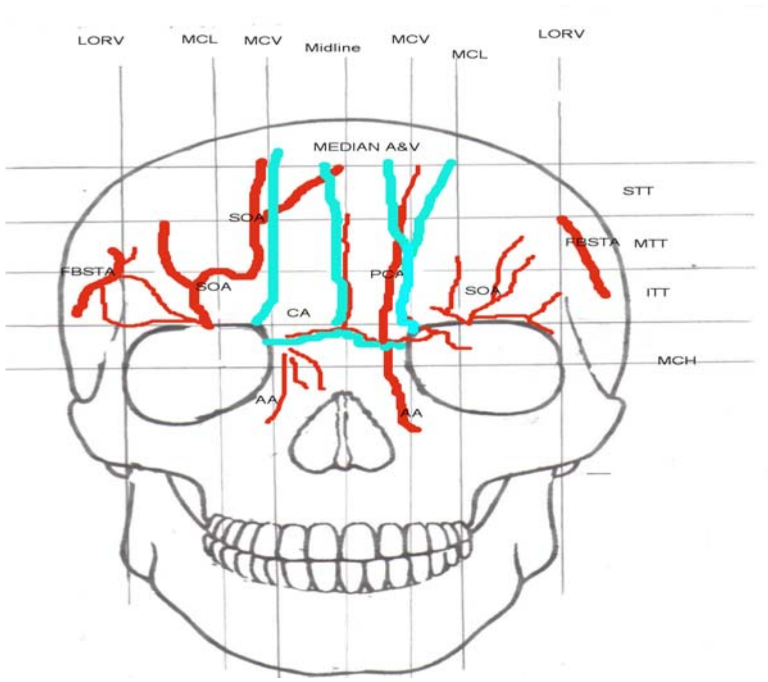


Fig CADAVER 29: Variations of the CV do occur, and here a true median vein and artery of the forehead was found.

SUMMARY OF CENTRAL VEIN OBSERVATIONS:

1) The *central vein* is often associated with the CA medially and PCA laterally. This knowledge was now applied to midline forehead flap planning:

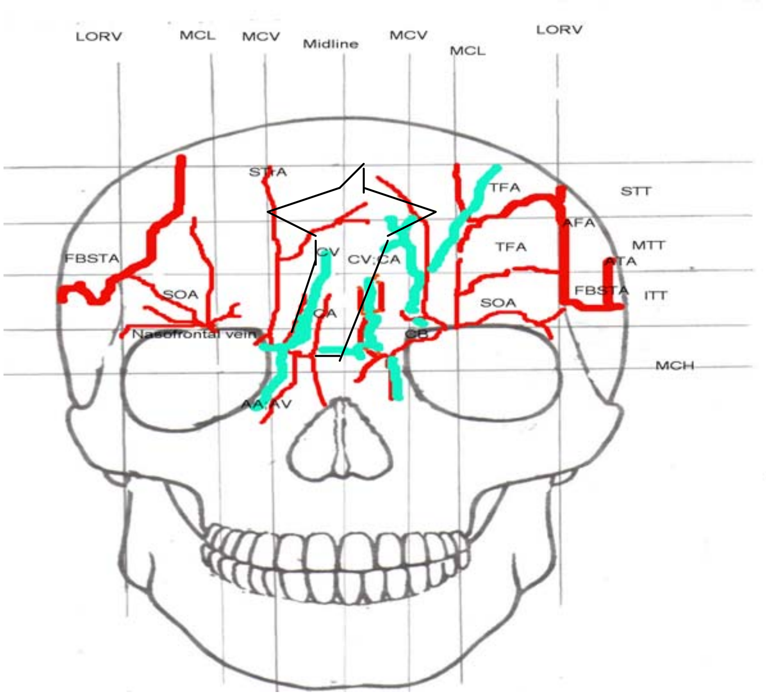


Fig CADAVER 26: Since the CV is often macroscopically visible on the forehead, it is used as the central axis for the design of the midline forehead flap with the knowledge that medially and laterally the CA and PCA can be included in the flap. This method ensures not only arterial inflow, but more importantly it secures venous outflow. Because the CV has an ipsilateral tendency as shown in the cadaver and Doppler study, the correct placement of the midline pedicle is critical to ensure the most robust and reliable flap.

THE OBLIQUE BRANCH OF THE SUPRAORBITAL ARTERY AND ITS CLINICAL SIGNIFICANCE

This artery was seen to have a consistent anastomosis with either the transverse frontal artery (TFA) or the FBSTA at the lateral orbital rim vertical line and mostly at the junction of the middle and inferior transverse thirds of the forehead. This artery can be used to augment the blood supply of temporal based forehead flaps within certain pedicle limitations.

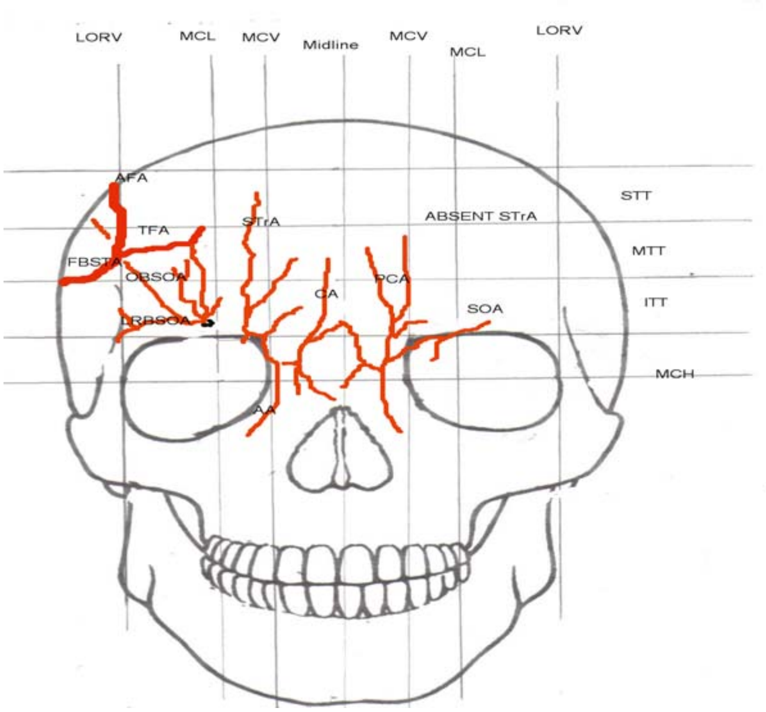


Fig CADAVER 27: The OBSOA of the right hemi-forehead anastomoses with the TFA at its origin. This branch is at a periosteal level almost right up to its anastomosis with the TFA/FBSTA where it pierces the frontalis muscle to join the muscle on its posterior surface.

Fig 1. Ease of finding the FBSTA macroscopically is demonstrated (gentle anterior compression).

Fig 2. CASE 8: Bilateral hemi-forehead flaps based temporally (TFA; FBSTA; STA) elevated and the deep OBSOA was identified and saved to provide additional inflow

from the SOA. The additional advantage of sparing the OBSOA is that the deep oblique branch of the supraorbital nerve (OBSON) could also be spared.

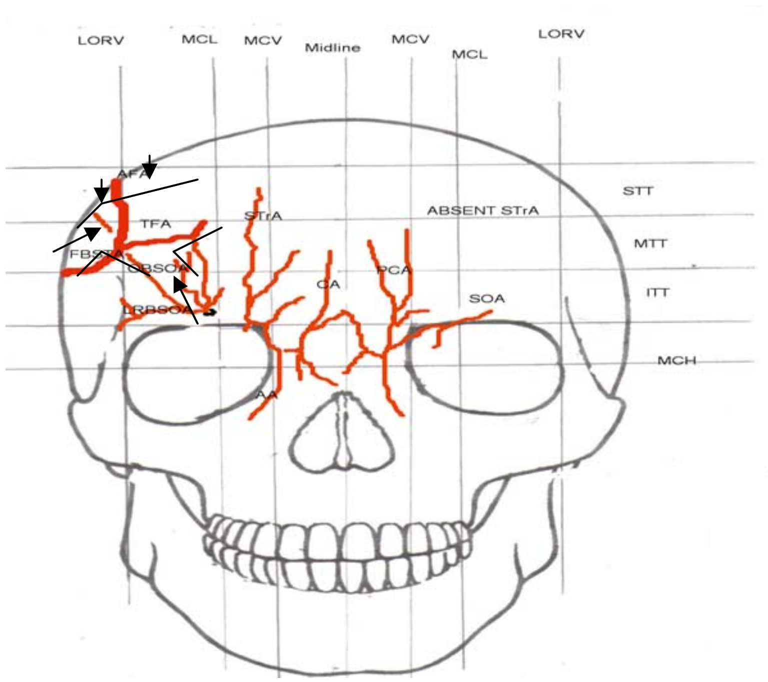


Fig CADAVER 27: Potential arterial pedicles or multiple pedicles are demonstrated for a hemi-forehead flap. The ascending frontal artery (AFA), the FBSTA, and the OBSOA can all contribute to the pedicle of this flap. Pedicles can be created on separate arteries: the AFA = a superior pedicle (not described); the OBSOA = an inferior pedicle (not described); the FBSTA = a lateral pedicle (well known).

THE "SNAKE" FOREHEAD FLAP

This flap was developed based on the transmidline anastomosis demonstrated by the FBSTA and TFA to the contralateral STrA. It is a new, original and investigational flap design for nasal or facial reconstruction. **It requires a delay procedure or broad pedicle and its use will be limited.**

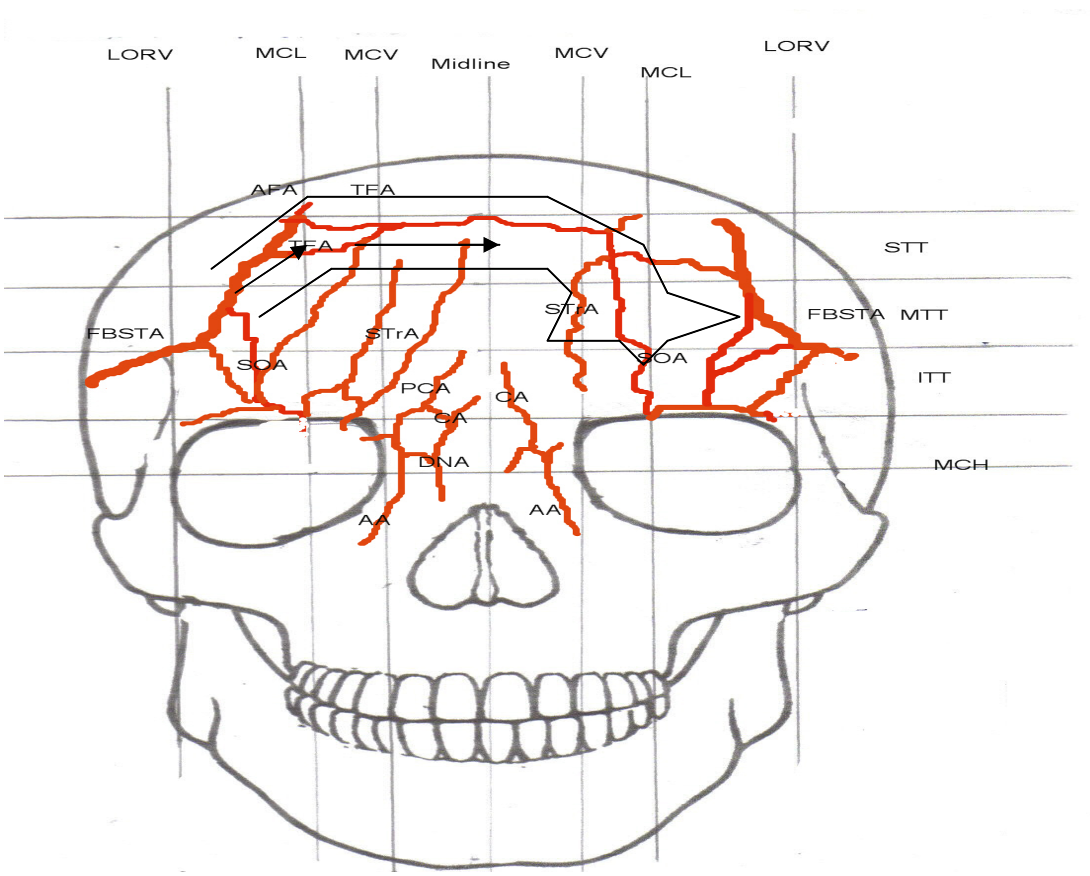


Fig CADAVER 8: The axial plan for the 'Snake' forehead flap based on the dual inflow from the FBSTA and the OBSOA. The transmidline anastomosis of the FBSTA with the contralateral STrA is demonstrated and included in the pedicle.

Fig 3.Tthe “Snake” forehead flap: a flap designed on the basis of the axial pattern of the FBSTA as identified during the cadaver study. At this stage it was the plan to delay the flap as venous drainage was expected to be a problem pre-operatively.

Fig 4. The flap was excellent for 48 hours, and after she slept on the pedicle for two hours which is her favourite sleeping side, she developed irreversible venous congestion and suffered partial flap loss. The appearance was that of venous congestion but an element of arterial insufficiency could not be excluded. Most of the flap was retained.

ARTERIAL AXIS IDENTIFIED FOR FLAP EXPLOITATION

1) <u>AA – DNA – CA axis</u>: This CA was never given credit for its significance and descriptions of this arterial axis were limited to - extensions from the AA. The importance of contributions from the AA was already realized by Sushruta 2500 years ago.

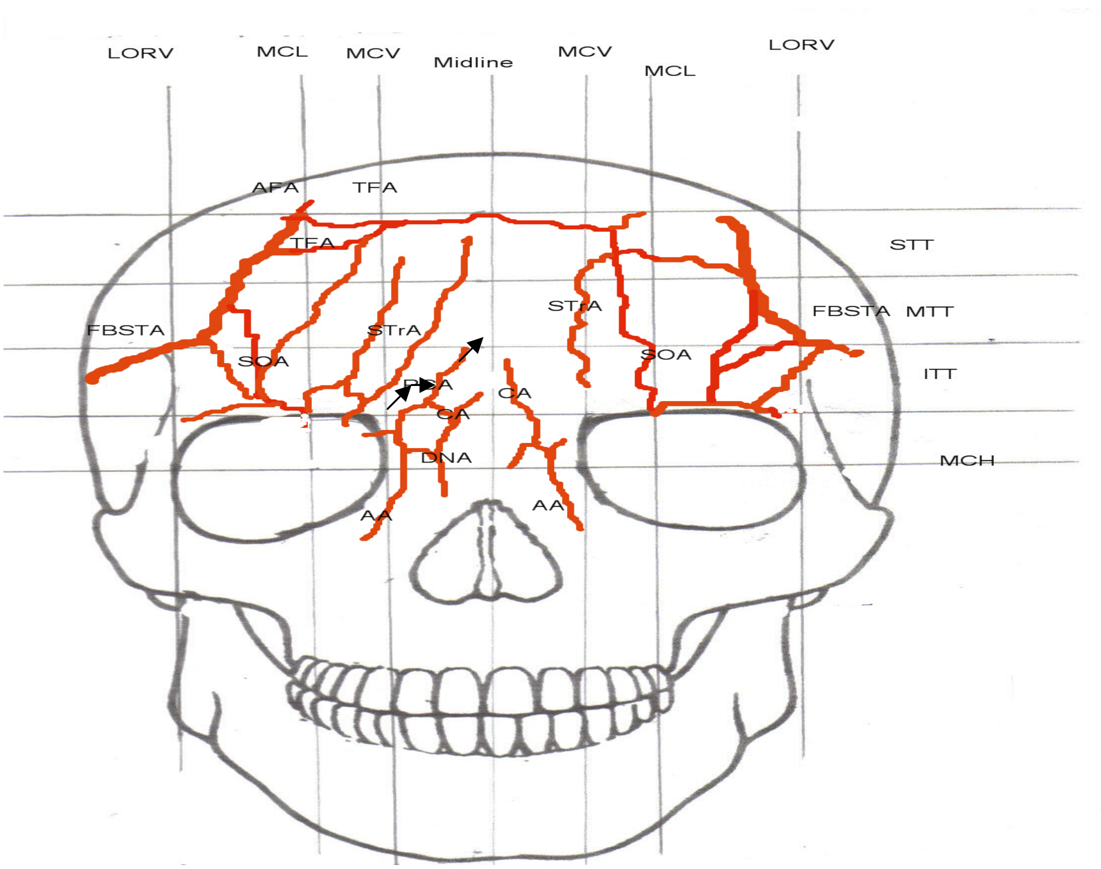


Fig 5. <u>The AA-DNA-CA arterial axis</u>.

2) AA – PCA: Again this axis was vaguely assumed to be present, but no effort was made to identify and name the PCA.

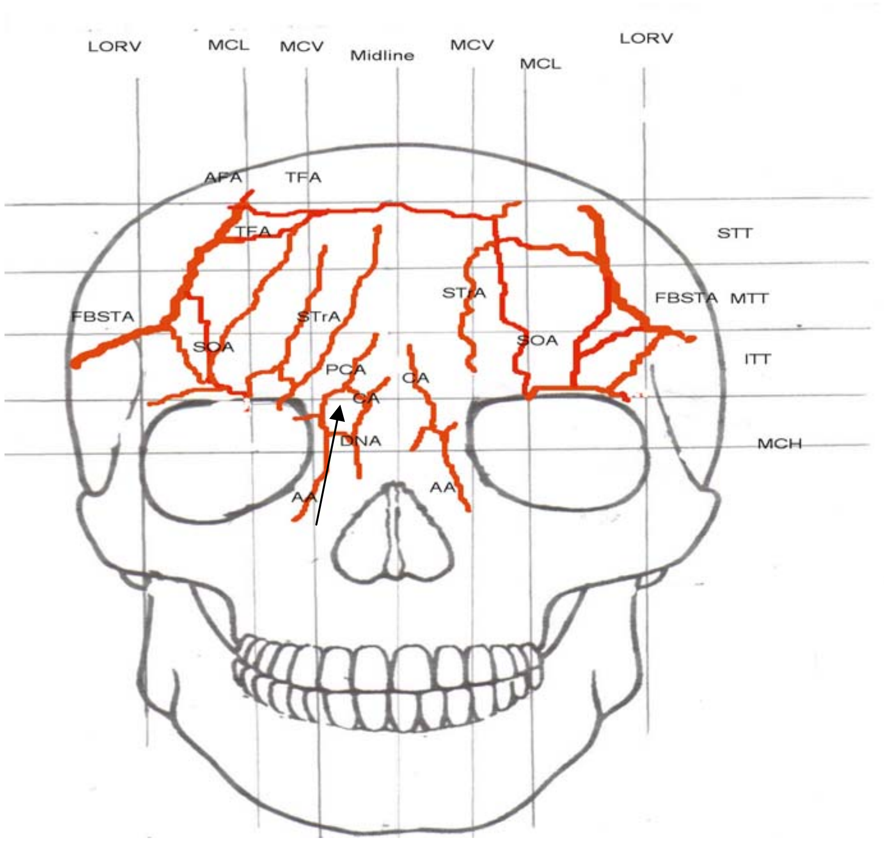


Fig 6. The AA-PCA arterial axis.

2) AA – CB – PCA: No effort was made to describe arterial variations of the AA and therefore this axis was never described specifically.

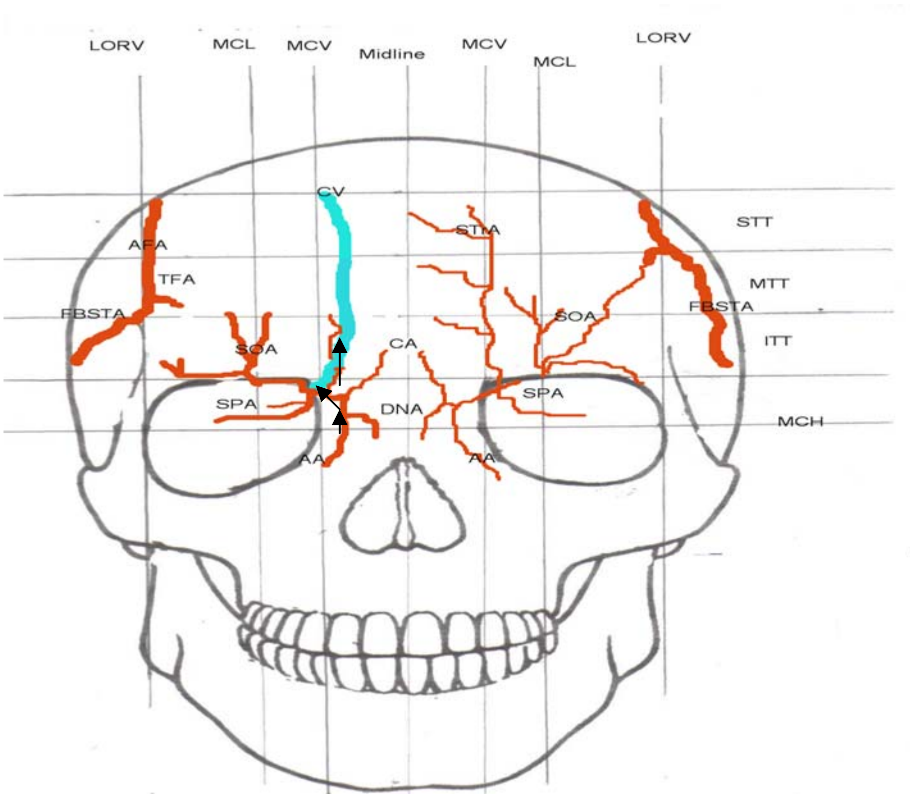


Fig 7. The AA-CB-PCA arterial axis

2) OBSOA – TFA/ FBSTA - STrA: The clinical exploitation of this axis was mentioned previously, but the OBSOA was not named. This axis is clinically exploited for the first time as illustrated in case 4 and 8.

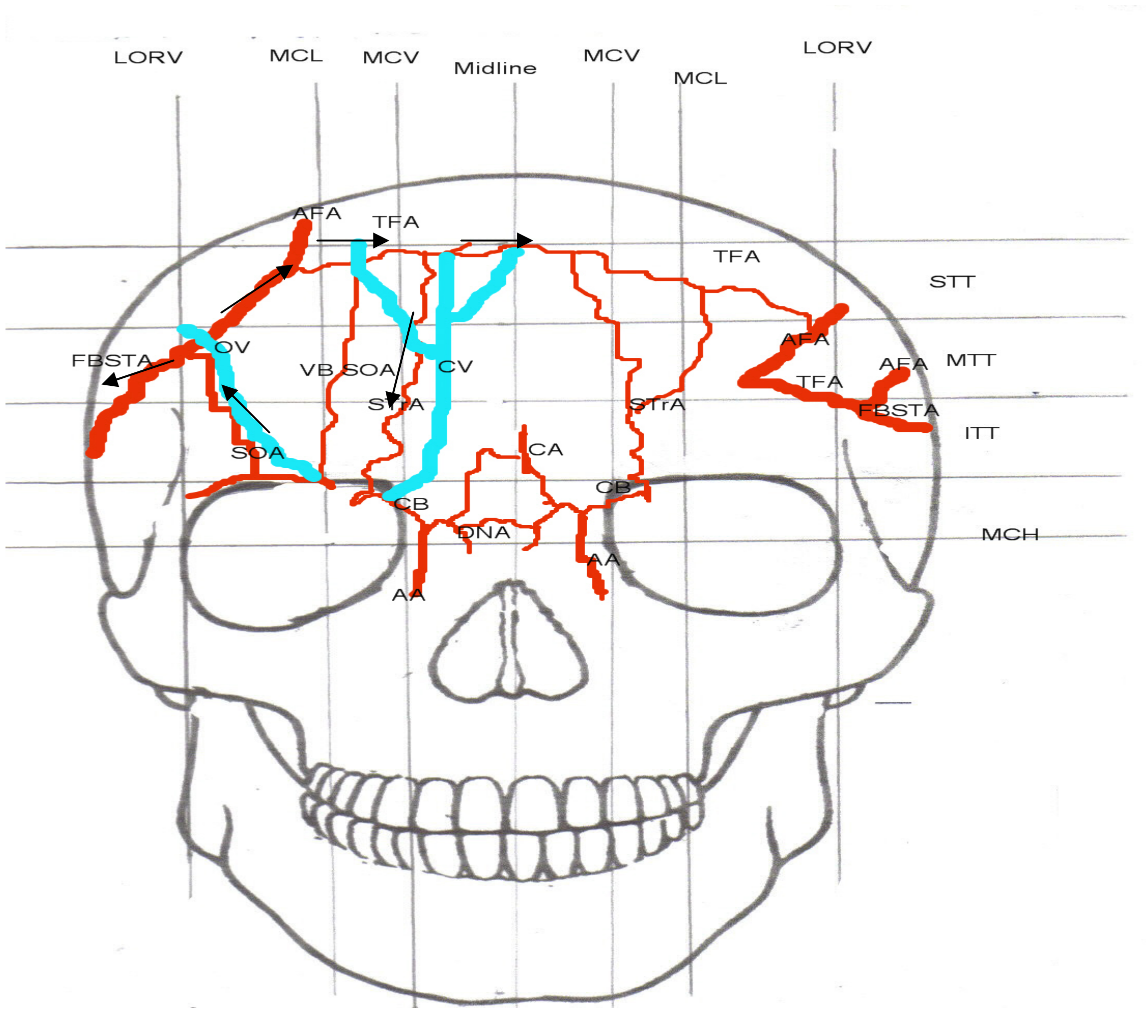


Fig 8. The OBSOA-TFA/FBSTA-STrA arterial axis. The FBSTA can be used superiorly to the forehead or scalp or posteriorly to its origin or both ways.

2) AFA – TFA – STrA: This superior pedicle for a forehead flap has never been exploited and poorly described. Close random pattern flaps were previously designed in this area such as the *sickle flap* of New and the *scalping flap* of Converse.

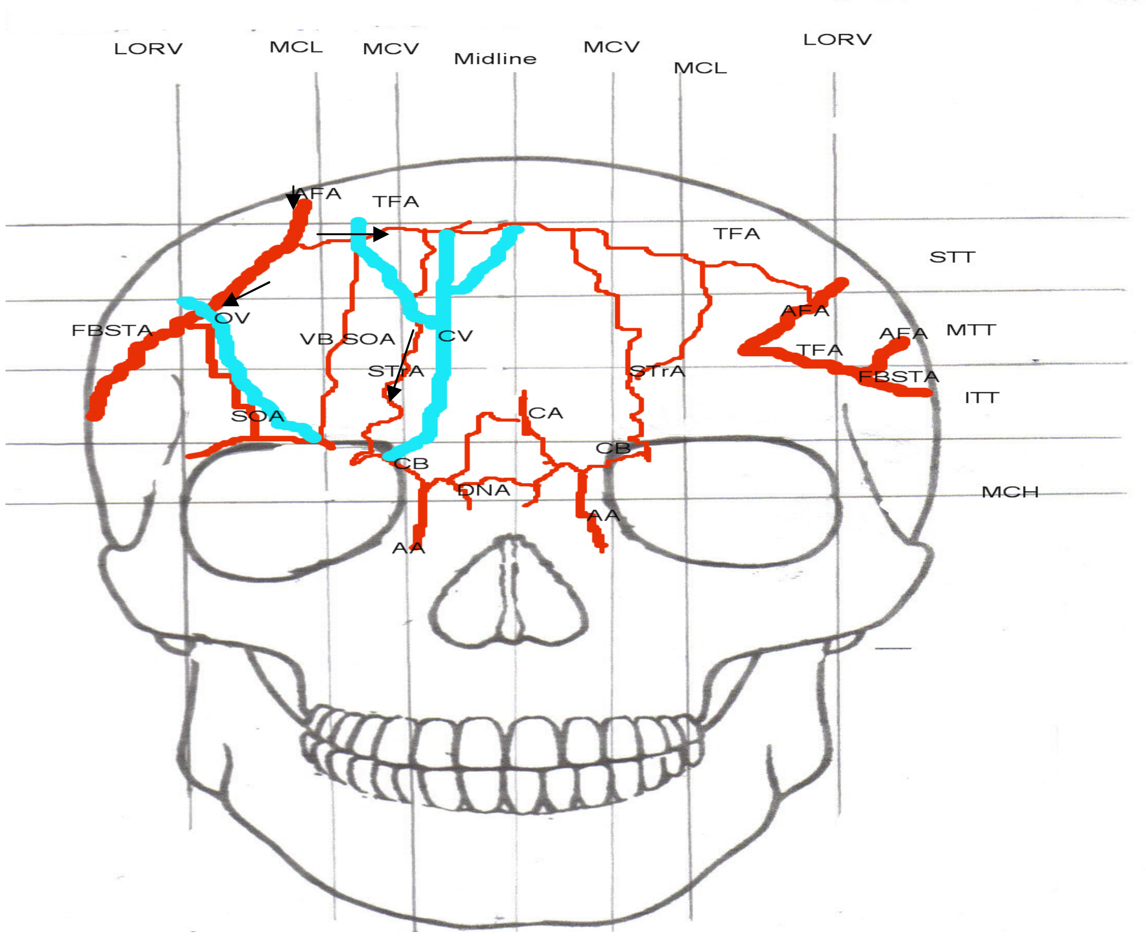


Fig CADAVER 8: The AFA can be used for medial or lateral flaps as demonstrated.

RECOMMENDATIONS REGARDING FLAPS DESIGNED IN 2003 (Dr Kleintjes, MMED thesis) APPENDIX 1. B.

ARTERIAL FLAP DESIGNS:

Where no venous axis is included in the flap design, it is advisable to either make the pedicle quite broad, or alternatively, and in our opinion the technique of choice, to delay the flap in order to augment the venous drainage of the flap. This is especially applicable to transverse forehead flap designs. For midline pedicles we would recommend inclusion of the central vein in the flap design to ensure good venous drainage. All these principles are advised to reduce vascular compromize of the flaps and potential flap necrosis.

VENOUS FLAP DESIGNS:

Both patterns of venous drainage were seen frequently in the cadaver study. The *central venous flap* was shown to be narrowly associated with two arteries (CA & PCA), and its use cannot be classified as solely venous. The lateral or oblique vein was seen in association with the OBSOA and sometimes VB of the SOA, but the frequent and close relationship seen with the CV was not present with the OV/LV. This vein is also often associated with the OBSON and sensory nerve damage (neuropraxia) from this nerve tends to be bothersome to patients. It cannot be recommended as an alternative flap.

POTENTIAL NEW FLAP DESIGNS FOR EXPLOITATION

THE SOA OSSEOUS FLAP: A vascularized frontal bone outer cortex flap. This flap was developed based on the close association of the deep branches of the SOA to the frontal bone. It has never been described before and its clinical use may be developed further by neurosurgeons or craniofacial surgeons, but still considered investigational.

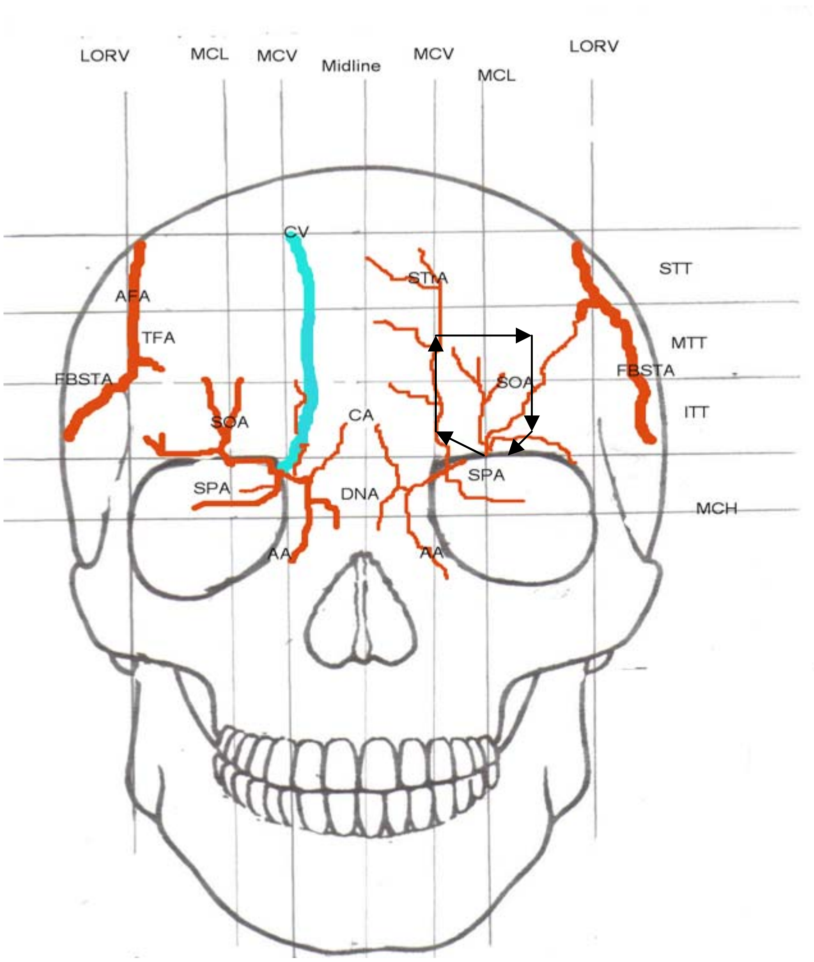


Fig CADAVER 10: The design of a frontal bone outer cortex flap based on the SOA. This flap can be swung on its arterial pedicle to defects of the orbital roof or anterior skull base or to medial orbital wall defects.

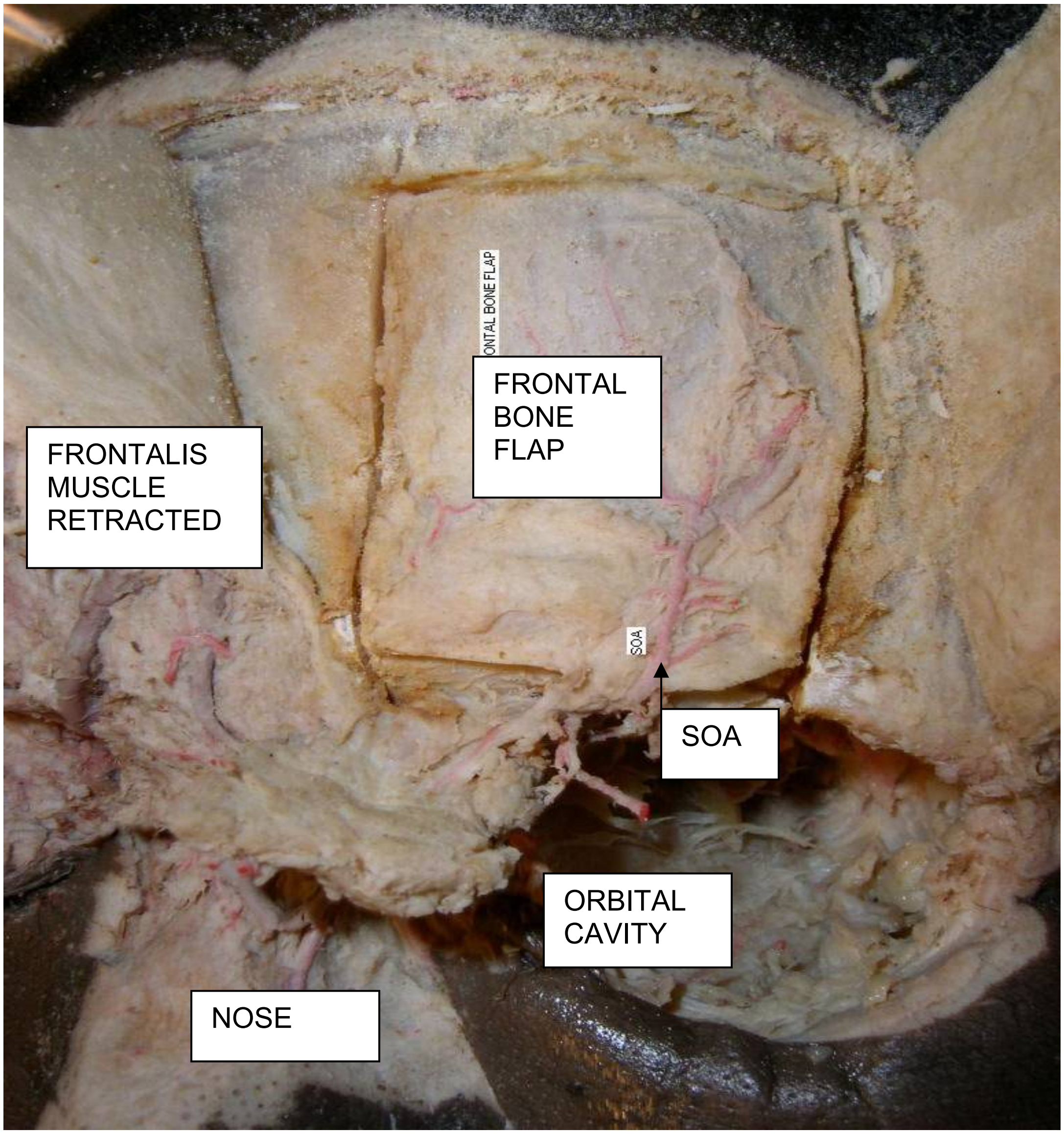


Fig 146. A SOA frontal bone flap has been cut with a bone saw (cadaveric specimen).

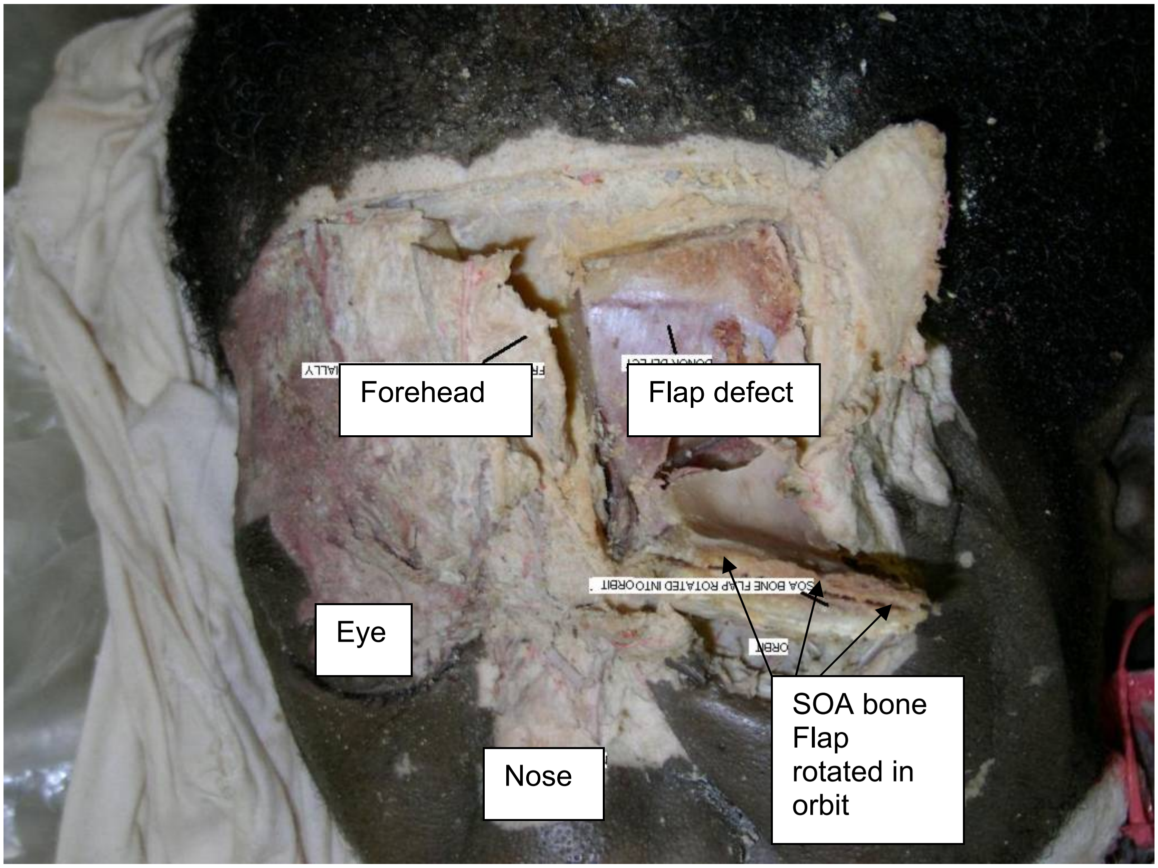


Fig 9. The SOA frontal bone flap rotated to fill the roof of the orbit.

CADAVERIC STUDY

CONCLUSIONS

The anatomy of the supraorbital artery regarding fronto-nasal flap reconstruction is poorly and inaccurately presented in standard anatomy text (see Gray's Anatomy, 1995). New anatomical terminology, to accurately describe the finer and distal branches of the SOA, has been suggested by this study.

4. <u>angular artery:</u>

The variations of the termination of the angular artery have not been defined in the literature as a result of no in-depth anatomical study looking specifically for this. It was of critical importance to name the arteries of the dorsal nasal artery and the angular artery in the forehead, in order to unveil "*the mystery of the blood supply of the central forehead*". Not only have the smaller branches been highlighted, but the variations and landmarks of the arteries are now known, as described in this small cohort of dissected cadavers.

5. <u>central forehead venous drainage:</u>

The venous drainage of the central forehead is important in forehead flap planning and the relationship of the central vein to the central artery, dorsal nasal artery, angular artery and paracentral artery, is critical. The venous drainage should be considered first when considering a central based (midline or) forehead flap. The relevance of the venous drainage is to engorgement of the flap and venous thrombosis.

6. <u>the median artery and vein:</u>

A true median artery and vein of the forehead exists, but only as a rare variation of the blood supply, as seen in this cadaveric study.

7. <u>general comments:</u> regarding nerves and vasculature:

The gross anatomy of the forehead for discussion purposes can be compartmentalized, but practically it is important to have a complete picture of the applied vascular anatomy if one wants to perform reconstructive surgery in that area. The observations of the *supra-orbital nerve* of surgical significance were included and it was shown that the oblique branch of the supraorbital nerve was the largest closely associated to the oblique branch of the supraorbital artery. The dissection study shows that the arteries of the forehead communicate across the midline as previously mentioned in the literature. This observation is also of importance during flap planning. This study has shown that previous documentation of the forehead blood supply focused more on providing a mental picture of a constant pattern of forehead blood supply and did not have sufficient material to adequately comment on arterial variations of the forehead. In conclusion, this study is therefore potentially a new benchmark regarding the central arterial anatomy of the forehead, when applied to fronto-nasal surgery or reconstruction rhinoplasty.

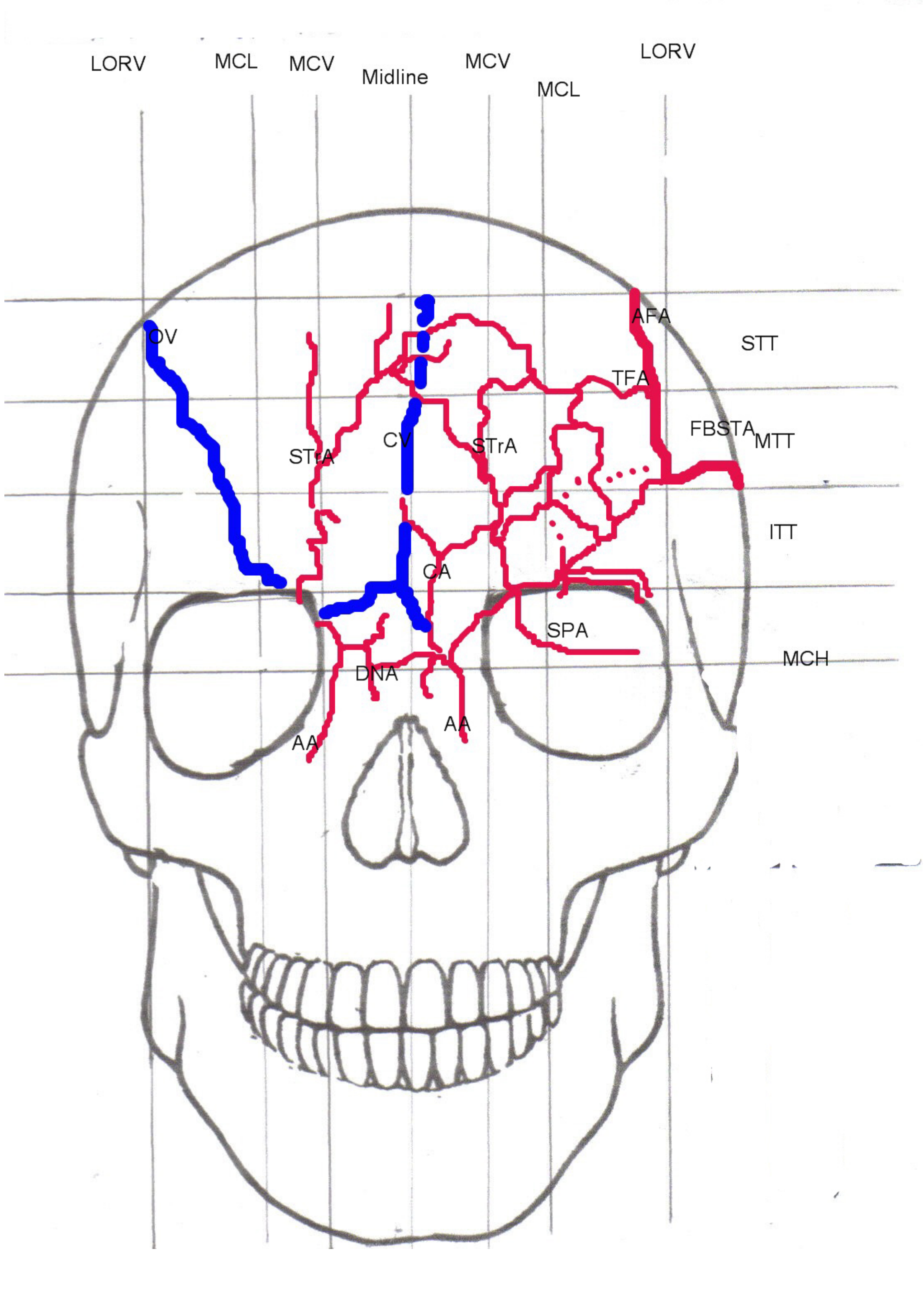
APPENDIX 1

A. CADAVER ARTERIAL PATTERNS

B. PREVIOUS INNOVATIVE FLAP DESIGNS (MMED THESIS, 2003)

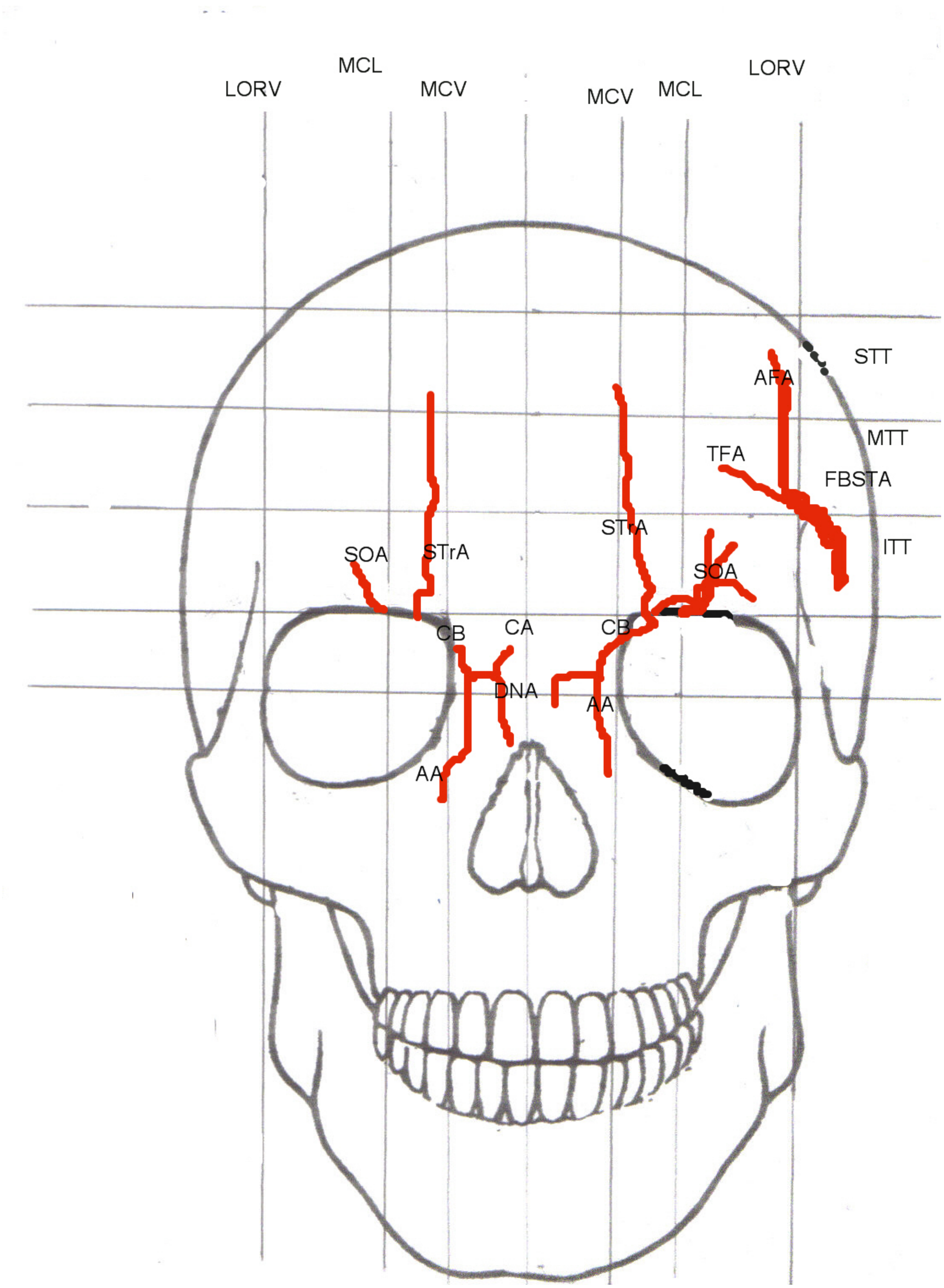
- **Details of individual dissections in 30 adult, latex-filled human cadavers**
- **Blood vessel variations, patterns in relationship to the forehead midline**
- **Cadavers 1 – 30**
- **Previous innovative flap designs**

CADAVER 1

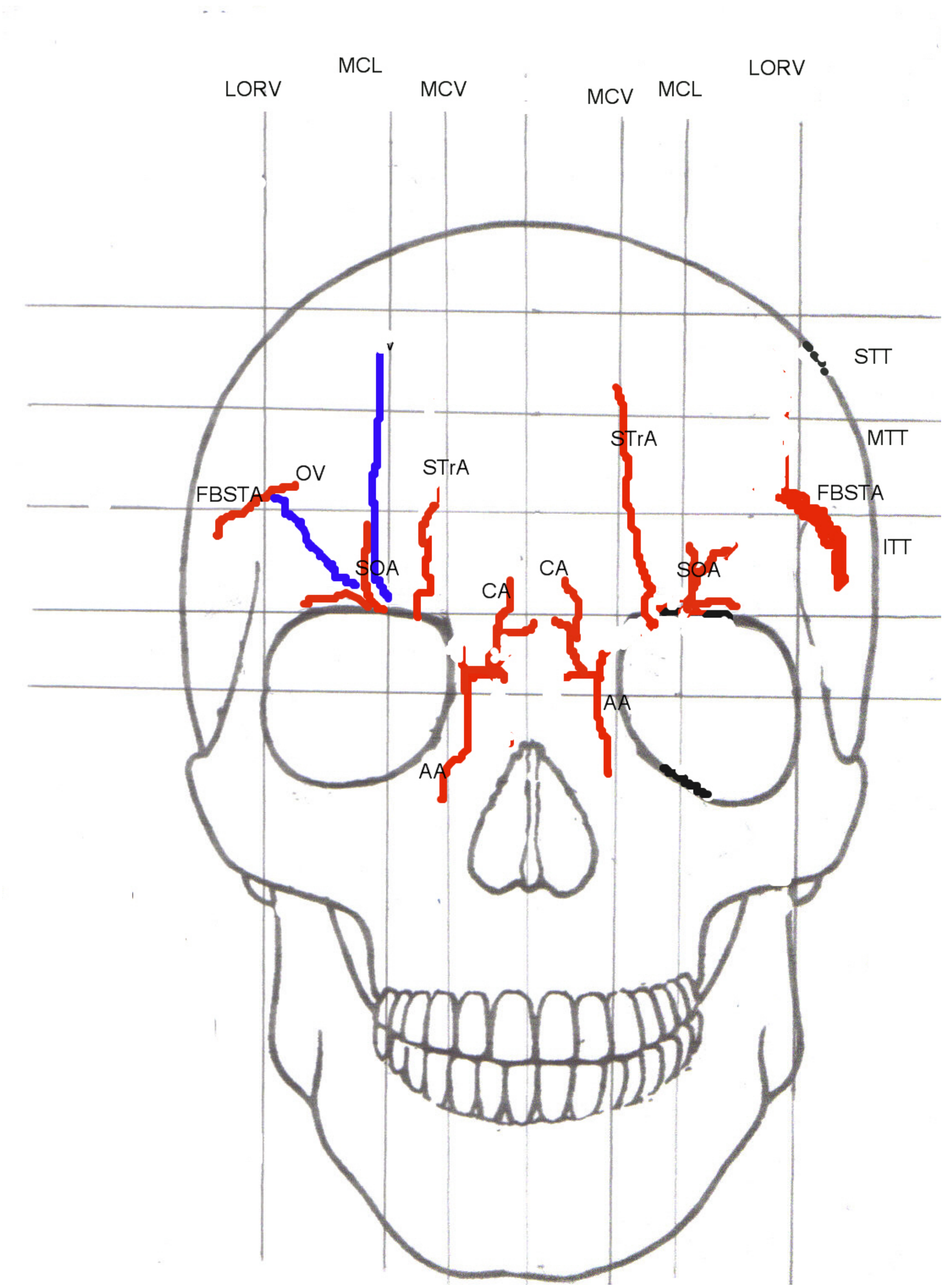


LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
STT
OV
TFA
FBSTA
MTT
CV
STrA
STrA
ITT
CA
SPA
MCH
DNA
AA
AA

CADAVER 2

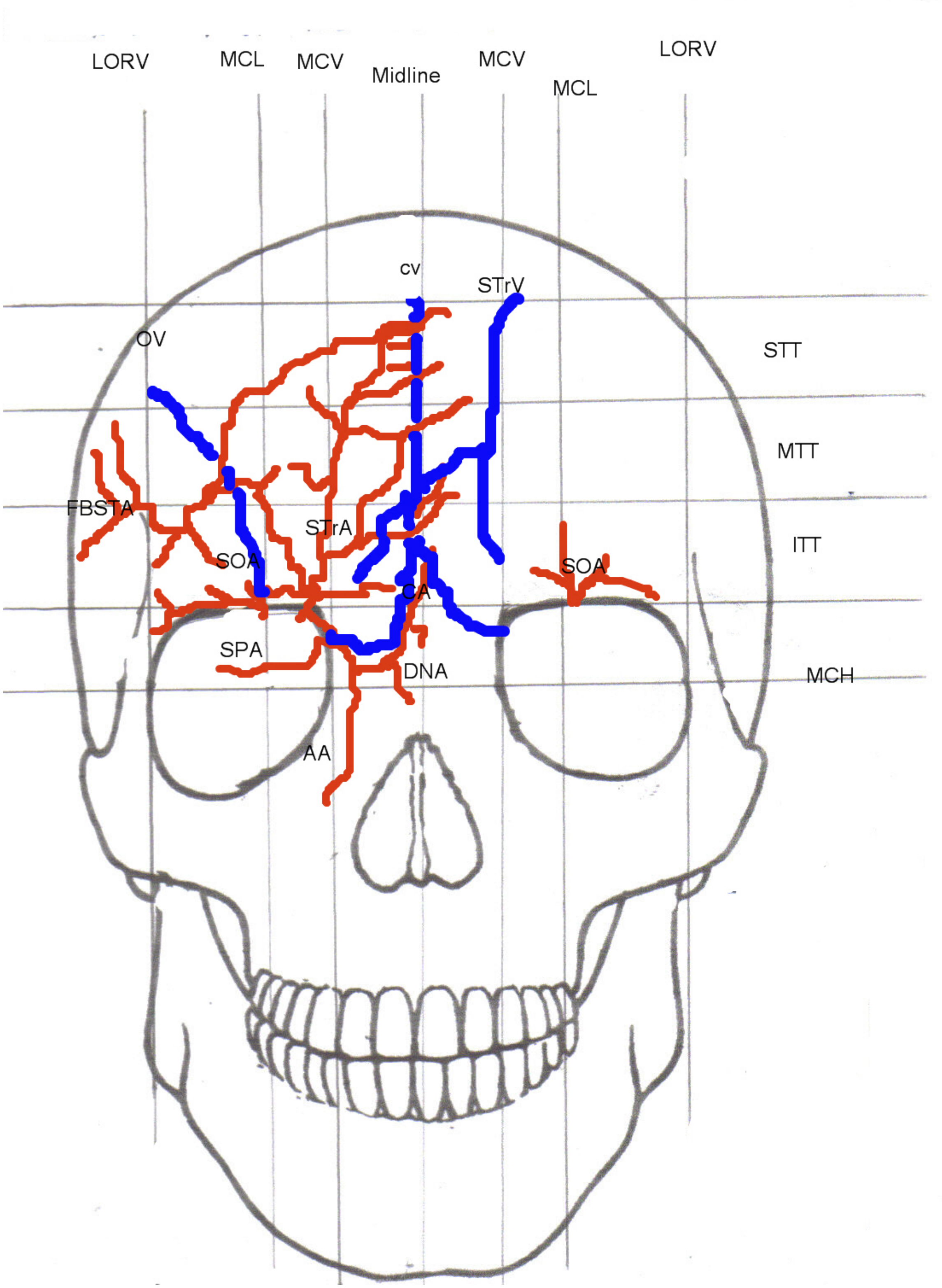

LORV
MCL
MCV
MCV
MCL
LORV
STT
AFA
MTT
TFA
FBSTA
STrA
ITT
SOA
STrA
SOA
CB
CA
CB
DNA
AA
AA

CADAVER 3

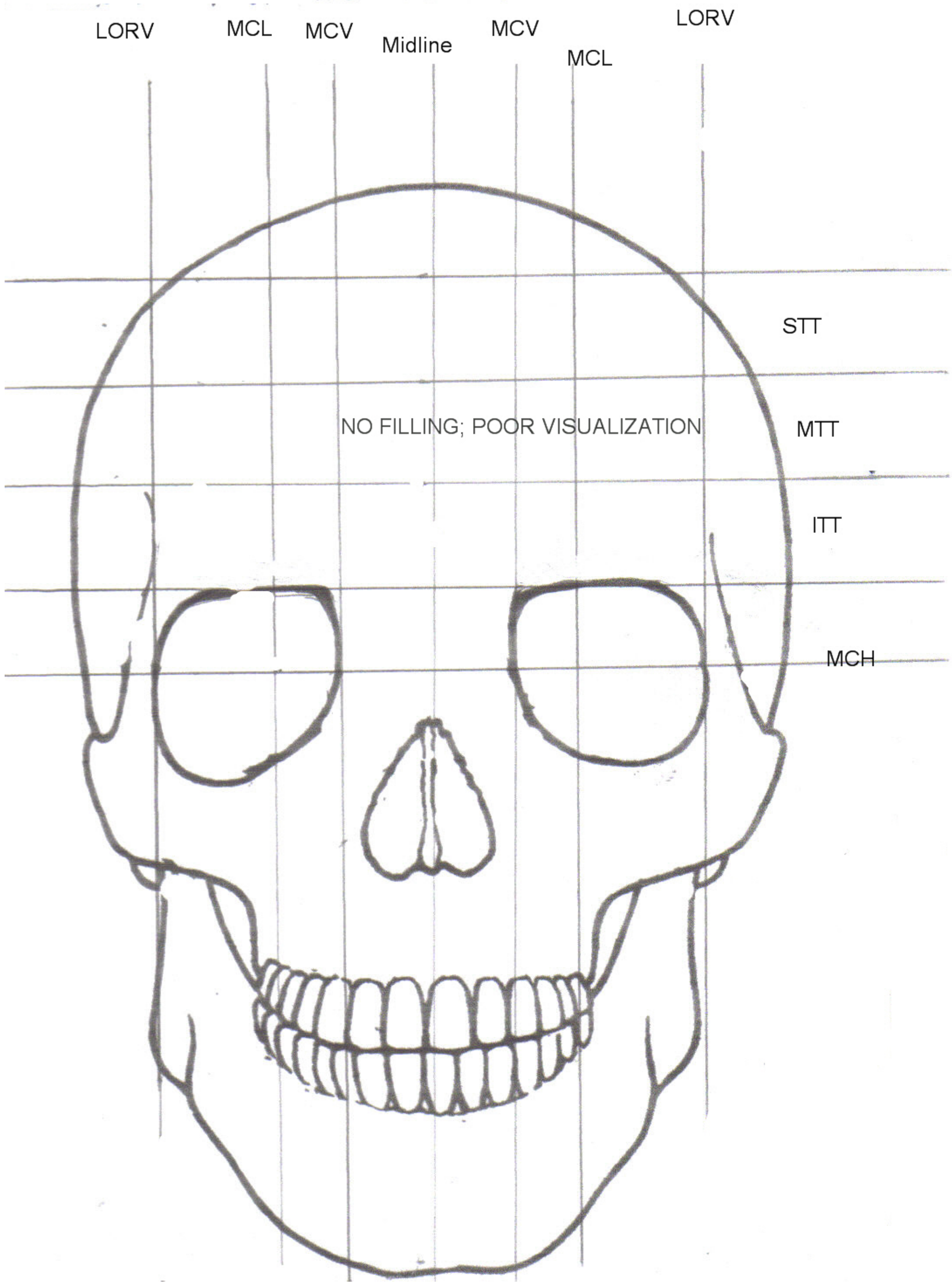


LORV
MCL
MCV
MCV
MCL
LORV
STT
MTT
STrA
STrA
OV
FBSTA
FBSTA
ITT
SOA
SOA
CA
CA
AA
AA

CADAVER 4

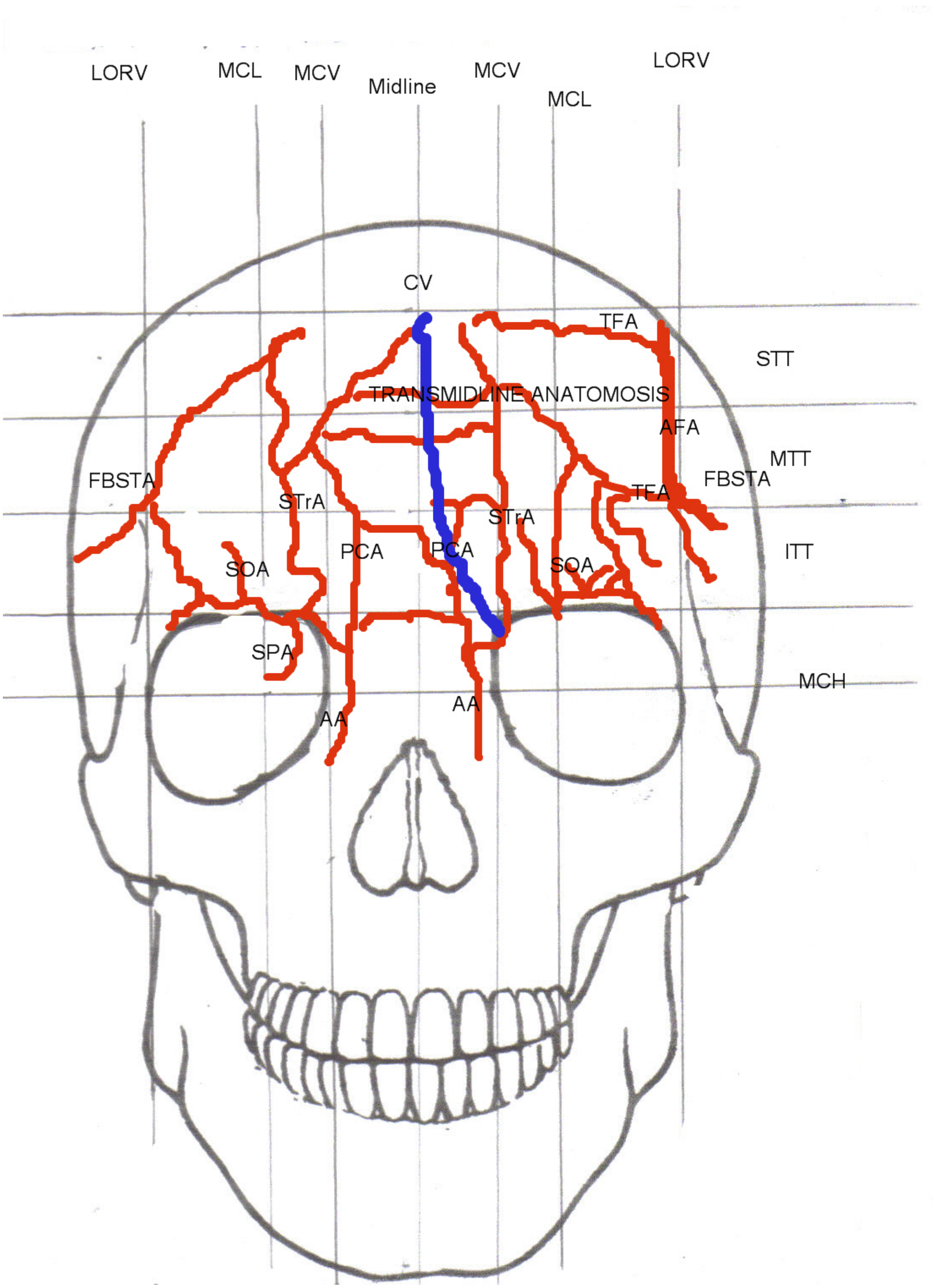

LORV
MCL
MCV
Midline
MCV
MCL
LORV
cv
STrV
OV
STT
MTT
FBSTA
STrA
ITT
SOA
SOA
CA
SPA
DNA
MCH
AA

CADAVER 5

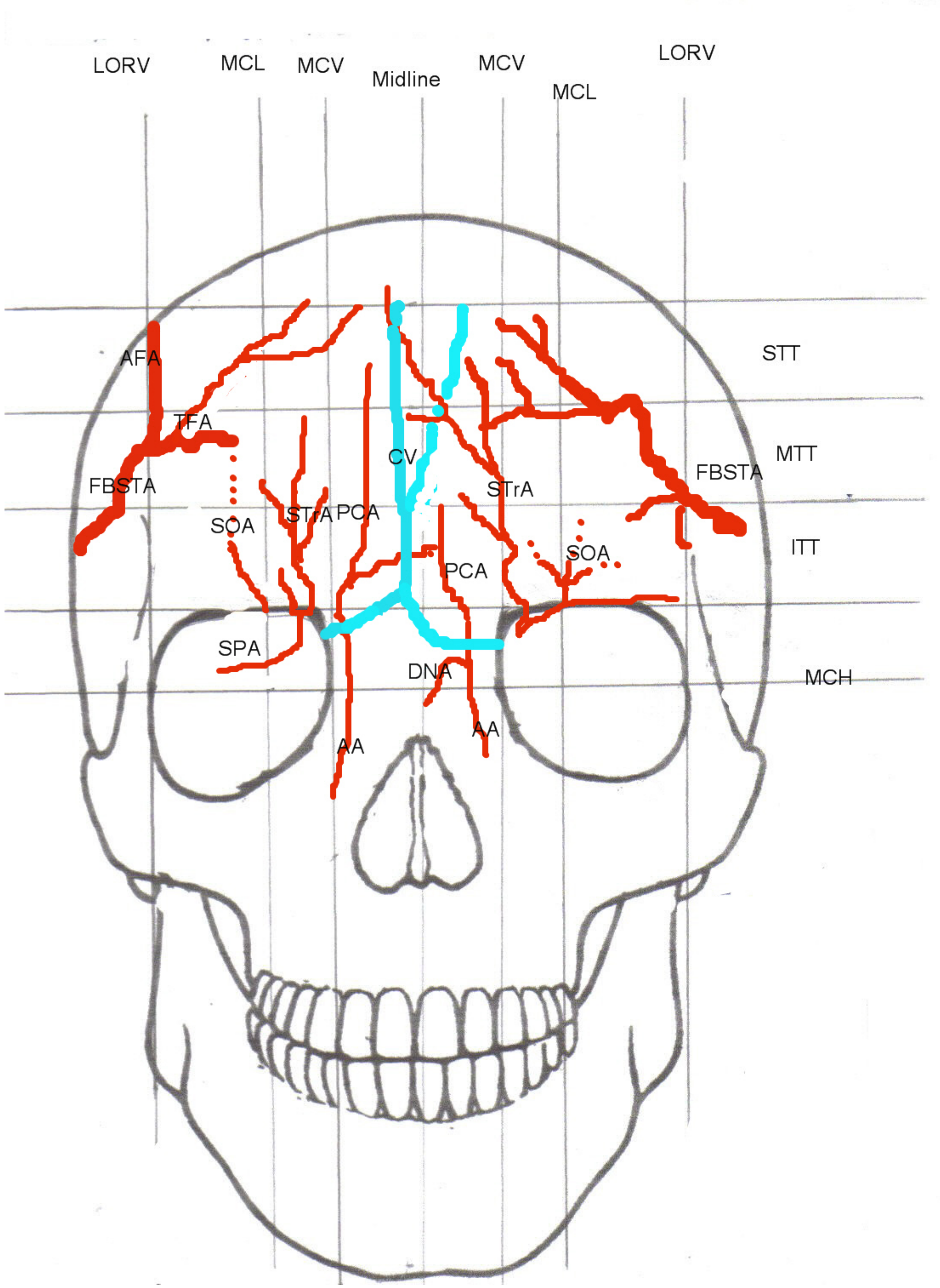


LORV
MCL
MCV
Midline
MCV
MCL
LORV
STT
MTT
ITT
MCH
NO FILLING; POOR VISUALIZATION

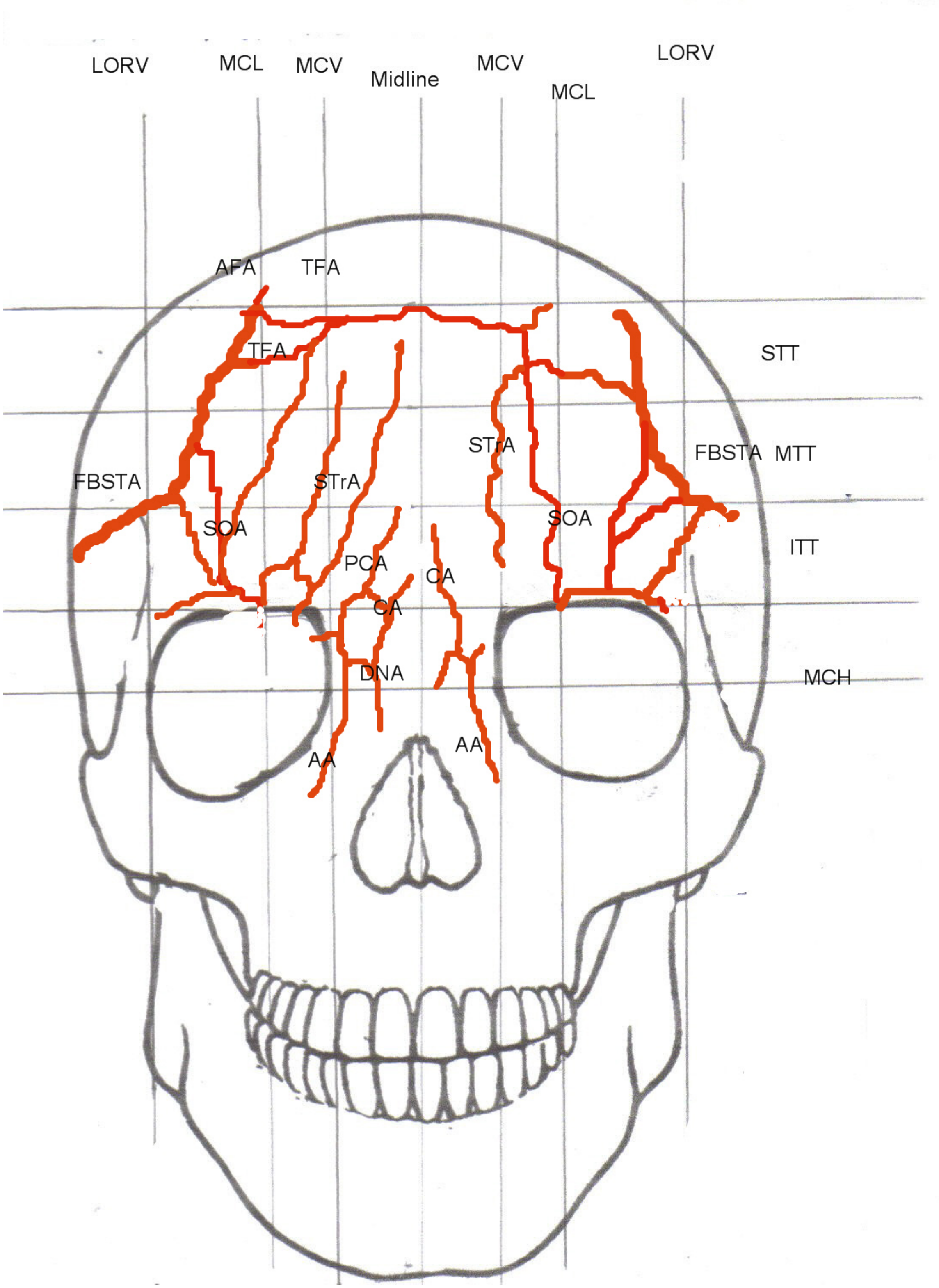
CADAVER 6


LORV
MCL
MCV
Midline
MCV
MCL
LORV
CV
TFA
STT
TRANSMIDLINE ANATOMOSIS
AFA
MTT
FBSTA
FBSTA
TFA
STrA
STrA
PCA
PCA
SOA
SOA
ITT
SPA
MCH
AA
AA

CADAVER 7

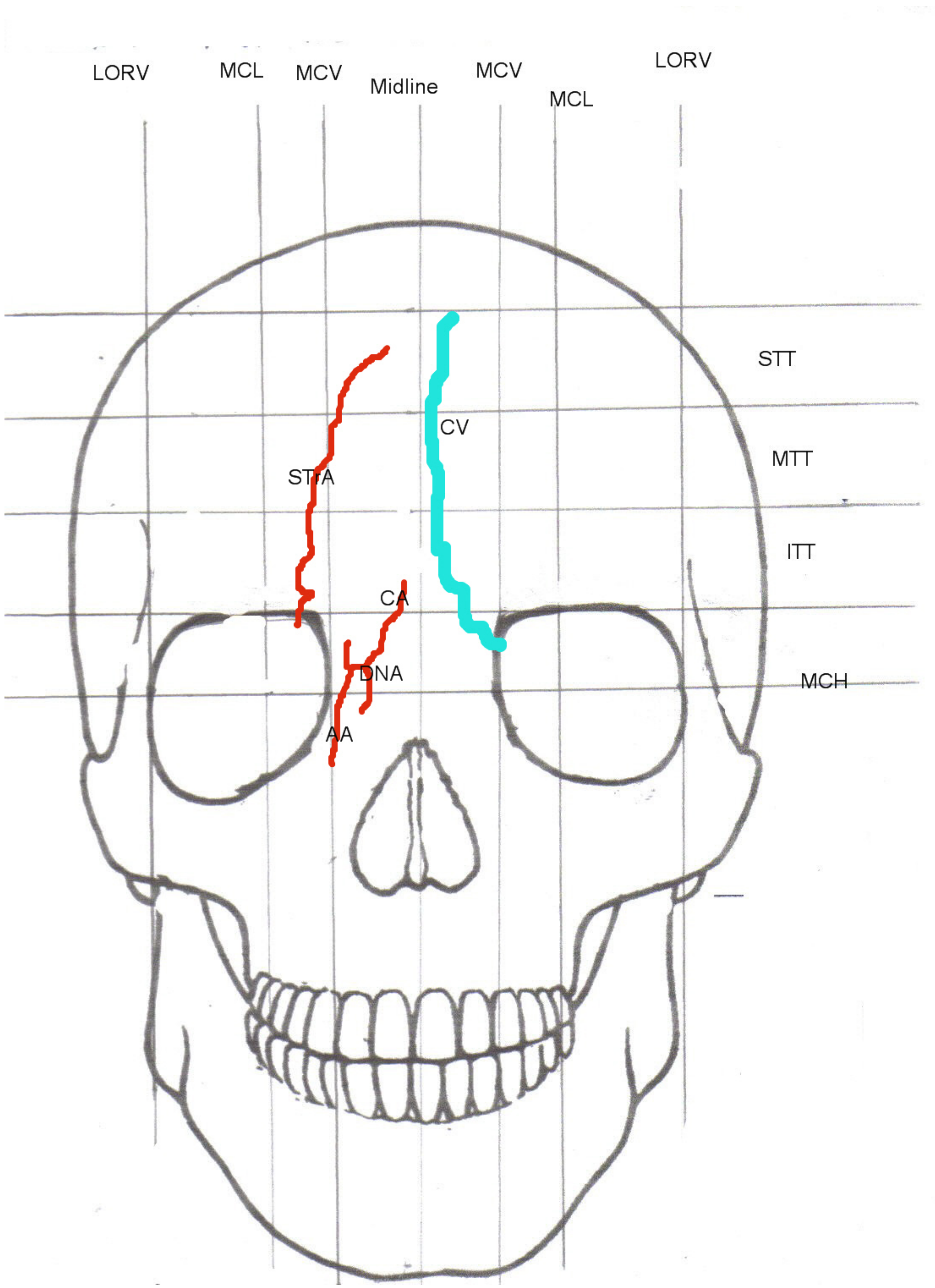

LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
TFA
FBSTA
SOA
STrA
PCA
CV
STrA
PCA
SOA
SPA
DNA
AA
AA
FBSTA
STT
MTT
ITT
MCH

CADAVER 8



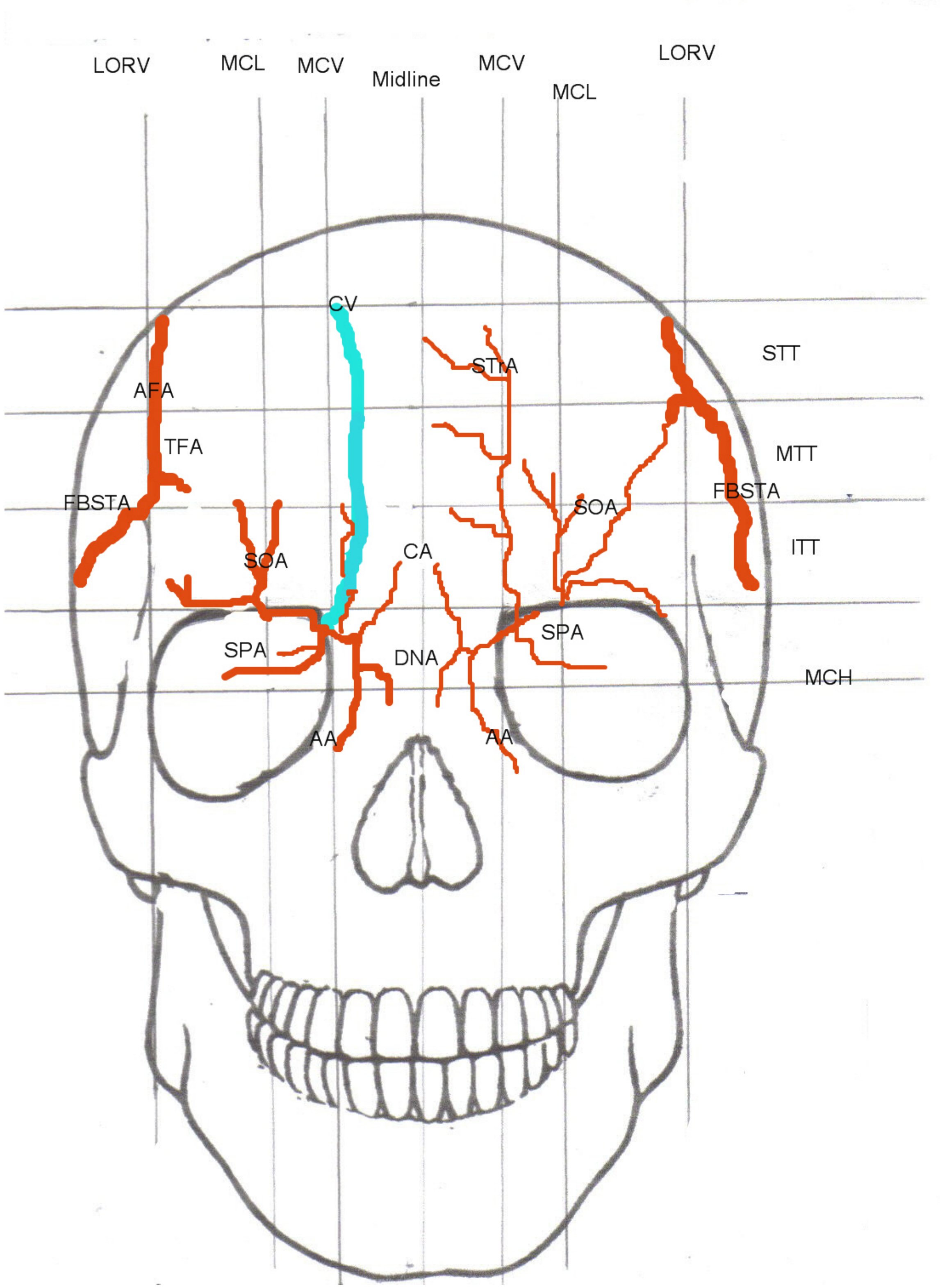
LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
TFA
TFA
STT
STrA
FBSTA
MTT
FBSTA
STrA
SOA
SOA
ITT
PCA
CA
CA
DNA
MCH
AA
AA

CADAVER 9

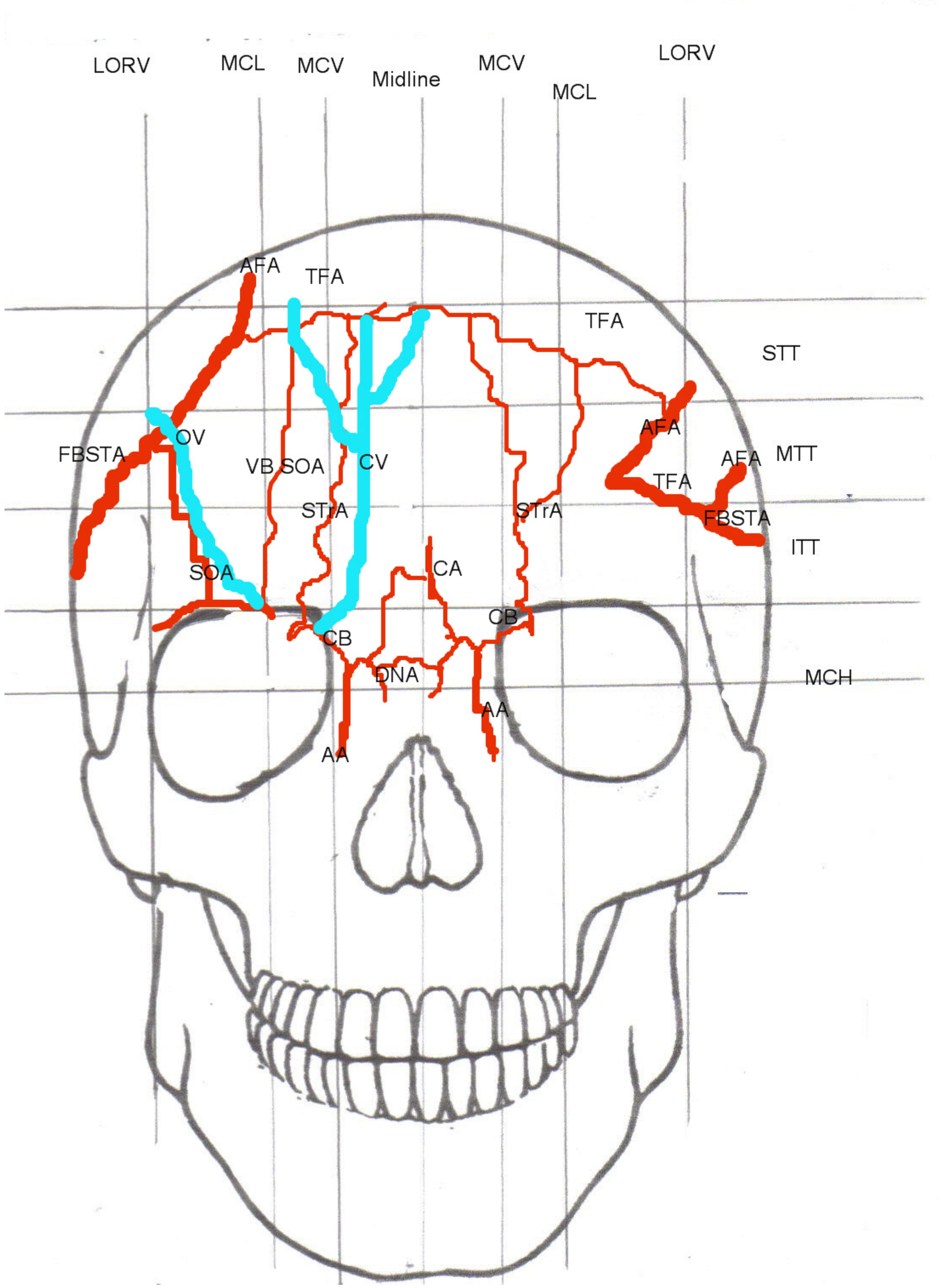


LORV
MCL
MCV
Midline
MCV
MCL
LORV
STT
MTT
ITT
MCH
CV
STrA
CA
DNA
AA

CADAVER 10

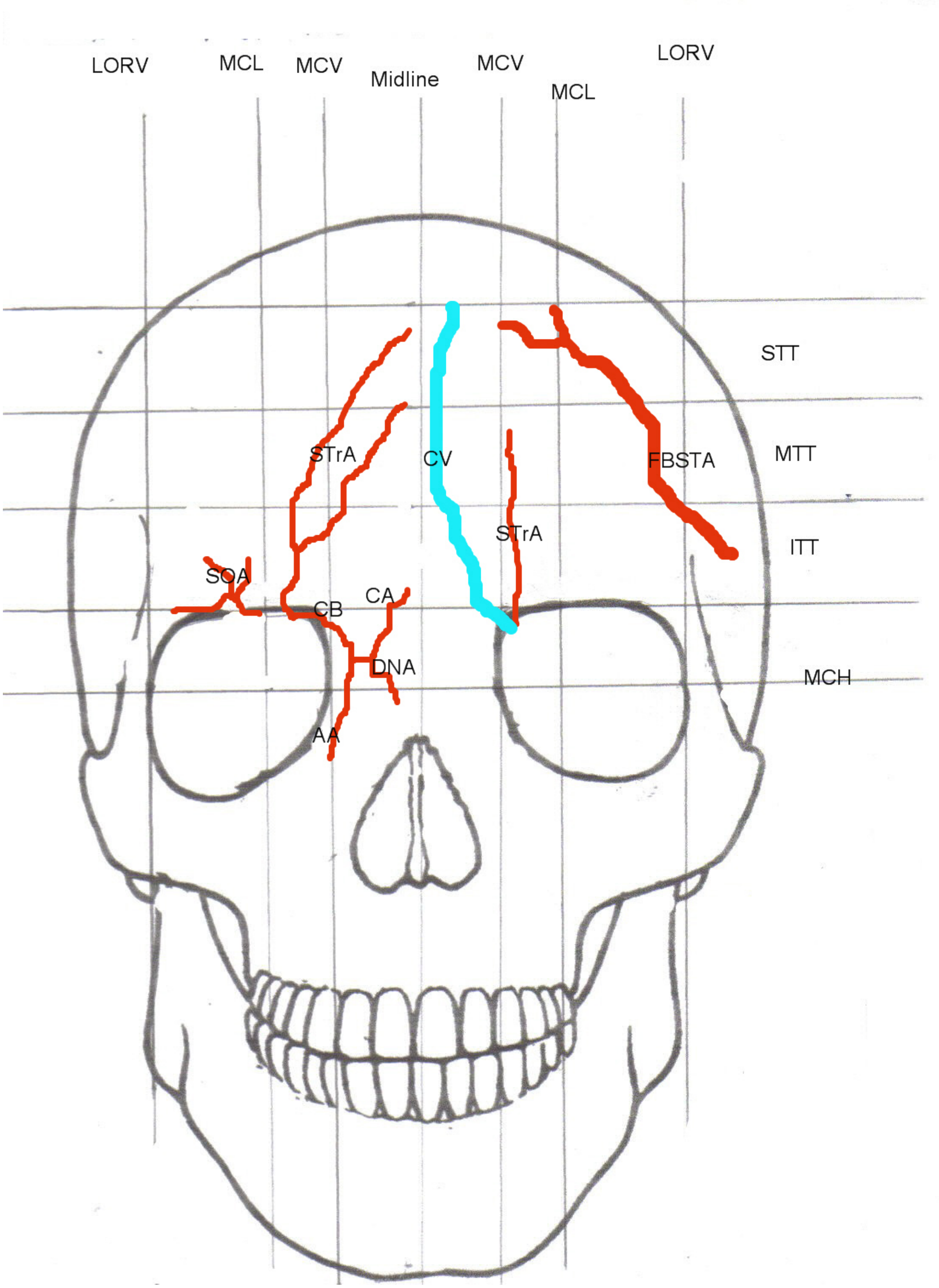

LORV
MCL
MCV
Midline
MCV
MCL
LORV
CV
STrA
AFA
STT
TFA
MTT
FBSTA
SOA
FBSTA
SOA
CA
ITT
SPA
SPA
DNA
MCH
AA
AA

CADAVER 11



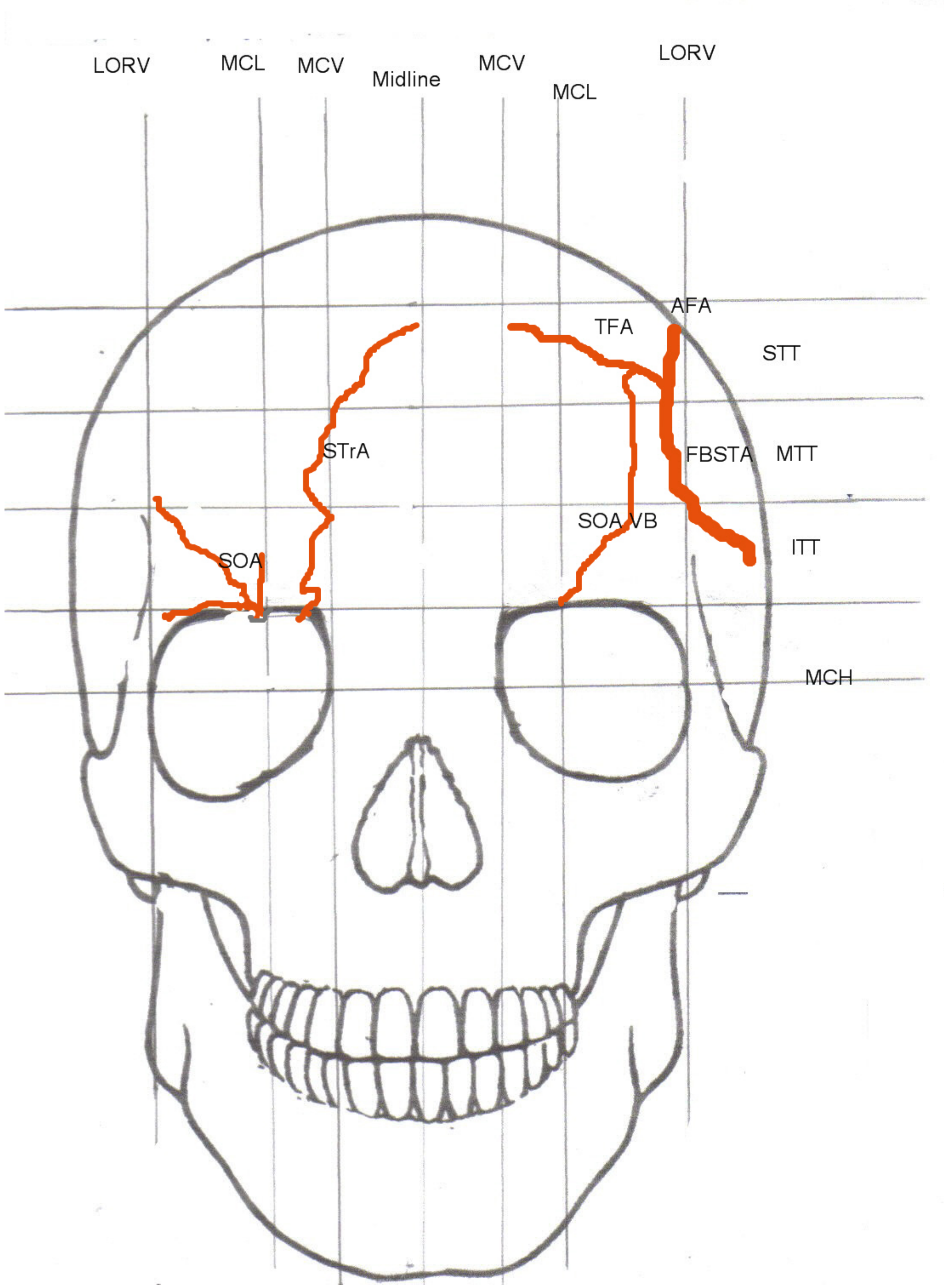
LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
TFA
TFA
STT
OV
FBSTA
VB
SOA
CV
AFA
AFA
MTT
TFA
STrA
STrA
FBSTA
ITT
SOA
CA
CB
CB
DNA
MCH
AA
AA

CADAVER 12

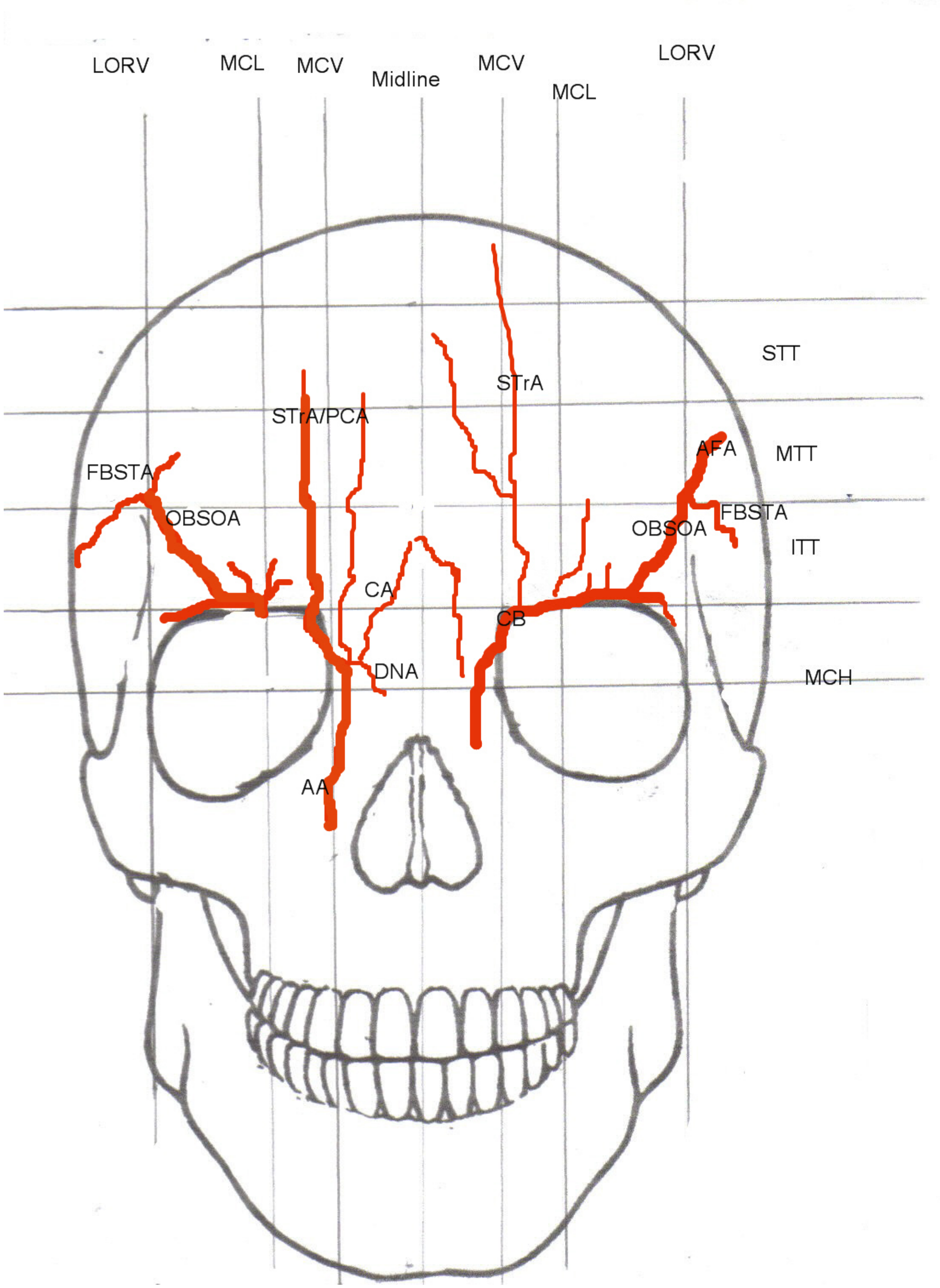


LORV
MCL
MCV
Midline
MCV
MCL
LORV
STT
MTT
ITT
MCH
STrA
CV
STrA
FBSTA
SOA
CB
CA
DNA
AA

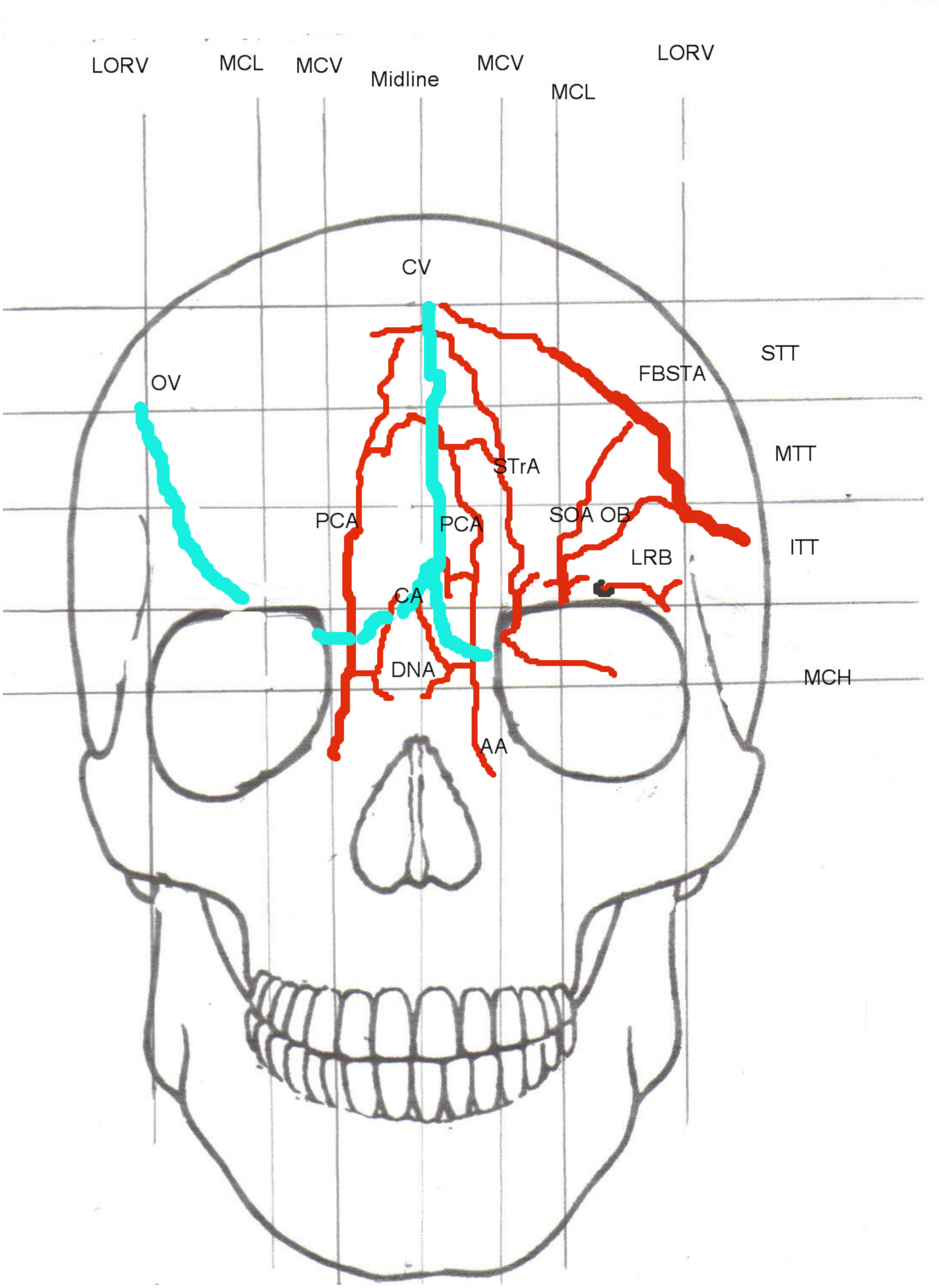
CADAVER 13


LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
TFA
STT
STrA
FBSTA
MTT
SOA VB
SOA
ITT
MCH

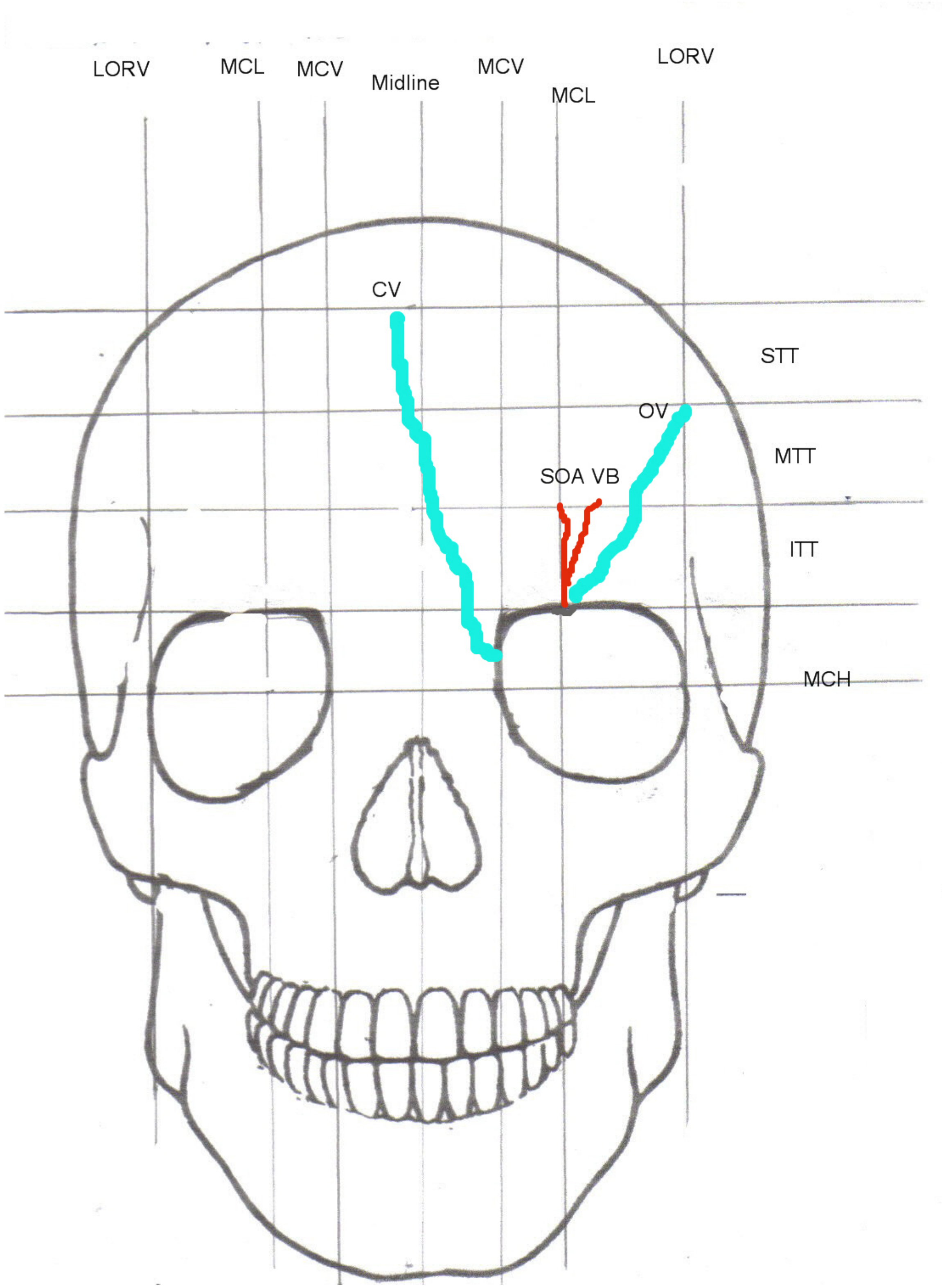
CADAVER 14


LORV
MCL
MCV
Midline
MCV
MCL
LORV
STT
STrA
STrA/PCA
AFA
MTT
FBSTA
OBSOA
FBSTA
OBSOA
ITT
CA
CB
DNA
MCH
AA

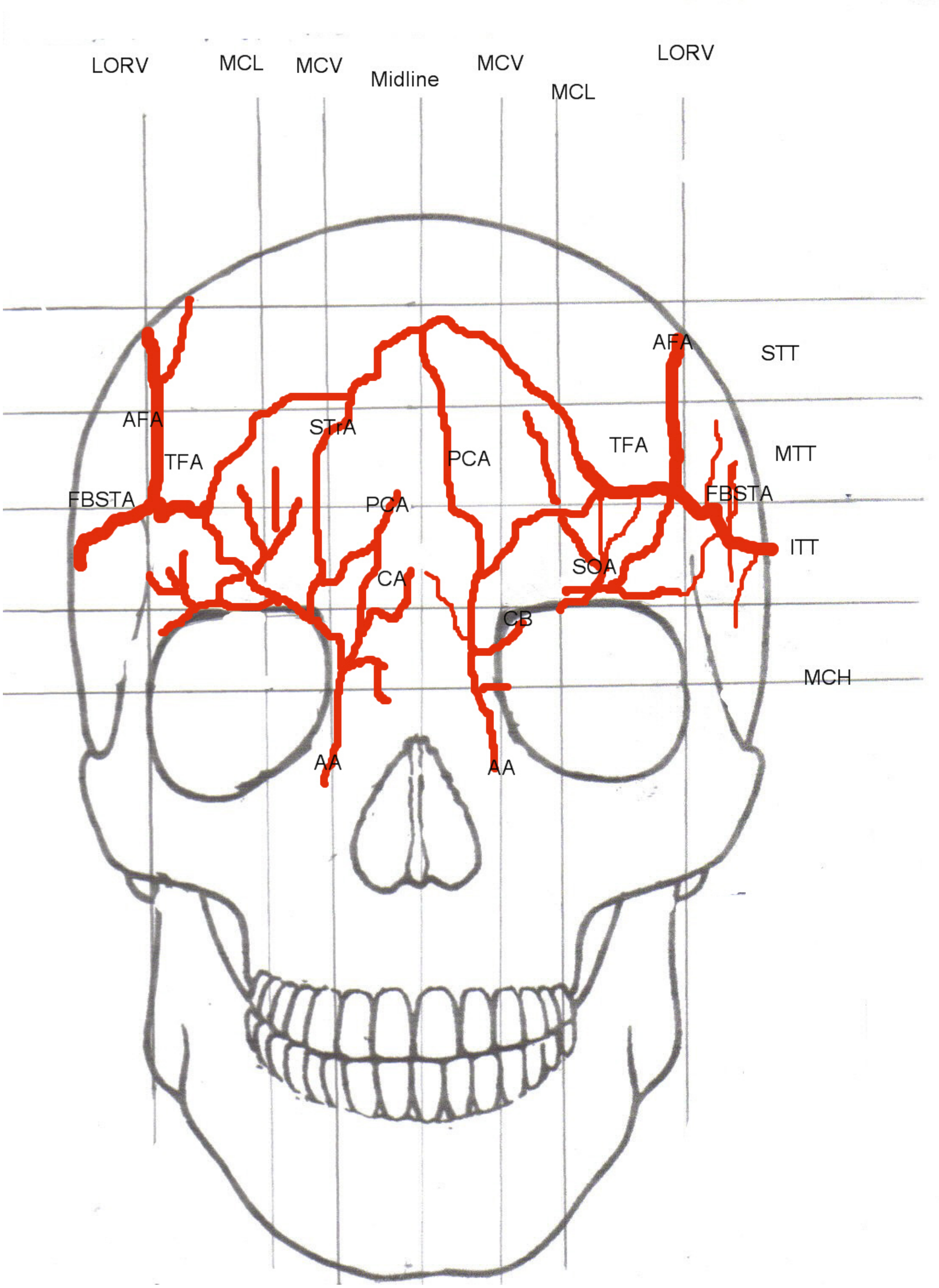
CADAVER 15


LORV
MCL
MCV
Midline
MCV
MCL
LORV
CV
OV
FBSTA
STT
MTT
STrA
PCA
PCA
SOA OB
LRB
ITT
CA
DNA
MCH
AA

CADAVER 16

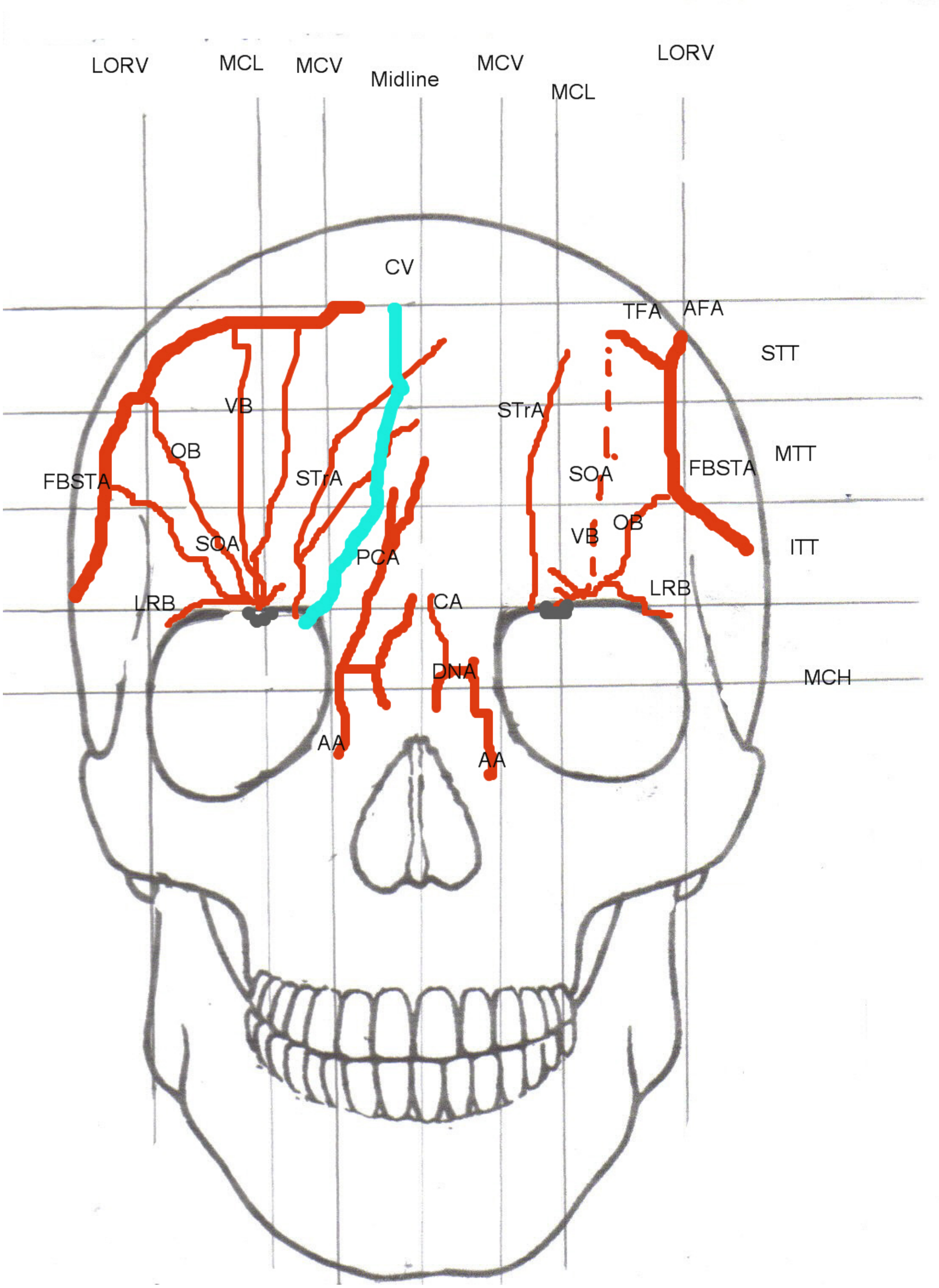


CADAVER 17



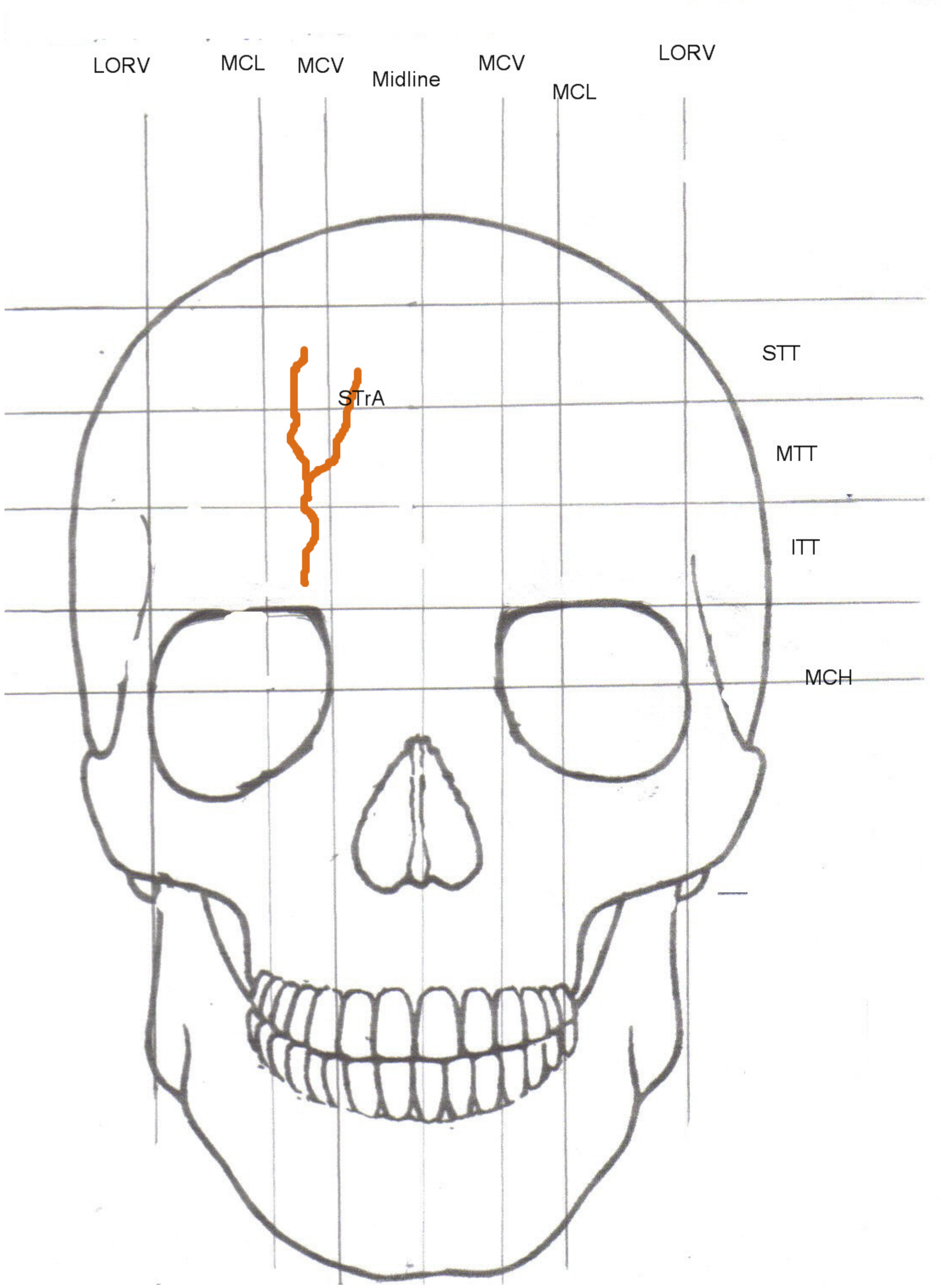
LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
STT
AFA
STrA
TFA
MTT
TFA
PCA
FBSTA
PCA
FBSTA
ITT
SOA
CA
CB
MCH
AA
AA

CADAVER 18

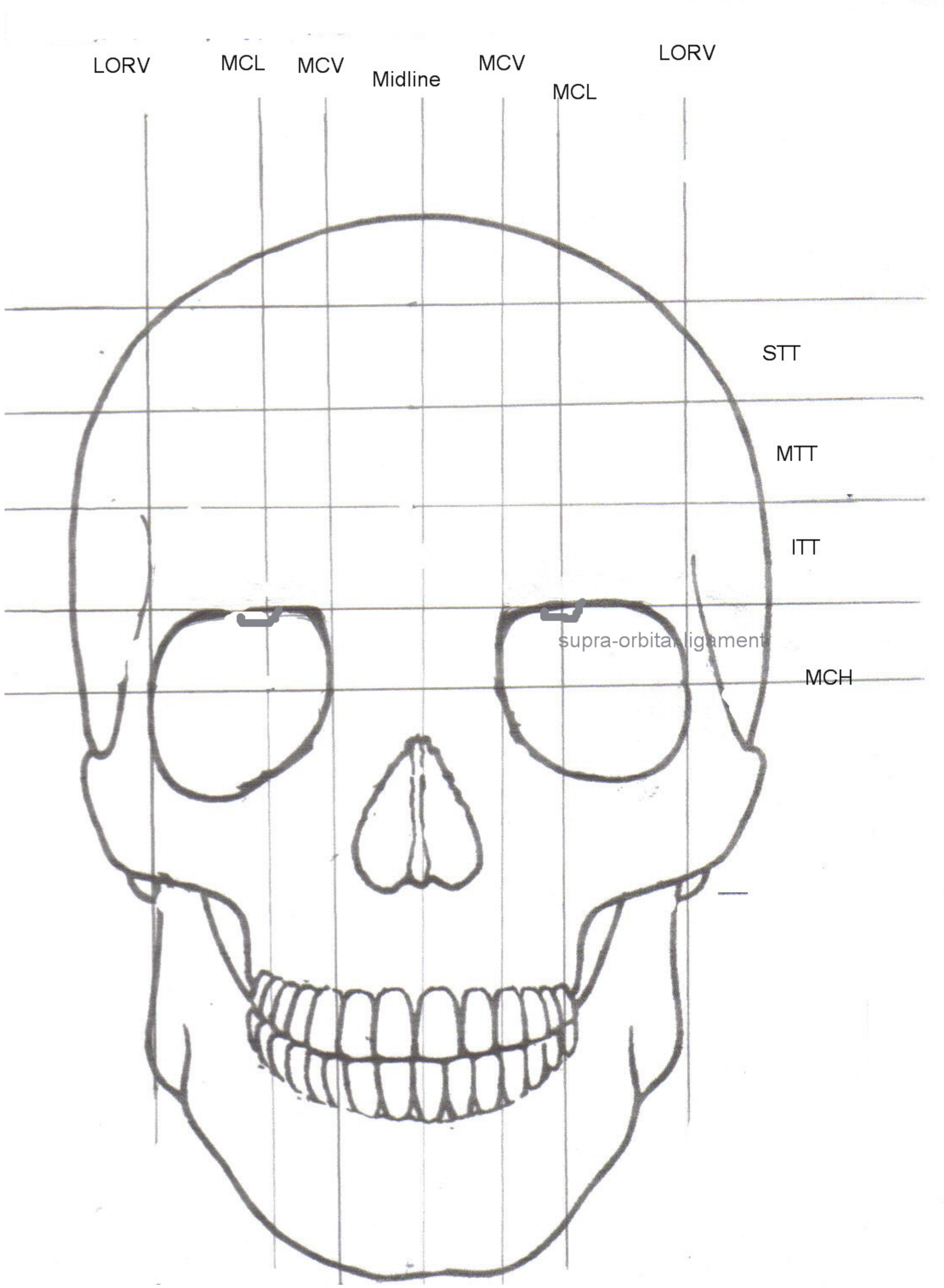


LORV
MCL
MCV
Midline
MCV
MCL
LORV
CV
TFA
AFA
STT
VB
STrA
OB
SOA
FBSTA
MTT
FBSTA
STrA
SOA
VB
OB
ITT
PCA
LRB
LRB
CA
DNA
MCH
AA
AA

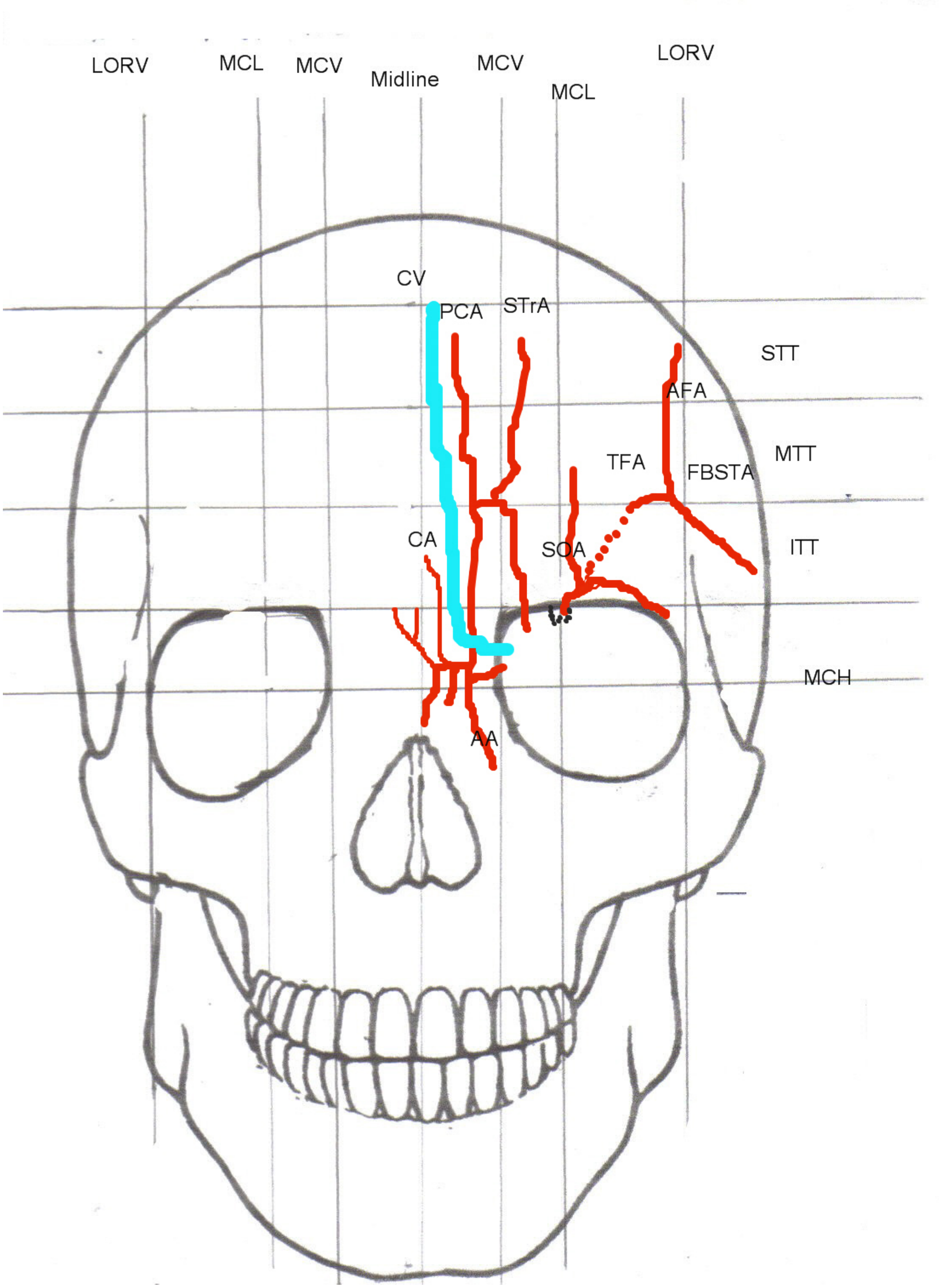
CADAVER 19



CADAVER 20

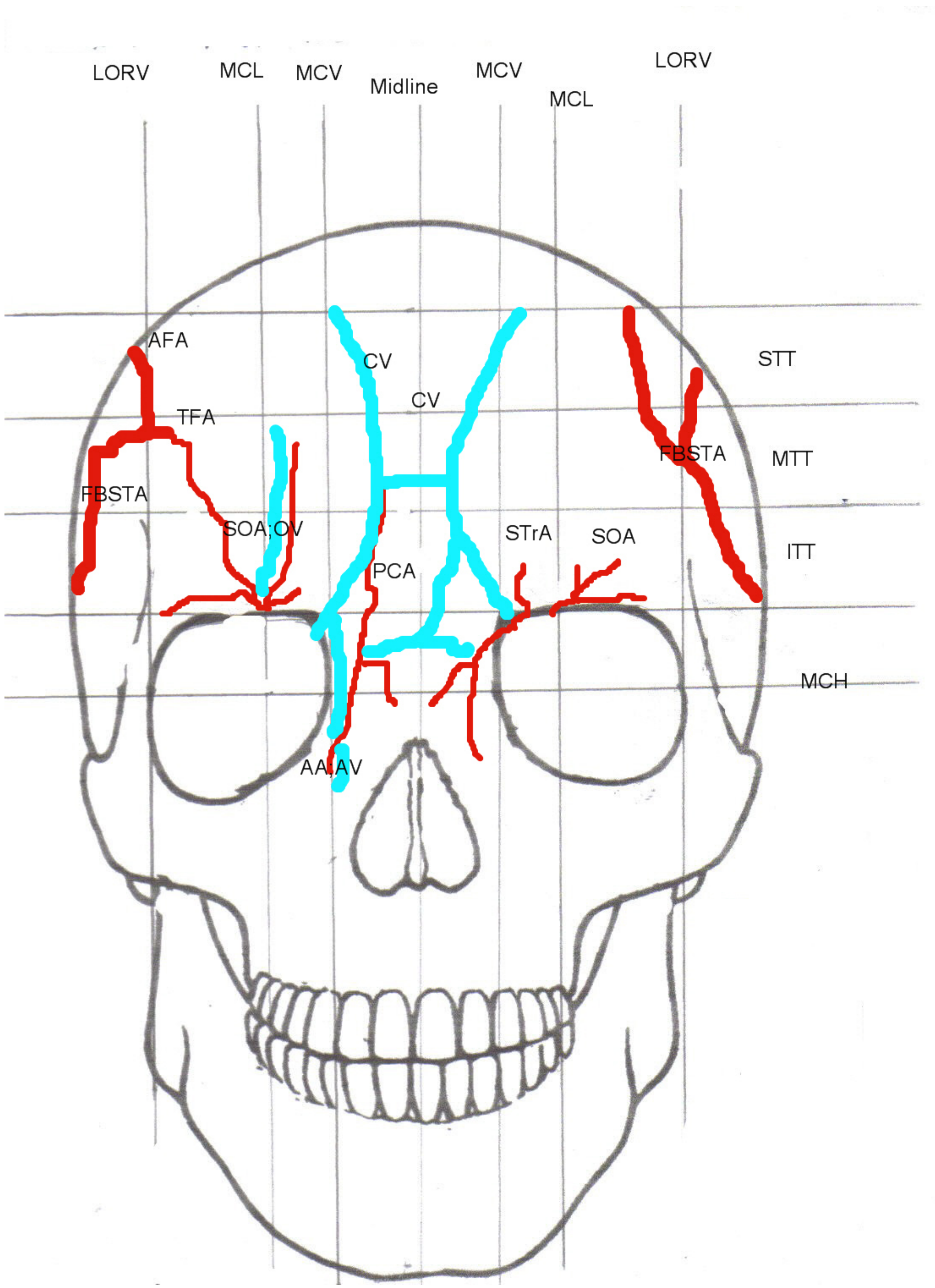

LORV
MCL
MCV
Midline
MCV
MCL
LORV
STT
MTT
ITT
supra-orbital ligament
MCH

CADAVER 21



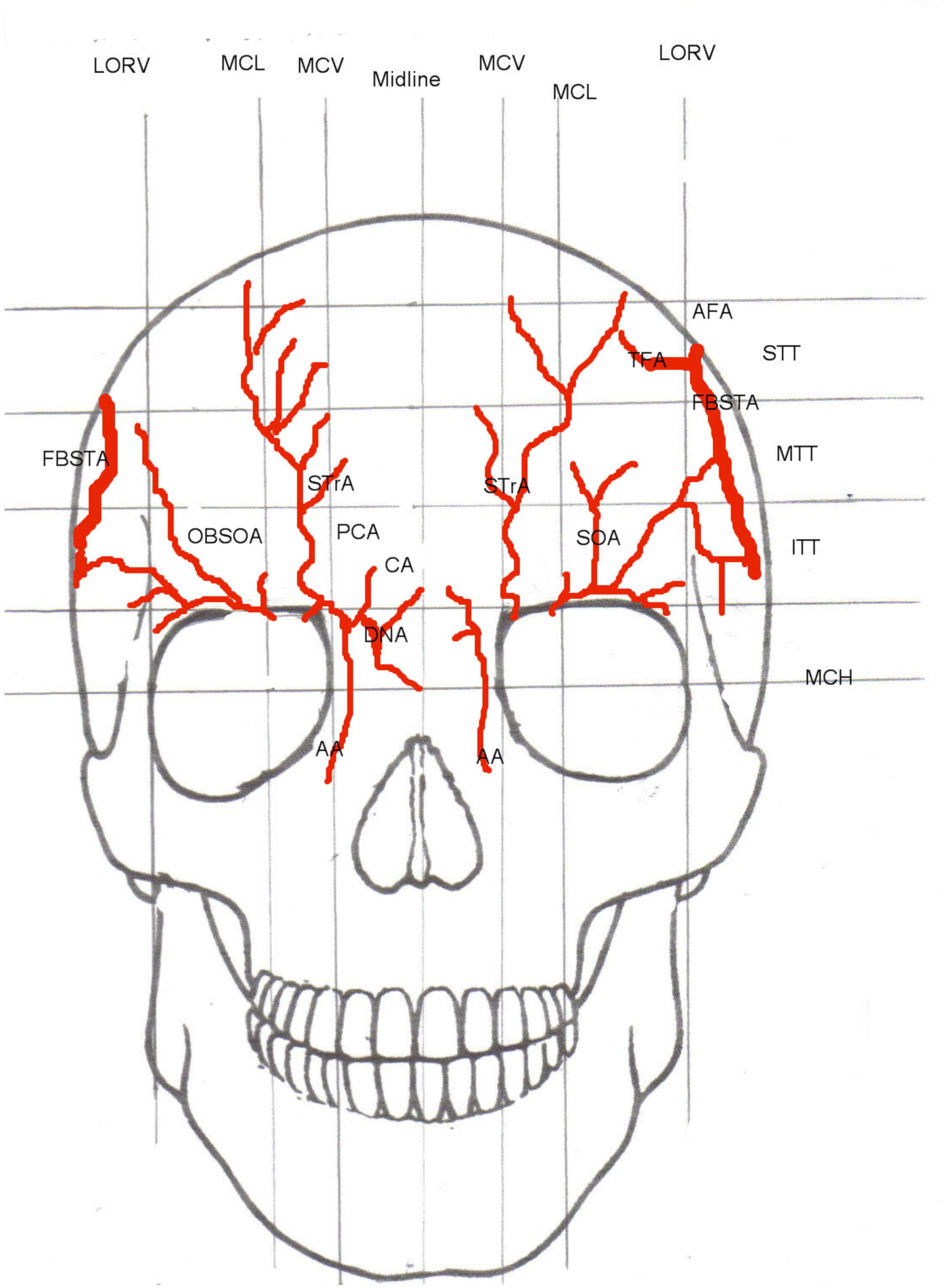
LORV
MCL
MCV
Midline
MCV
MCL
LORV
CV
PCA
STrA
STT
AFA
TFA
FBSTA
MTT
CA
SOA
ITT
MCH
AA

CADAVER 22

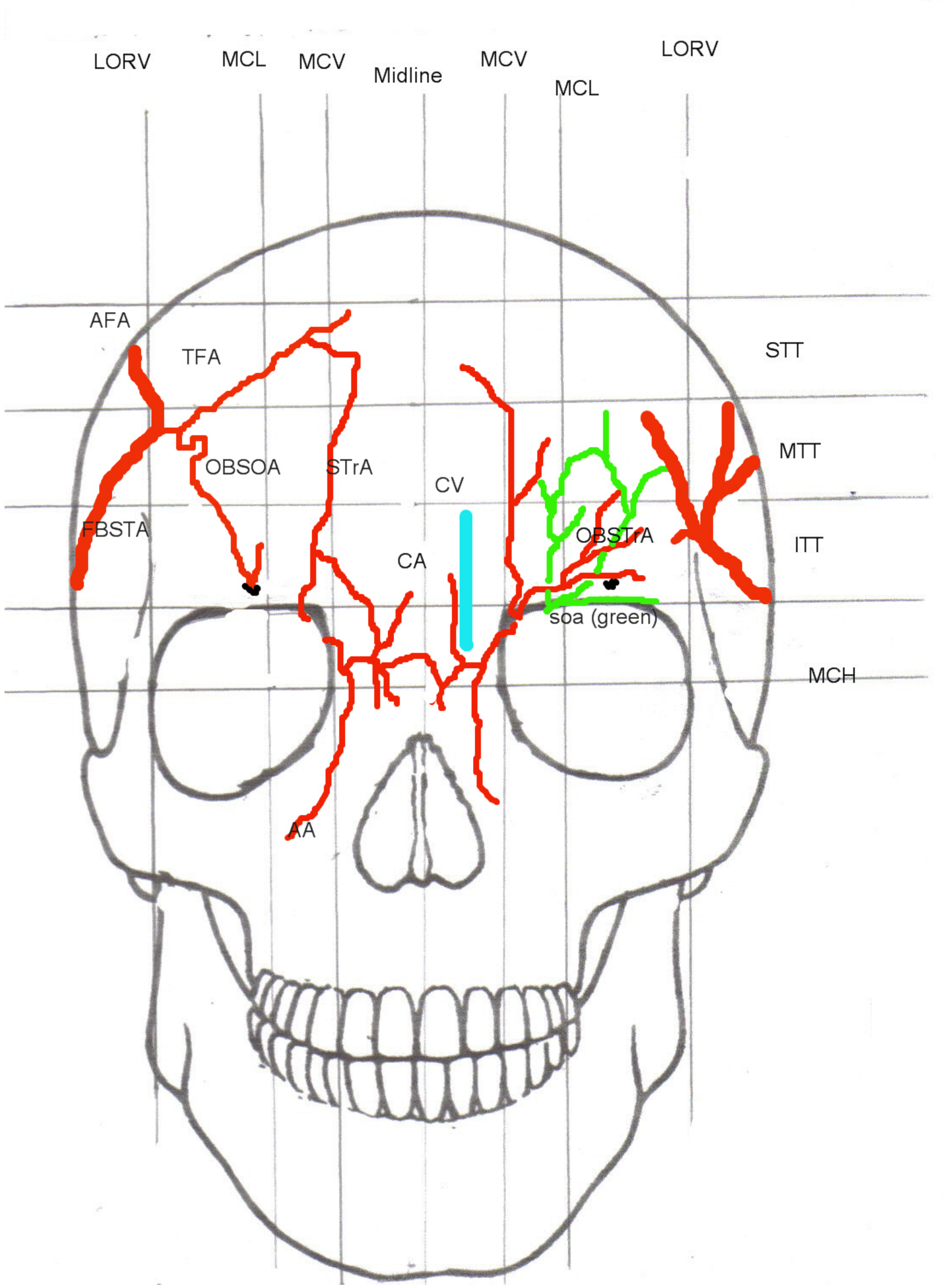


LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
TFA
FBSTA
SOA;OV
CV
CV
PCA
STrA
SOA
FBSTA
STT
MTT
ITT
MCH
AA;AV

CADAVER 23

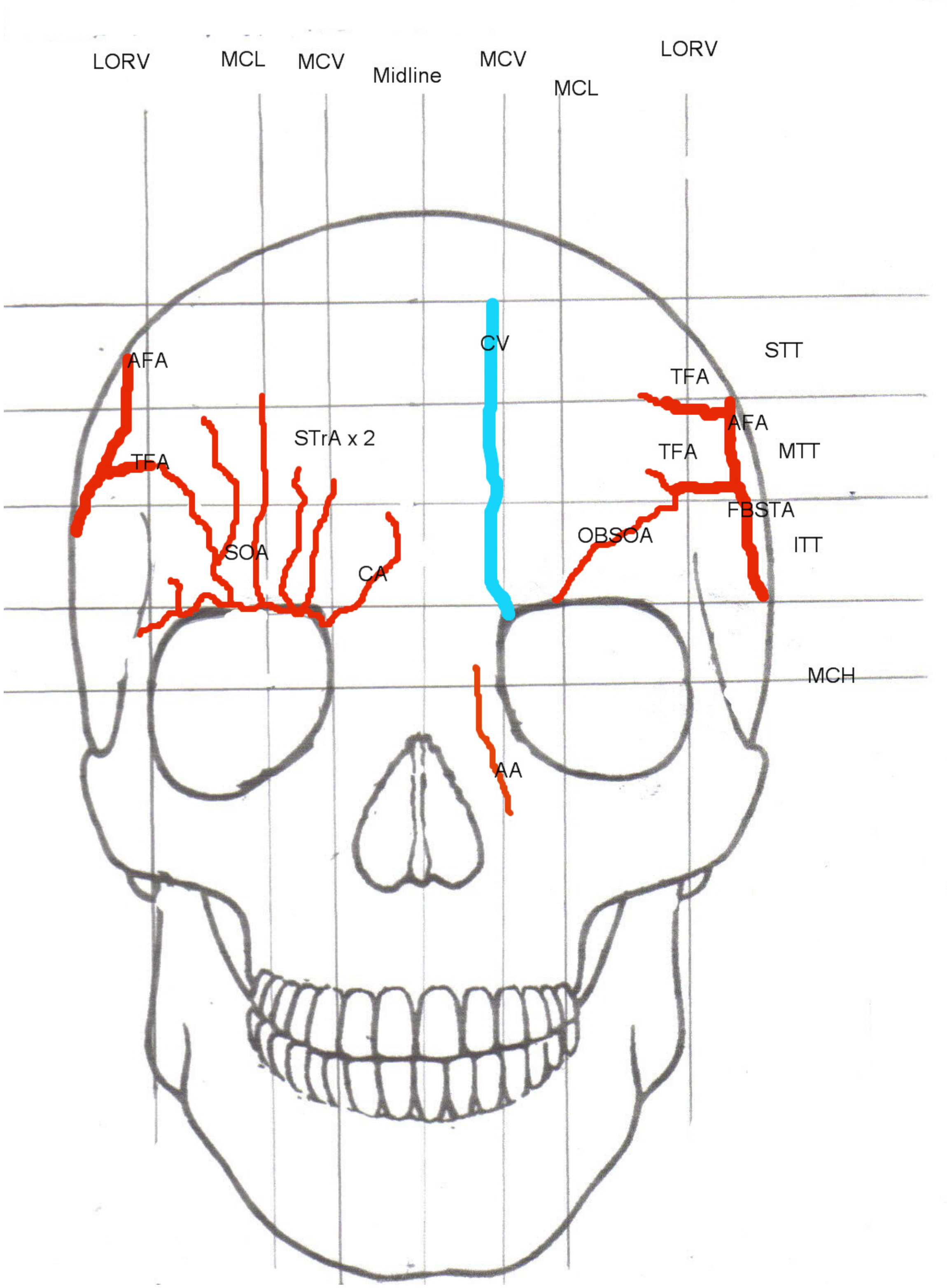

LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
STT
TFA
FBSTA
MTT
FBSTA
STrA
STrA
OBSOA
PCA
SOA
ITT
CA
DNA
MCH
AA
AA

CADAVER 24



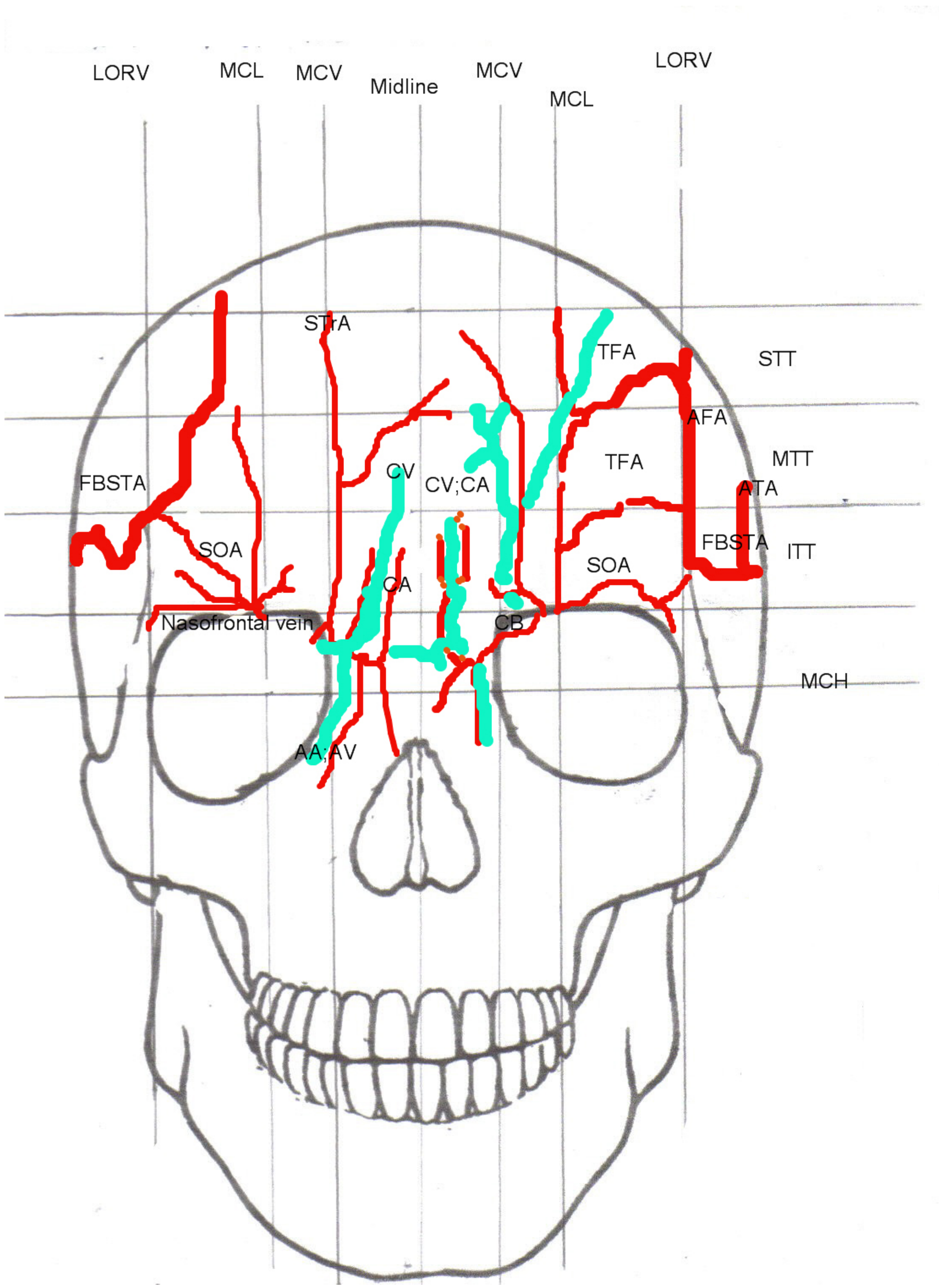
LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
TFA
STT
MTT
OBSOA
STrA
CV
FBSTA
OBSTrA
ITT
CA
soa (green)
MCH
AA

CADAVER 25

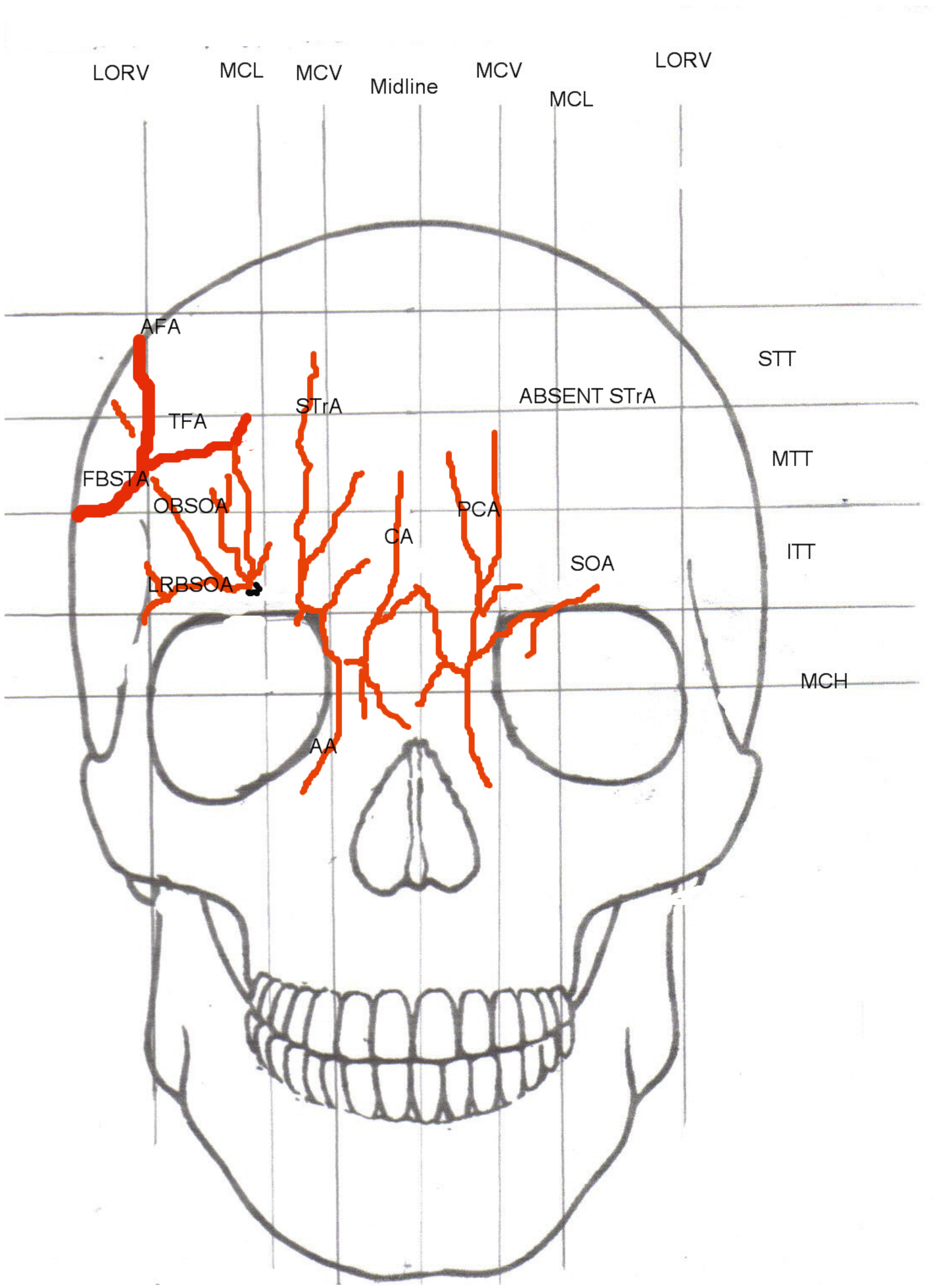


LORV
MCL
MCV
Midline
MCV
MCL
LORV
CV
STT
AFA
TFA
AFA
STrA x 2
TFA
MTT
TFA
FBSTA
OBSOA
SOA
ITT
CA
MCH
AA

CADAVER 26

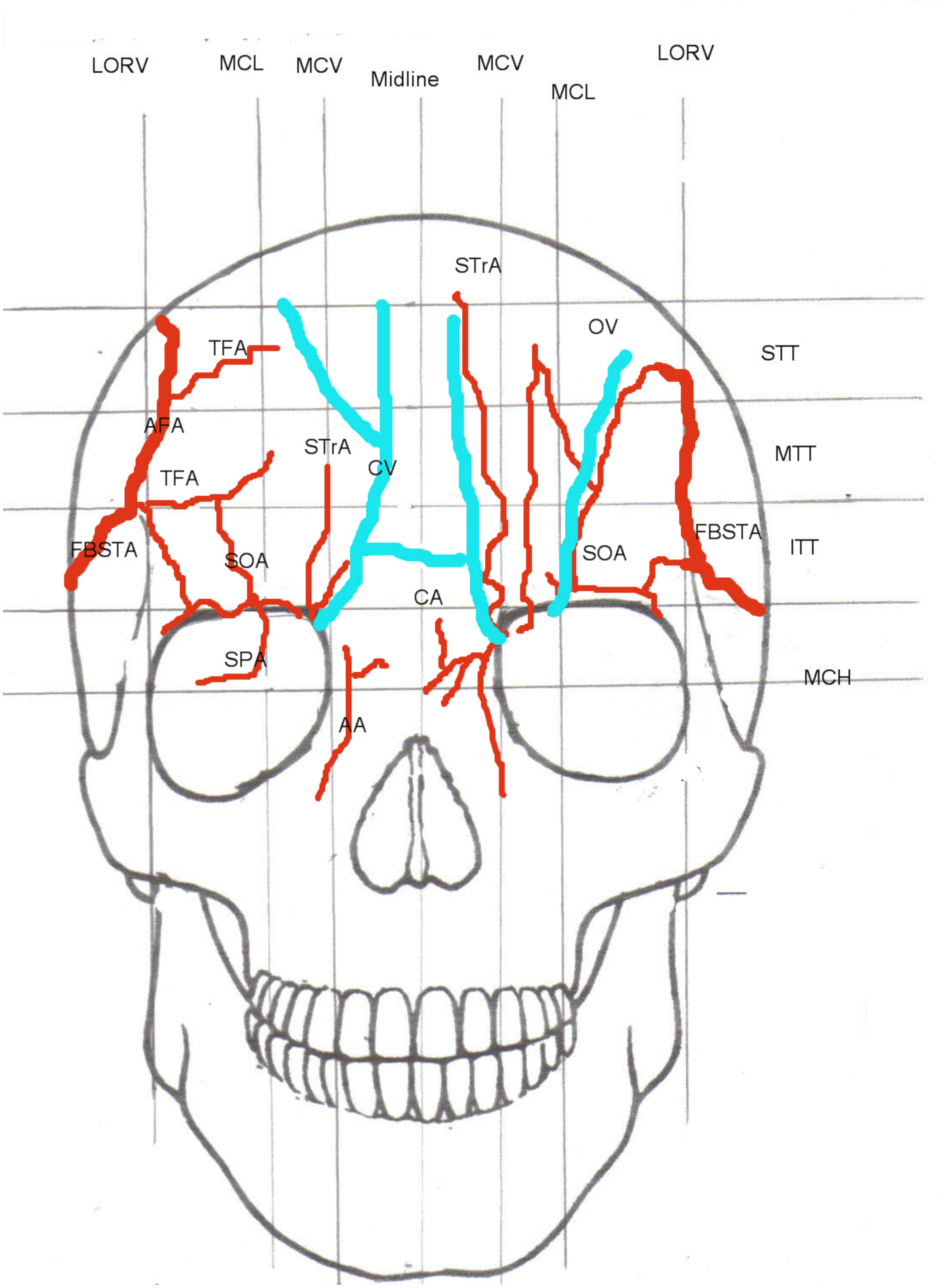

LORV
MCL
MCV
Midline
MCV
MCL
LORV
STrA
TFA
STT
AFA
TFA
MTT
FBSTA
CV
CV;CA
ATA
SOA
FBSTA
ITT
SOA
CA
Nasofrontal vein
CB
MCH
AA;AV

CADAVER 27



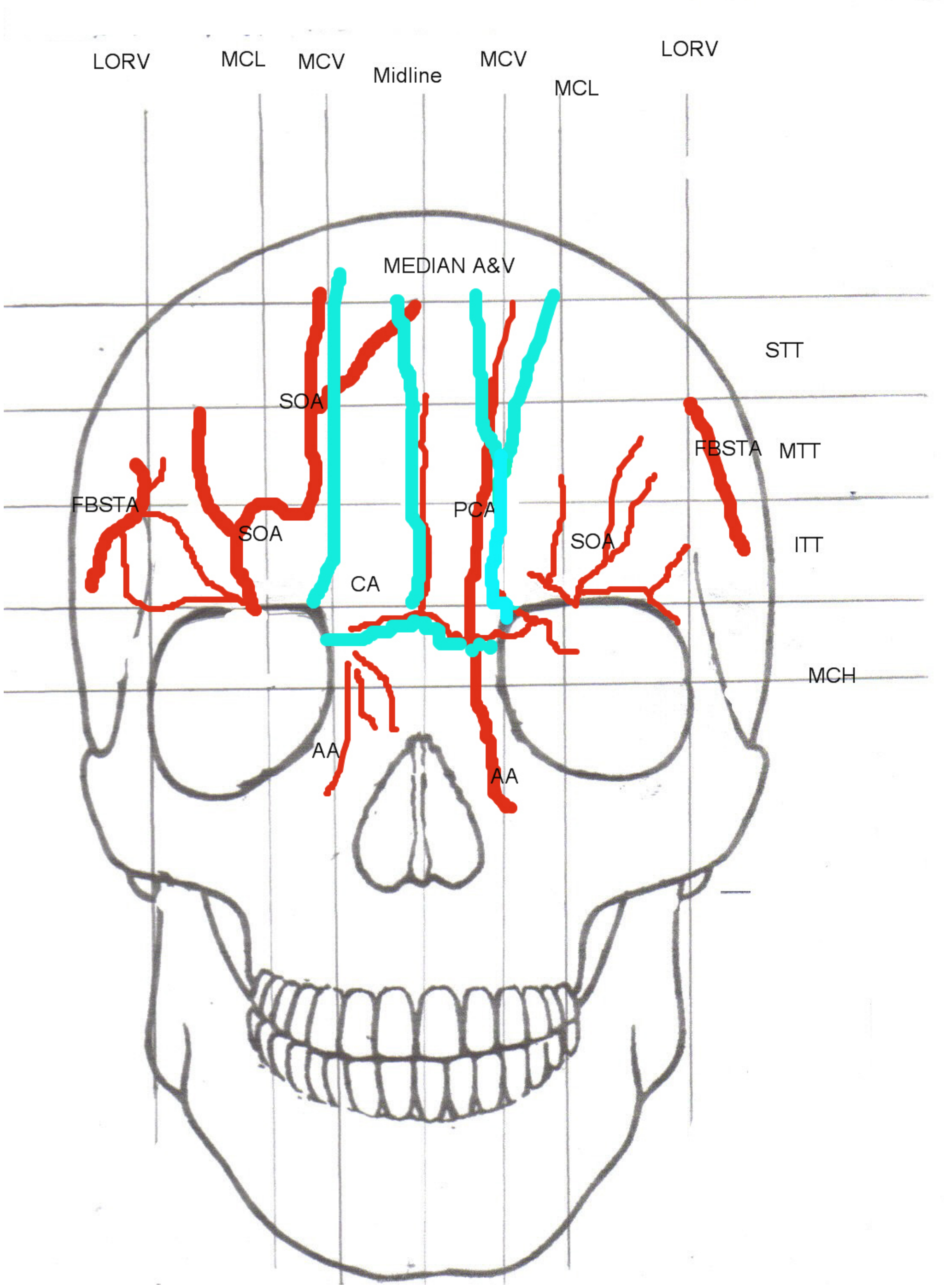
LORV
MCL
MCV
Midline
MCV
MCL
LORV
AFA
STT
STrA
ABSENT STrA
TFA
MTT
FBSTA
OBSOA
PCA
CA
ITT
SOA
LRBSOA
MCH
AA

CADAVER 28

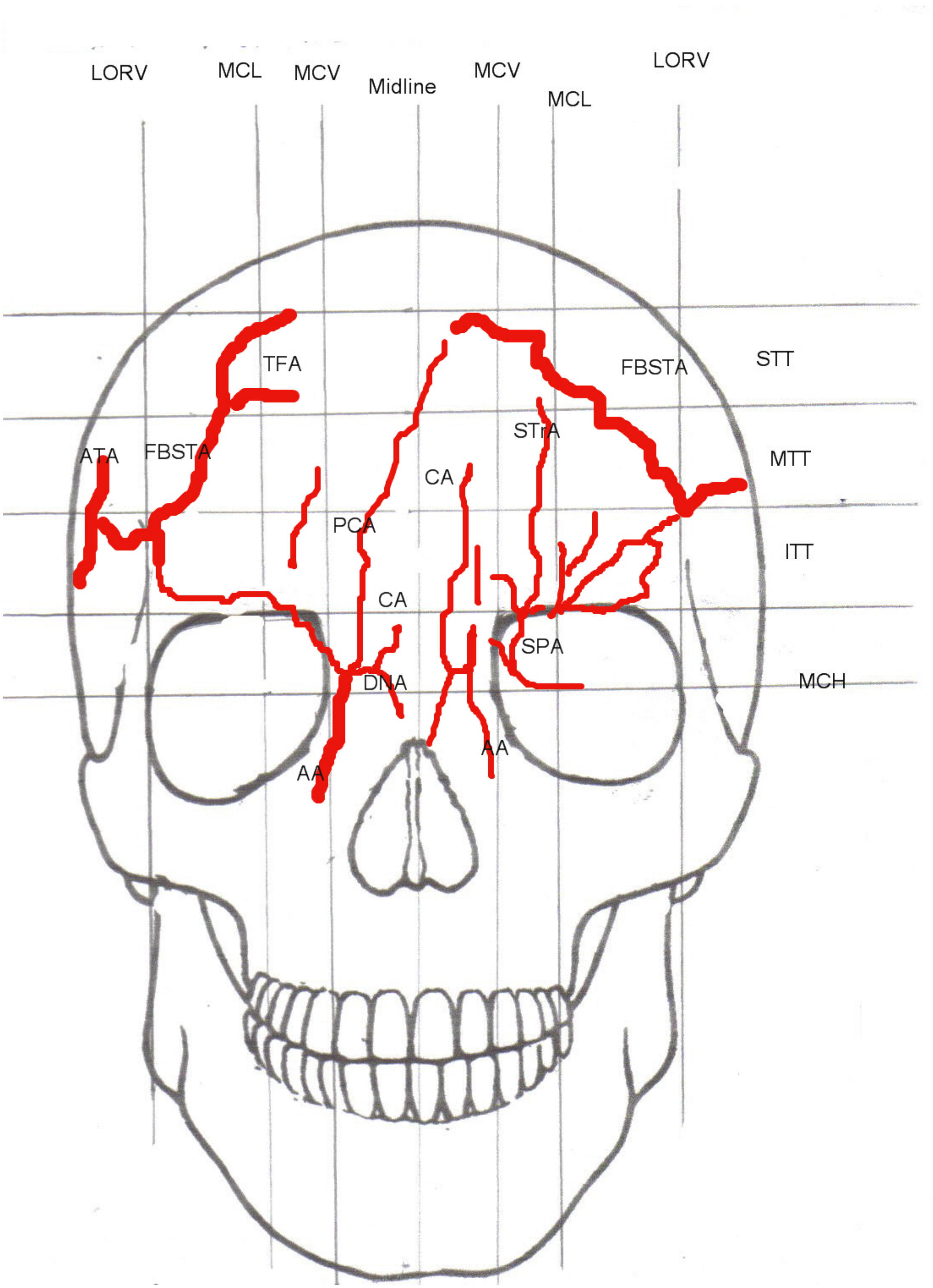


LORV
MCL
MCV
Midline
MCV
MCL
LORV
STrA
OV
STT
TFA
AFA
STrA
CV
MTT
TFA
FBSTA
ITT
FBSTA
SOA
SOA
CA
SPA
MCH
AA

CADAVER 29

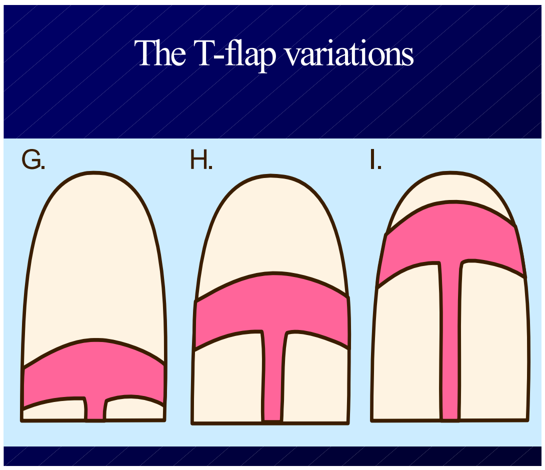

LORV
MCL
MCV
Midline
MCV
MCL
LORV
MEDIAN A&V
STT
SOA
FBSTA
MTT
FBSTA
SOA
PCA
SOA
ITT
CA
MCH
AA
AA

CADAVER 30



LORV
MCL
MCV
Midline
MCV
MCL
LORV
TFA
FBSTA
STT
ATA
FBSTA
STrA
CA
MTT
PCA
ITT
CA
SPA
DNA
MCH
AA
AA

B. PREVIOUS FLAP DESIGNS



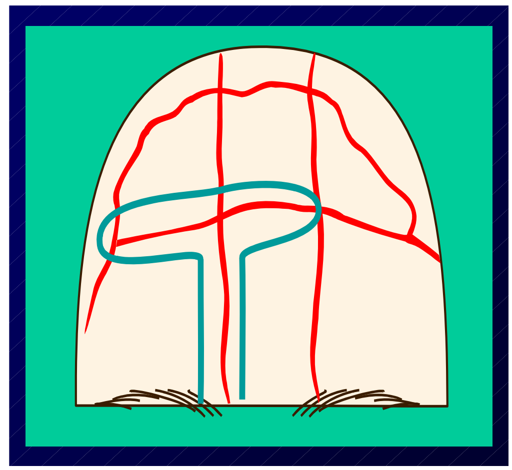
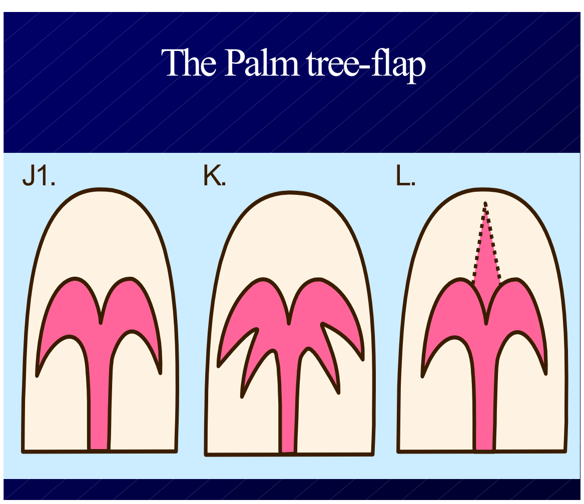


Fig. 41. The T-flap variations



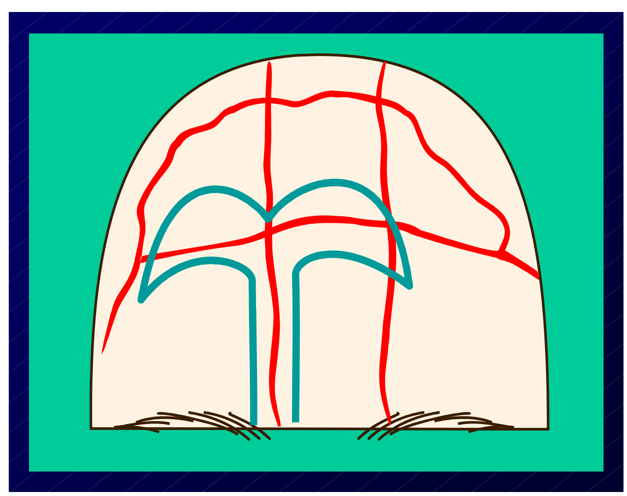


Fig. 42. The Palm tree-flap

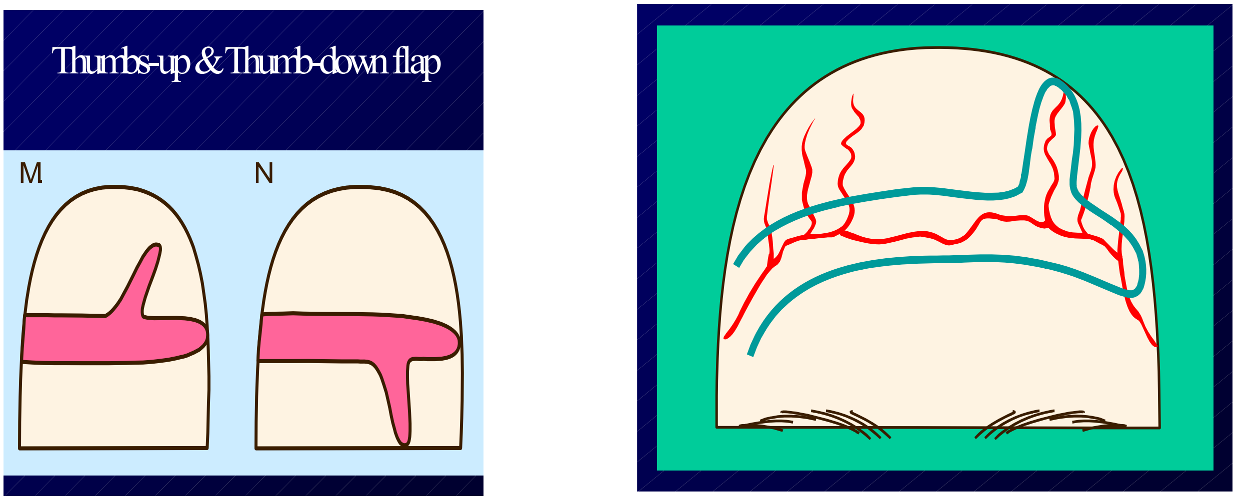


Fig. 43. Thumbs-up & Thumb-down flap

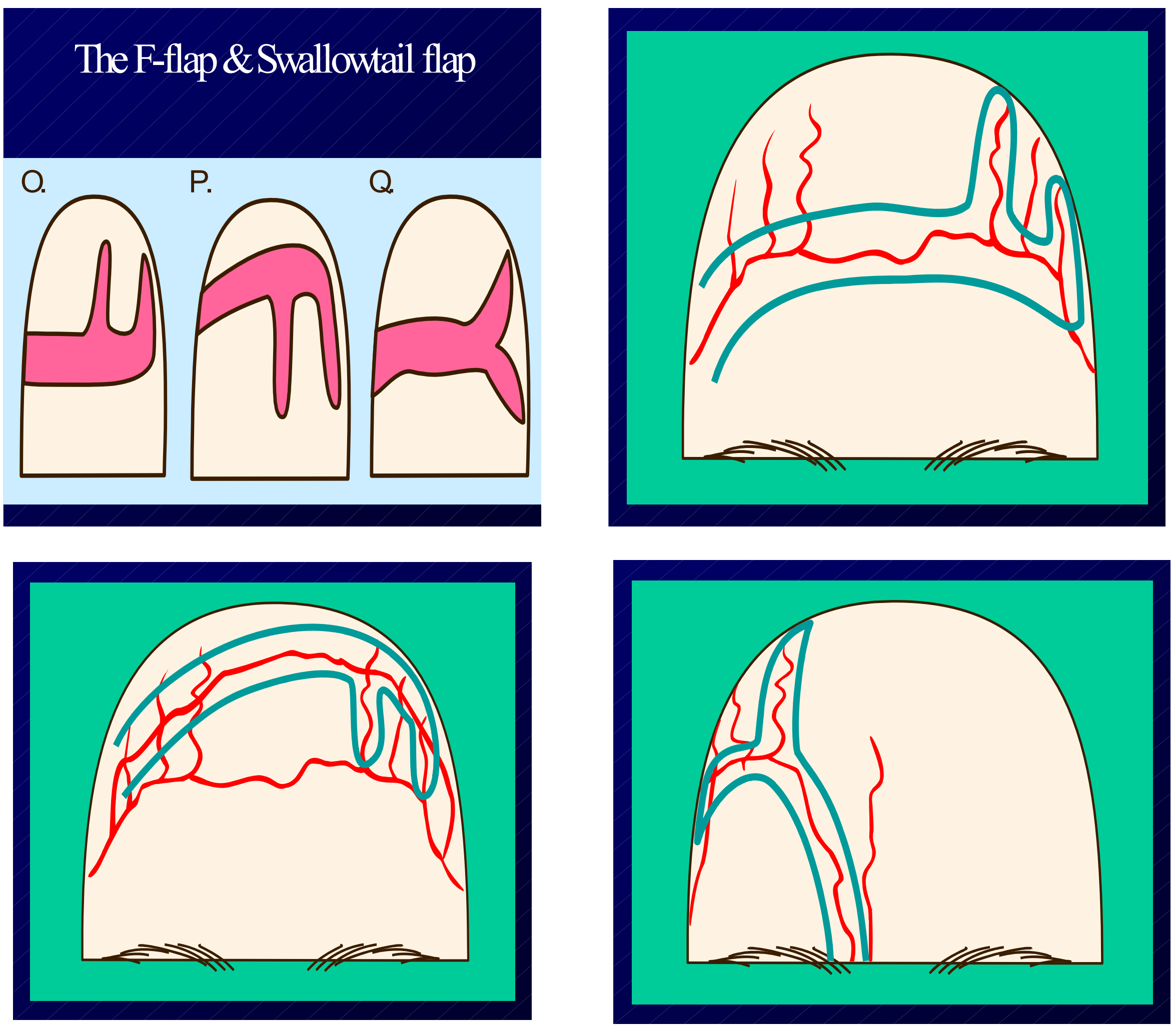


Fig 44. F-flap & Swallow tail flap

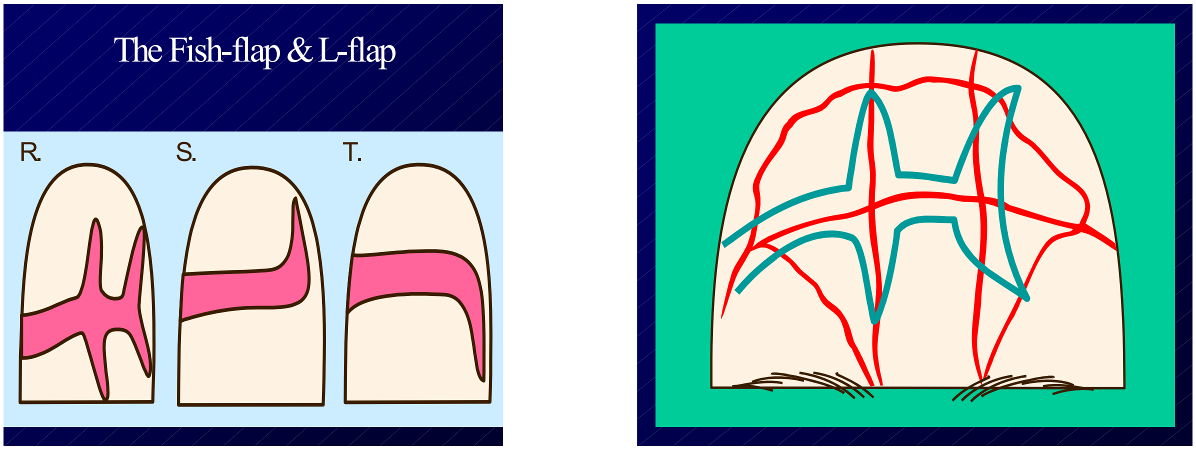


Fig. 45. The Fish-flap & L-flap

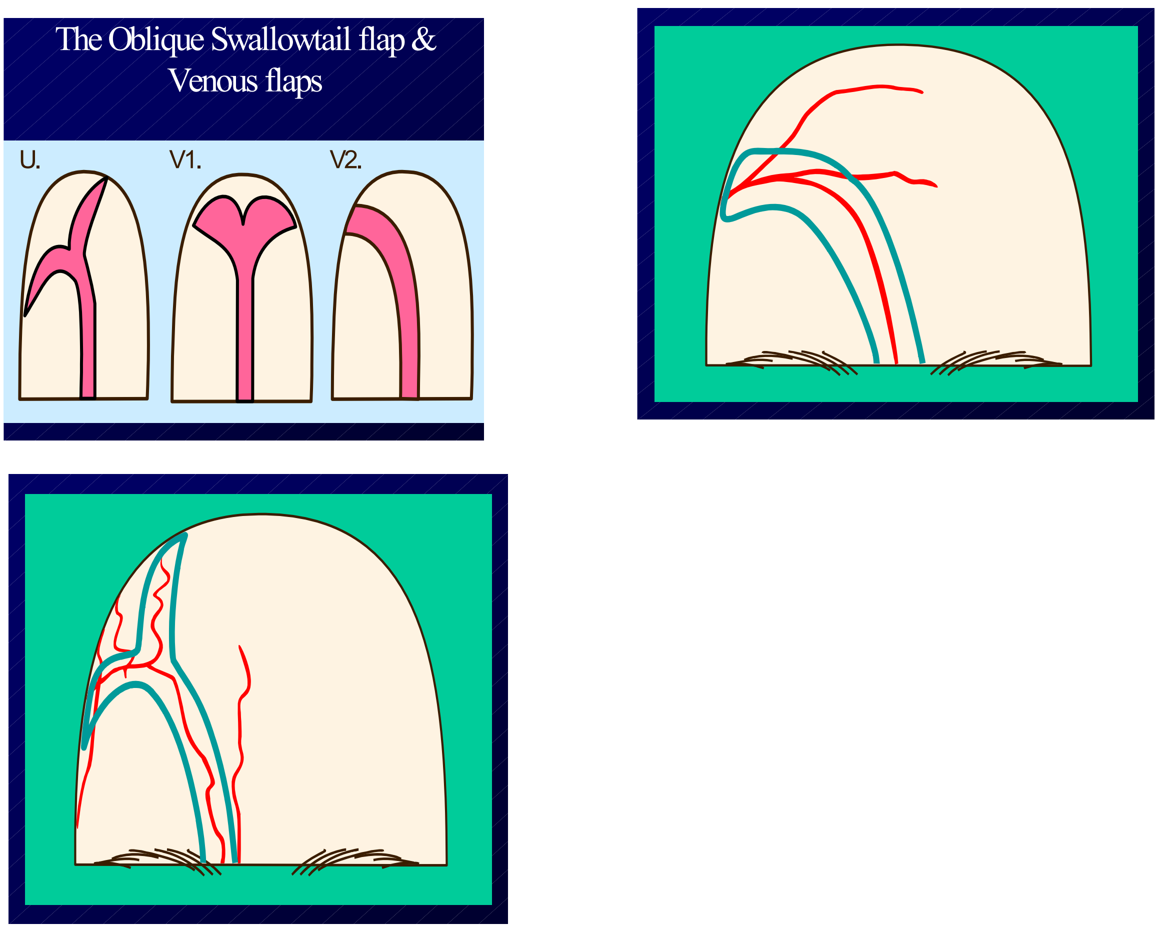


Fig 46. The Oblique Swallow tail flap and venous flap designs

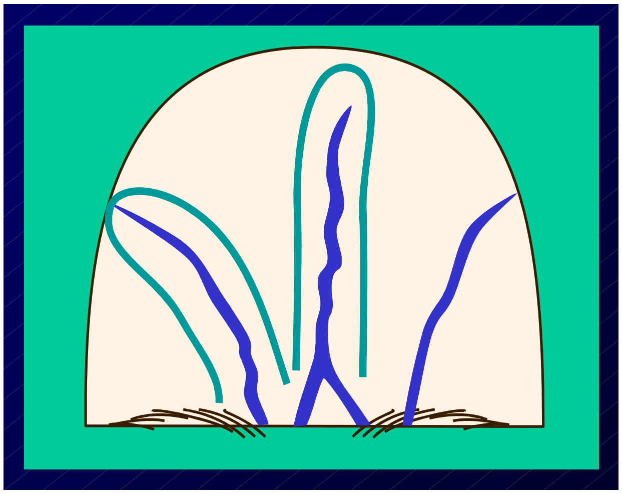


Fig. 47. Potential venous flap patterns

CHAPTER 5

CLINICAL STUDIES IN PLASTIC RECONSTRUCTIVE SURGERY FOR NASAL DEFECTS: APPLICATION OF NASAL FLAPS BASED ON CADAVER BASIC SCIENCE FINDINGS

- **Overview**
- **Illustrations**
- **Integration of cadaveric studies into the clinical setting**
- **Case studies (1-12)**
- **Doppler studies and evaluation**
- **Discussion**
- **Clinical applications: central vein (integrated anatomy)**
- **Potential new flap designs**
- **Conclusions**
- **Recommendations**
- **General summary**

5.1. OVERVIEW OF THE CLINICAL PROBLEM

1. **DEFECTS ADDRESSED**

2. **DISEASES TREATED**

3. **EXISTING PROBLEM WITH CONVENTIONAL FLAPS**

4. **OVERVIEW OF CONVENTIONAL FOREHEAD FLAPS**

5. **CONVENTIONAL FLAP PLANNING:**

    1. **Forehead flap**

    2. **Midline forehead flap**

    3. **Transverse forehead flap**

DEFECTS ADDRESSED:

In the past, reconstruction with forehead flaps have been applied for many facial defects ranging from the cheeks, lips, floor of mouth, tongue, nose and eyelids (Adamson, 1988; Bunkis et al., 1982; Burget, 1988; Chiarelli, 2001; Kavarana, 1975). The defects reconstructed in this study were limited to the cheeks, nose and lower eyelids. Defect zones are reflected in Figure 1.

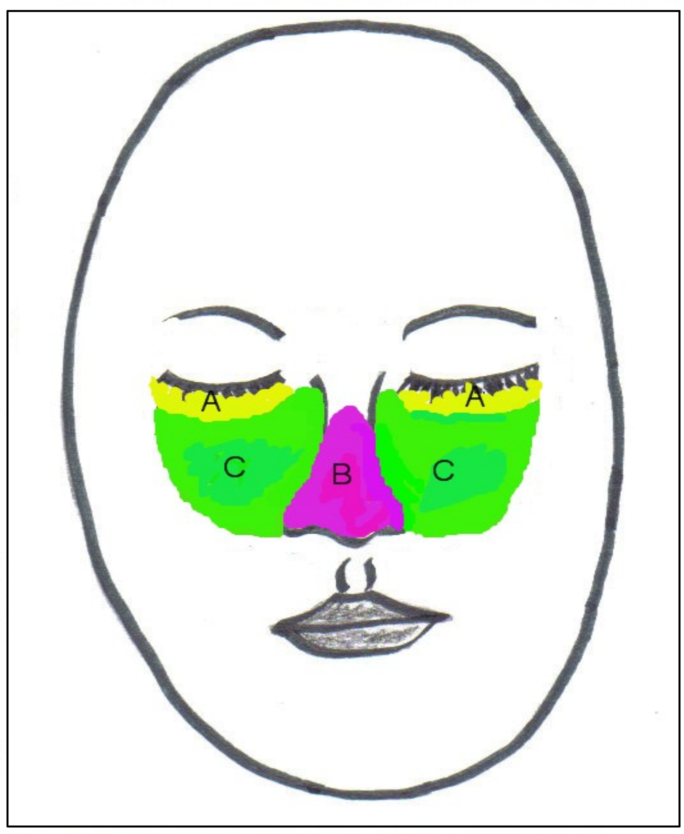


Fig 1. The facial areas where defects were reconstructed are shown: A= **lower eyelid defects (yellow); B= nasal defects (purple**); C= cheek defects (green).

3. <u>DISEASES TREATED</u>

The following **pathologies were** recorded in the **surgical** cases **of this study**:

CANCERS: Melanoma – 1 case

Basal cell carcinoma - 5 cases

TRAUMATIC DEFECTS:

Human bites – 2 cases

Blunt trauma – 1 case

INFECTIVE LESIONS:

Mycobacterium tuberculosis – 1 case

Chronic frontal sinus infection – **1 case**

CONGENITAL:

Forehead cosmetic deformity- 1 case

All cancerous lesions were reconstructed after margins were cleared intra-operatively for cancer deposits by frozen section. The cases of human bites were reconstructed several months after the initial incidents, after all the local infection had resolved. In most cases the patients neglected their wounds and reported late.

In the case of the cutaneous Mycobacterium infection, a full six month course of anti-mycobacterial treatment was completed prior to reconstruction. The chronic frontal sinusitis was caused by underlying metal plates and screws used during a previous frontal bone reconstruction and the wound healed after removal of the plates and screws and frontal sinus obliteration. Autogenous lipofilling and an endoscopic forehead lift were used to address the congenital forehead deformity. This case report was just added as the observations were interesting to plastic and reconstructive surgery.

4. OVERVIEW OF CONVENTIONAL FOREHEAD FLAPS:

Classification of forehead flaps:

A. According to **blood supply**:

- **Axial** pattern flaps
- **Random** pattern flaps
- **Prefabricated**

B. According to method of **movement**:

- Advancement
- Rotation
- Transposition
- Pedicled
- Islanded
- Free

C. According to **composition**:

- Cutaneous
- Myocutaneous
- Osteomyocutaneous
- Periosteal
- Galea-periosteal

Myogalea-periosteal

Prelaminated

Conventional forehead flaps previously described:

A. Axial pattern flaps:

1. Para-median forehead flap based on the supratrochlear artery (Gillies, 1920; Millard, 1974).
2. Transverse/ horizontal forehead flap (McCurdy, 1898; McGregor, 1963) based on the frontal branch superficial temporal artery.
3. Midline forehead flap with broad pedicle (Blair, 1925) based on bilateral supratrochlear arteries and supraorbital arteries.
4. Midline forehead flap with narrow pedicle (Sushruta, 2500BC) based on the angular artery branches.
5. Gillies Up and Down flap (1935) based on both supratrochlear arteries.
6. Converse 'Scalping' flap (1942) based on the "parietal branch" superficial of the superficial temporal artery.

B. Random pattern flaps

1. Sickle flap of New (1945) based on the superficial temporal artery.
2. Frontotemporal flap of Schmidt flap (1952) based on the supratrochlear artery.
3. Other local flaps: Limburg flap, V-Y flap, etc.

4. CONVENTIONAL FLAP PLANNING:

4.1. Paramedian forehead flap:

This flap is considered a novel flap in nasal reconstruction (Grabb & Smith's Plastic Surgery, 5th Ed., 1997, Lippincott-Raven; Plastic Surgery, McCarthy JG, 1990 WB Saunders Company). It was derived from the midline forehead flap, originally described as raised on both supratrochlear vessels, but now only based on one. It has been shown that there is sufficient collateral flow from the angular arteries if the supratrochlear artery is ligated (McCarthy, 1985). **Usually the position of the supratrochlear artery is determined pre-operatively by hand-held Doppler at the medial eyebrow (Shumrick & Smith, 1992). In the absence of a hand-held Doppler the pedicle is placed at where the supratrochlear artery is most likely to be included at the medial eyebrow. A paper template can be used to copy the defect onto the forehead for flap design. A gullwing pattern is commonly used for ease of closure. In the event of short foreheads where additional length of the pedicle is required, the base can be extended to the nasal root. (Grabb & Smith's Plastic Surgery, 5th Edition, 1997) It should be pointed out that even with this extension of the flap inferiorly, the nasal root can still be one centimetre above the medial canthus horizontal line. A narrow pedicled midline forehead flap if based at the medial canthal horizontal inferiorly will therefore have a longer reach than a paramedian forehead flap. The paramedian forehead flap is raised from superior to inferior. The superior third of the flap can be disscted subcutaneously (preserving the subdermal plexus) or at a galeal plane. The flap is rotated from superior on its pedicle**

onto the reconstruction site. Various techniques of donor site closure exist. The flap is sutured in place and usually two weeks later the pedicle is divided and the flap is thinned or refined. A three-stage technique was popularized by Burget and Menick where an intermediate step of flap thinning was introduced at two weeks before final pedicle division at a later stage.

4.2. <u>Midline forehead flap:</u> **The anatomical basis for pedicle modifications of the midline forehead flap is not found in standard plastic and reconstructive surgery text books (Grabb & Smith, 5th Ed, 1997; McCarthy's Plastic Surgery, 1990). Flap length can be gained by tilting the superior part of the flap or by using a back-cut at the pedicle base. No anatomical detail regarding the pedicle base modifications are common in the forehead literature and this problem is erased in the present anatomical study. The supratrochlear artery is described in addition to the angular artery as contributors to the flap arterial inflow. This is true for a broad pedicle where one will sacrifice mobility of the flap in order to secure more arterial inflow.**

Modification of the flap to create an islanded flap for a one-stage reconstruction was not favourable due to commonly encountered venous congestion (Converse and Wood-Smith, 1963). Had the relationship of the central vein been known by then, this problem might not have arised. The

present study of the central vein thus can also improve the reliability of the islanded forehead flap and increase its use.

4.3. Temporal based forehead flap

The *temporal forehead flap* as popularized by McGregor (1963) is widely recognized for its reliability and safety for cheek and oral reconstructions (Adamson, 1988; Bunkis et al., 1982; Burget, 1988; Chiarelli, 2001; Kavarana, 1975; etc.). **This flap has a transverse design on the forehead and can include the entire forehead with its base at the temporal area. The frontal branch of the superficial temporal artery is the source artery. The donor site on the forehead is skin grafted and usually the donor defect is not aesthetically pleasing. It is a reliable flap however and one to consider when other options are not available.**

<u>**ILLUSTRATIVE FIGURES**</u>**:**

Sketch of the aesthetic areas of the nose and face **as seen by the author**.

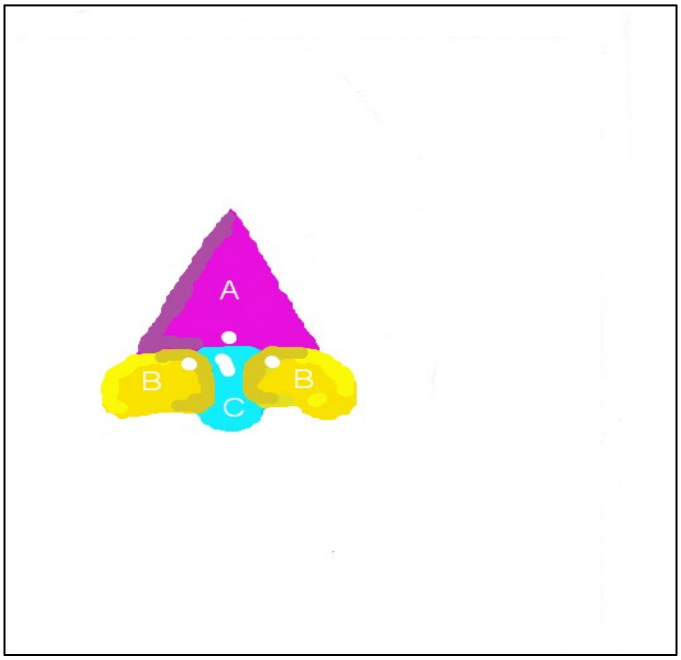


Fig 2. Aesthetics of the nose and face. Anterior view. A= Dorsal triangle (purple) ; B= Alar beans (yellow) ; C= Columella-tip handle (blue).

Fig 3. A hand-held Doppler demonstrating the location of the supratrochlear artery.

<u>AIMS/ OBJECTIVES OF CLINICAL STUDY</u>:

The goal of the clinical study was to apply the knowledge gained from the anatomical investigation of the vascular variations of the forehead, successfully to clinical cases and clinical practice. Also to define the safe landmarks for forehead flap pedicle dissections and secondarily highlight the danger areas for pedicle dissection. Next was to find objective clinical predictors of these variations pre-operatively in order to increase the safety of forehead flaps (Doppler study).

MATERIAL AND METHODS: CLINICAL PHASE-1 STUDY

A. CLINICAL STUDY PLAN:

The clinical study is based on *the anatomical dissections* regarding vasculature as described in the cadaver study (n=30 cadavers). As the results of the dissections became apparent, the surgical techniques could be refined. **All the surgery was performed by the same plastic surgeon (W.G. Kleintjes), except for case 11 where Dr. Deon Van Der Westhuizen performed the endoscopic surgery and the author was an attendant.**

B. PATIENT INCLUSION CRITERIA:

Patients who provided informed consent for reconstruction with forehead flaps as well as patients who had cosmetic surgery in the forehead region were considered candidates for this study. All patients who were considered suitable candidates had to give informed consent (for the phase-1 clinical study) according to the protocol of the study that was approved by the Ethical Committee of Stellenbosch University. The pathology randomized for the reconstructive surgery cases were predominantly skin cancers and tissue loss as a result of infection or human bites. The reconstructive areas were the nose, cheeks, forehead and lower eyelids. The cosmetic surgery cases were forehead lifts and forehead scar revisions.

C. RECONSTRUCTIVE PROCEDURE SELECTION

The flap selection was individualized in each case according to the reconstructive challenges of the defect present and vascular pedicles available. The initial plan was to validate forehead flap designs based on anatomical and cadaveric dissection. New flaps were used. The results of the anatomic study, more importantly led to the development of a new way of planning the 2500-year-old Indian forehead flap, which has lost its appeal. After the refining of this *new method* of forehead flap planning, the subsequent clinical cases were used to delineate the midline forehead flap technique.

D. OPERATIVE MARKING OF THE MIDLINE FOREHEAD FLAP

With the patient sitting upright, the forehead is inspected for the position of the central vein. If the central vein is not visible immediately, the glabella area can be pinched between the thumb and index fingers, in order to engorge the vein. If no vein is visualized, then the flap is designed on the position of the artery or just based on the landmarks given later. A hand-held Doppler probe can be used to locate the STrA or PCA. The central vein is then marked with a dotted ink line from the hairline to the glabella. Next the length of the pedicle is measured to the defect with a piece of string or elastic. This length is marked superiorly from where the defect template design will start. A template of the shape of the defect is made out of sterile paper and placed on the forehead. The marking of the flap is completed with the central vein at the central axis of the flap. Another very important aspect of the flap design, which has never been clarified before, is the exact safety landmarks for the pedicle base design of the Indian forehead flap. The landmark for the inferior extent of the flap is the medial canthal horizontal line. The landmark for the cessation of the pedicle design is the line of the angular artery, which is a vertical line 5 mm medial to the medial canthus. Further lateral extension of the incision at these points will compromise the flap.

E. <u>FLAP ELEVATION</u>

The forehead flap is elevated from superior to inferior on the subgaleal plane and subperiosteal from the supraorbital rim level inferiorly (flap elevation is based on the information gained from the anatomical arm of the study relevant to flap reconstructions in the mid face).

F. FLAP MOBILISATION AND TRANSFER

The flap can be mobilized further by meticulous dissection around the superior border of the pedicle base. A blunt scissors is recommended for this task. Once the flap has been elevated, it is rotated approximately 180 degrees to be placed over the defect.

G. FLAP FIXATION

The flap is sutured in place from inferior to superior with interrupted nylon 6/0 sutures with some interposed horizontal mattress sutures at the alar margins. Care is taken not to fasten the sutures too tight, thus avoiding strangulation of the underlying tissue.

H. DONOR SITE CLOSURE

Extensive mobilization of the forehead is done at a subperiosteal level. The periosteum and gala is scored vertically. An intra-operative method of tissue expansion (exploitation of the visco-elastic properties of skin) is used by the application of sharp tipped towel clamps for five to ten minutes, pulling the skin together. The wound is then sutured in two layers with subcutaneous Vicryl 3/0 and interrupted cutaneous Nylon 6/0 sutures.

I. INTRA-OPERATIVE ASSESSMENT OF FLAP VIABILITY

The viability is assessed **clinically** by checking the distal end of the flap after elevation for bright red subdermal bleeding. Sluggish bleeding could reflect inflow compromise and any pressure at the pedicle base should be relieved. Any bluish discoloration would imply venous compromise of the flap. No objective assessment modalities were deemed necessary for this intra-operative study.

J. IMMEDIATE POST-OPERATIVE FLAP SURVEILLANCE

The flaps were assessed hourly for the first twenty-four hours post-operatively and then two hourly for the next 48-hours by the nursing staff and as often as was possible for the surgeon (Utley et al., 1998). Any white, blue or purple discoloration and change in capillary refill of the flap had to be reported immediately. The nursing staff as well as the patient was asked not to apply any pressure over the pedicle or flaps. Patients were also asked to refrain from smoking pre- and post-operatively.

K. GRADING OF FLAP VIABILITY

Flap viability was evaluated by using the following clinical parameters: edema, venous discoloration, and capillary refill time (Utley et al., 1999).

L. FOLLOW-UP PROTOCOL AND ASSESSMENTS

After flap separation and inset at the second stage operation (two weeks after the first), the patients were discharged and follow-up dates at three monthly intervals were given. Factors assessed were: flap necrosis, subjective aesthetic appearance, patient satisfaction, flap definition and bulkiness (Utley et al, 1998). Secondary revision implied a third stage for either flap defatting or aesthetic improvement by various techniques such as dermabrasion or alar base resections. Patients have now been followed up for a period of 2 years.

M. CLINICAL END-POINT

The clinical end-point was a cosmetically acceptable reconstruction for the patient.

The following factors affected the final cosmetic result: partial flap necrosis and partial flap dehiscence.

1. SUBJECTIVE IMPROVEMENT:
2. OBJECTIVE ASSESSMENT: FLAP VIABILITY (definitions are provided)
3. DEFECT CORRECTED:

TABLE XIV: CLINICAL END-POINTS			
Patient	Subjective improvement	Objective improvement	Defects corrected
1	YES	IMPROVED	YES
2	YES	IMPROVED	YES
3	YES	IMPROVED	YES
4	YES	IMPROVED	YES
5	YES	IMPROVED	YES
6	YES	IMPROVED	YES
7	YES	IMPROVED	YES
8	YES	IMPROVED	YES
9	YES	IMPROVED	YES
10	YES	IMPROVED	YES
11	YES	IMPROVED	YES
12	YES	IMPROVED	YES

N. INTERVENTION AND REMODELLING

Only one forehead flap had partial flap necrosis requiring revision. Flap viability was thus in excess of 90%. The flap was based on the frontal branch of the superficial temporal artery. Interventions required for flap salvage were: application of leeches (*Hirudo Medicinalis*). Other measures that could be used to salvage a failing pedicled flap are: release of any pressure on or around the pedicle, hematoma evacuation and release of any constricting sutures (Utley et al., 1998). To date no revision has been performed for the patient with the partial flap necrosis, although this option was offered and recommended to the patient. The patient is happy two years after surgery and said she would inform us when she feels ready for any revision surgery. Only one flap required revision for excessive bulk of the flap. This was a case of lower lid reconstruction and the debulking was uncomplicated and a good result was obtained.

O. <u>THE DOPPLER STUDY: ASSESSMENT OF VASCULATURE</u>

The reason for the Doppler study was to assess whether it can be used as a preassessment test to demonstrate critical blood supply to the intended flap in order to ensure maximal viability of the flap after transfer. This modality rendered additional objective information for the placement of the pedicle of the forehead flap.

P. <u>ASSESSMENT: INTERVENTION</u>

a. **<u>SYMPTOMATIC IMPROVEMENT</u>:**

All patients experienced symptomatic improvement and objective assessment of the flap reconstruction was also considered important. The subjective assessment post-operatively included the subjective cosmetic improvement and functional improvement.

TABLE XV: GRADING SYSTEM FOR SYMPTOMATIC IMPROVEMENT		
Patient	Subjective	Functional
1	IMPROVED	IMPROVED
2	IMPROVED	IMPROVED
3	IMPROVED	IMPROVED
4	IMPROVED	IMPROVED
5	IMPROVED	IMPROVED
6	IMPROVED	IMPROVED
7	IMPROVED	IMPROVED
8	IMPROVED	IMPROVED
9	IMPROVED	IMPROVED
10	IMPROVED	IMPROVED
11	IMPROVED	IMPROVED
12	IMPROVED	IMPROVED

One average result was observed in the patient who slept on her flap and developed partial flap necrosis.

b. **OBJECTIVE ASSESSMENT:**

Acute post-operative assessment was with surface temperature monitoring. This modality is cheap and effective. The guidelines followed were: recording the patient's core temperature, avoidance of extragenous light-heat sources, dressings should not cover flaps and a constant room temperature and air currents maintained (Plastic Surgery, J.G. McCarthy, W.B. Saunders, 1990; 1: 321).

FLAP GRADING SYSTEM: A scoring system was employed for the objective assessment of flap success. 1 = Venous congestion, 2 = partial or complete necrosis, 3 = complete necrosis and the need for revision = 1.

TABLE XVI: OBJECTIVE FLAP ASSESSMENT				
Patient	Forehead flap(ff)	Venous congestion	Necrosis	Revision
1	midline FF, no CV plan	No	None	No
2	FF	No	None	No
3	midline FF, no CV plan	No	None	No
4	Snake' FF	No	Partial	Planned
5	midlineFF, CV plan	No	None	Debulking
6	Temporal based FF	Yes	None	No
7	midlineFF, CV plan	No	None	No
8	Temporal based FF	No	None	No
9	midline FF,CV plan	No	None	Debulking
10	Limburg Flap	No	None	No
11	Endoscopic surgery	No	None	No
12	MidlineFF,CV plan	No	None	No
TOTAL SCORED =		1	3	2

Statistics of flap viability:

i. Number of temporal based flap necrosis: 1/3
ii. Number of midline forehead flap necrosis: 0/7
iii. Number of flaps requiring revision: Two
iv. Revisions performed: Necrosis = none
v. Bulky flap = two debulkings
vi. Number of patients satisfied after two stages: 11/11

A. TABLE XVII: DEMOGRAPHICS OF THE CLINICAL STUDY									
Patient	**Race**	**Age**	**Sex**	**Pathology**	**Defect**	**Forehead flap(ff)**	**Success**	**Necrosis**	**Revision**
1	White	44	M	Basa cell Ca.	lower eyelid	midline FF, no CV plan	Yes	None	No
2	White	58	F	Basal cell Ca.	nose; cheek	FF	Yes	None	No
3	Black	44	F	Human bite	Nose	midline FF, no CV plan	Yes	None	No
4	Mixed	39	F	Human bite	Nose	Snake' FF	Yes	Partial	Planned
5	White	75	M	Melanoma	lower eyelid	midlineFF, CV plan	Yes	None	Debulking
6	Mixed	84	M	Basal cell Ca.	nose; cheek	Temporal based FF	Yes	None	No
7	White	84	M	Basal cell Ca.	Nose	midlineFF, CV plan	Yes	None	No
8	Mixed	36	M	Frontal Sinus	Forehead	Temporal based FF	Yes	None	No
9	White	64	M	Basal cell Ca.	cheek; nose	midline FF,CV plan	Yes	None	Debulking
10	White	34	F	Basal cell Ca.	Forehead	Limburg Flap	Yes	None	No
11	Mixed	38	M	Deformity	Forehead	Endoscopic surgery	Yes	None	No
12	Black	9	M	Noma; TB	Nose	MidlineFF,CV plan	Yes	None	No

PLASTIC AND RECONSTRUCTIVE SURGERY FOR NASAL DEFECTS:

A. CLINICAL STUDY: INDIVIDUAL CASE REPORTS AND DISCUSSIONS

CASE 1: Mr VT

History: The patient was referred for secondary wider excision of a right medial canthal basal cell carcinoma.

Pathology: Recurrent basal cell carcinoma affecting the medial canthus and lower eyelid.

Reconstructive plan: A secondary midline forehead flap based in the medial canthal area was planned after the margins had been cleared histopathologically.

Discussion: No concept of the arterial supply in the flap existed and it was thought that the supratrochlear artery was the axial vessel. No thought was given to the venous drainage and the central vein concept did not exist. A flap of adequate length was marked, incised, elevated and rotated into the defect at the medial canthus and lower eyelid. A conchal cartilage graft was used for structural support of the lower eyelid. Although the flap didn't have any necrosis, a longer flap length could have been harvested quite confidently had the blood supply been understood better. Had reliable landmarks been known, the flap planning and execution would also have been easier. The pedicle dissection in this case was done carefully, but with a lot of "prayer" since the anatomical detail of this region has not been clarified in the literature.

CASE 2: Mrs O

History: This 58 year old lady presented with a large tumour of the right ala and adjacent cheek.

Pathology: Basal cell carcinoma.

Reconstruction:

The defect was reconstructed after the tumour margins were confirmed to be clear of residual cancer. An ipsilateral forehead flap based on the STrA was designed. The pedicle was long and tilted horizontally with a 'swallow tail' design. The one tail was used for the ala and cheek defects and the other tail for the lining of the ala. An islanded cheek advancement flap was used for the medial cheek defect.

Discussion:

This forehead flap had an excessively long pedicle. Even though the flap extended well into the temporal area no delay was employed. At the time of the reconstruction there was no knowledge of the CV significance. The flap based on the STrA seemed to be the best way to design a forehead flap since the artery was better described in comparison with the arteries from the AA and DNA. This early case is included to show exactly how the approach to *forehead flap design* has evolved as a direct result from the meticulous study of the arterial variations of the forehead and the incidental but important finding of the CV significance.

CASE 3: Mrs M

History: Human bite.

Pathology: Loss of nose tip and partial ala loss.

Reconstruction: Forehead flap

Flap planning:

Vertical and transverse pedicles were considered. A template of the nose was made with sterile fabric (Telfa). This was used mark the flap on the forehead. When the template was placed transversely the alar tips overlapped the hairline superiorly and the eyebrow inferiorly. The transverse design based on the FBSTA was thus not optimal because the forehead was too short in vertical diameter. The vertical design fitted better in the midline. Placing the design directly superior to the STrA the pedicle would have to be longer to reach the nose, than if it were paced more centrally in the forehead. The base of the pedicle was angled to the supero-medial orbit to include the STrA. In this design the ipsilateral central artery from the DNA was most likely cut. This inferior cut of the pedicle allows for easier rotation of the pedicle. Three flap positions were considered in this patient: transverse, medial and paramedian. Three pedicles were considered: FBSTA, CA and STrA. Although one would associate flap position with pedicle position (median flap design with CA, design with STrA; transverse design with FBSTA), this was not so for this case: median flap design with a pedicle base. At the time of doing this operation the anatomy of the CA was not yet clear to us from our dissections. The only fact we relied upon was that the STrA was the larger vessel of the two and would therefore theoretically at that point in time constitute a safer blood supply for the flap. In retrospect, the pedicle base design could also have been placed to include an ipsilateral CA without compromising the result as in the classic median forehead flap. An additional advantage of the medial pedicle design is that it includes one of the central veins of the forehead which drains into the supero-medial orbit. We often use clamps to assist with forehead donor site closure by manipulating the visco-elastic properties (stretch-relaxation) of the skin. The clamps are applied for approximately 5 minutes. The lessons we learnt from this case was that in a short forehead the median forehead flap is for practical purposes the best forehead flap. It is well known that the shortest distance between two points, is a straight line. From our cadaver dissection analysis the CA is consistently present.

CASE 4: Mrs D

History: Human bite

Pathology:

This lady had a loss of the nasal tip and soft triangle bilaterally. Defect was skingrafted at a secondary hospital. Skingraft hyperpigmented and patient was socially embarrassed by her appearance. She considered the proposed reconstruction for 3 months before she gave informed consent.

Reconstruction:

A transverse forehead flap based on the FBSTA was planned. The design of the flap was based upon the underlying arterial axis as identified in all cadaver dissections. The initial plan was to delay the flap under local anaesthetic by incising the margins and elevating the distal third (STrA angiosome). After elevating the distal third of the flap we noted continual bleeding from the distal portion of the flap. As a decrease in blood supply is needed to induce the delay phenomenon, we continued elevating the flap while checking for continued bleeding from the distal portion of the flap. Eventually the whole flap was elevated and there was still bleeding from the distal flap margins. At this point we placed the whole flap in our hands and the temptation of putting this apparently vascular uncompromised flap into its recipient site was too strong to resist. The skin colour of the flap was unchanged and it was bleeding distally. So we went ahead and prepared the recipient site still under local anaesthetic. Before inserting the flap we looked again for any signs of vascular compromise (skin discoloration, decreased subdermal bleeding), but these were absent. After inset of the flap it looked satisfactory. The donor defect was partially closed and the superior part was left open and covered with a moist dressing. She was instructed to sleep in the supine position only. The flap looked normal the next day up to the evening. At 22h00 of that evening we went to visit the patient to check the flap. We found her lying on her stomach face down on a pillow with her head turned slightly to the right. In this position she was lying on her flaps pedicle which was based on her left FBSTA. We couldn't determine exactly how long she was sleeping in that position. We were disturbed to find the flap to be slightly blue over the ala. The next morning, day 2 post-operatively, the flap was slightly more dusky at the alae and columella. We ordered some leeches and there was very mild improvement in the flap colour. This is an established technique to reduce engorgement of a flap. On day 3 post-operatively the alae and columella was a purplish blue and looked slightly worse than on day 2. Again some leeches were applied, but there wasn't a noticeable improvement in the flap. On day 4 the right ala was black and dry. Again a leech was applied, but no significant improvement was noticed. Over the next few days the nasal tip and left ala also underwent dry necrosis.

Management of the partial flap necrosis:

It was tempting to debride the necrotic part of the flap early and resurface the defect with a full thickness skin graft. After 14 days the pedicle was cut and the proximal portion of the flap was sutured back into the forehead defect. The necrotic areas were removed and the wound was dressed and allowed to heal by secondary intention.

Discussion:

The blood supply of this flap was derived from the FBSTA and its anastomosis with the contralateral STrA. When looking at the blood supply more critically, the FBSTA anastomosis with the ipsilateral STrA first, then indirectly with the contralateral STrA. The contralateral STrA is thus the third angiosome. We know from the work of Taylor et al (1990) that to safely incorporate the third angiosome a delay procedure must be used. There is no recognisable venous drainage pattern for this flap. This is another fact in favour of the delay procedure. The purplish blue discoloration in the flap was probably a combination of initial ischemia caused by the patient sleeping on the pedicle and venous congestion. A design variation to consider is one where the base of the flap is made broader, which might improve the venous drainage. When critically looking at this patient some may think that a forehead flap is too big an operation for the relatively small defect. There is no doubt that had the flap completely survived it would have given her the best cosmetic result and that was the ultimate goal for the operation.

Conclusion:

With the clinical experience gathered from this case the 'snake' forehead flap can be used, but a delay procedure must be considered to make the venous drainage more reliable. A central forehead flap was considered a second best option in this patient.

CASE 5: Mr S

History:

This 75 year old man was referred by a colleague for the further treatment of a recurrent malignant melanoma of the right lower eyelid. He had two previous incomplete excisions and there was residual tumour on the medial and lateral margins. After the last excision the defect was closed with a semi-circular advancement flap.

<u>Pathology</u>:

The tumour clinically involved the whole right lower eyelid. A 5 mm margin was excised around the lesion using magnification.

<u>Reconstruction</u>: Midline forehead flap

<u>Flap planning</u>:

Transverse and vertical forehead flaps were considered. The distance from the pedicle base of the transverse flap based on the FBSTA was further from the defect when compared to the midline forehead flap based on the CA. This fact was in favour of the midline forehead flap. In consideration of the venous drainage, a *central vertical vein* was clearly visible. This vein was closely associated with the CA. The FBSTA is not always closely associated with a vein and would require a broad base to allow for better venous drainage. With the above facts in mind, although the transverse flap has a stronger inflow, the midline forehead flap has at least reliable inflow from the CA and more reliable venous drainage. The midline forehead flap also doesn't require as broad a base as the transverse flap. Another consideration of significance to the patient when considering donor site morbidity is the sensory disturbance over the scalp from the surgery. The transverse flap will definitely injure more sensory branches affecting a larger area than the midline forehead flap. The transverse flap can be raised anterior to the frontalis muscle and the temporal branch of the facial nerve can be avoided during dissection. However, the vertical diameter of the forehead will decrease after donor site closure and the ipsilateral eyebrow would be pulled up. Also there remains a risk of accidental facial nerve injury for the transverse flap, whereas the midline forehead flap has no significant risk of adversely affecting the frontalis muscle function, even if the flap is raised down to bone for its whole length. The periosteum was therefore included in the midline forehead flap to provide lining for the new lower eyelid. It was sutured with 6/0 chromic (catgut). The pedicle was cut after two weeks and the flap was set in. At inset of the flap it was left large and bulky to accommodate for postoperative shrinkage. Cosmetic revision of the flap would be done as needed after 3 months.

Summary:

This case illustrates the advantages of *a midline forehead flap* for complete lower eyelid reconstruction in comparison to transverse forehead flaps based on the FBSTA. Choice of this flap was based on the consistency of the central midline vein.

CASE 6: Mr B

History:

84-year old man was referred from a peripheral hospital for the further management of a recurrent basal cell carcinoma of the nose. At this stage the nose was completely eaten away by the tumour and it had spread to the adjacent cheek and deeper nasal septum.

Pathology:

This patient suffered from recurrent infiltrative basal cell carcinoma and had a complete destruction of the external nose.

Reconstruction: Full Transverse Forehead Flap.

Flap planning:

NEW METHOD OF UTILIZING THE TRANSVERSE FOREHEAD FLAP THAT IS CONVENTIONALLY RESERVED FOR CHEEK OR INTRA-ORAL RECONSTRUCTION FOR NASAL RECONSTRUCTION

This flap was not intentionally used for reconstructing the patient's nose, but rather to plug a massive hole left after tumour excision. The technique of flap rolling from the pedicle side towards the nose at flap division to create a nose has never been described before and therefore considered experimental.

Fig 10. Transverse forehead flap before pedicle division and medial rolling of the flap and pedicle to create nasal projection.

Fig 11. An impressive nose was created without skeletal support that maintained its projection to this day (more that a year and a half).

Two flap designs were considered for the nasal reconstruction. The *snake pattern forehead flap* based on the FBSTA and contralateral STrA and a standard full transverse forehead flap was considered. **The patient was not suitable for microsurgical free flap surgery**. The venous drainage of the narrow pedicle in the snake design has been shown to be inadequate unless a delay procedure is employed. The snake forehead flap also relies on a more or less intact nasal framework for support. More tissue can be transferred with the transverse forehead flap. The defect after excision of the tumour was quite large and it was decided to keep the reconstruction simple. With the above factors in mind the standard full transverse forehead flap was chosen. A skin graft provided lining for the flap and the donor defect. No delay was employed and the flap was separated after two weeks. No attempt to provide structural support was made. The pedicle of the flap was tunnelled and a small split thickness skin graft was placed at its base. The flap was purplish blue immediately after initial inset. During elevation of the flap the FBSTA anastomosis with the lateral SOA branch could be seen and was preserved. The flap became progressively more swollen in the postoperative period and at the time of pedicle separation (two weeks later), it looked venous congested and there was elevation present. At the time of flap planning, we considered this flap as a plug in a hole and did not foresee the possibility of making this flap into a nose of any significance. A fact that was most distressing to us, as a cosmetically acceptable reconstruction, is what we always strive for. With the elevation in the flap resulting from venous congestion and peripheral scar contracture, we now, to our surprise, had a plan for creating a significant nose for the patient without adding structural support. During the second operation of flap separation, the flap was cut 4 centimetres lateral to the lateral border of the nose. This excess tissue was rolled medially to give the new nose projection. The rolling of the tissue created a concavity for a nostril. This cavity was made larger by excising some tissue from the flap. On the opposite side another nostril was made by excising a similar triangle of tissue, but because the tissue on this side was not rolled up as much the effect of an overhanging nostril rim was not spectacular. The nasal openings were made more or less 1 centimetre in diameter.

Summary:

This case illustrates the unimaginable making of a significant cosmetically pleasing nose from a full transverse forehead flap without using a skeletal/ cartilaginous framework. At surgery the case was found to be not suitable for a midline forehead flap. Cartilage reconstruction was considered but is reserved if further revision is indicated.

CASE 7: Mr. O.

History:

An 84-year old farmer was referred to us for the management of an ulcerative cancer of his nose.

Pathology:

An ulcerative basal cell carcinoma was diagnosed on biopsy.

Flap planning:

Intra-operative frozen sections were arranged for in theatre, to allow immediate reconstruction. The central vein was used as a landmark for planning the forehead flap. This was based on the principles of cadaveric dissection.

Reconstruction:

The defect after excision was 4 x 3 cm and stretched from the dorsum to the tip and small alar portions bilaterally. A *midline forehead flap* was designed with the CV in the axis of the flap. The pedicle base was high in the supero-medial orbit and the AA to DNA to CA axis was preserved in the pedicle by applying the consistent landmarks developed from the anatomical study.

<u>Discussion</u>:

The entire cosmetic subunits of the nose were reconstructed as this gives a better cosmetic result than a 'patch' reconstruction at the tip of the nose. A very long pedicle was obtained by using the *midline forehead flap design* as well as the placement of the pedicle in the supero-medial orbit just above the medial canthus horizontal line. Although we advised the patient not to wear his glasses it was evident from the red furrow over the pedicle base that he persisted to wear it. Miraculously his flap didn't show any sign of arterial or venous impairment. This is attributable to the excellent blood supply and most importantly the incorporation of the *central vein*.

CASE 8: MR S. J

<u>History</u>: The patient was injured in a car accident in 2004.

<u>Pathology</u>:

He had cranial base and frontal sinus fractures. A large midline forehead and scalp laceration exposed the frontal bone. The neurosurgeon repaired a dural leak using the frontal bone access route and the bone was fixed with titanium plates and screws. The laceration was sutured primarily. The patient developed a fontal sinus leak post-operatively. Initially this was treated conservatively for three months without success.

<u>Reconstruction</u>:

Access to the underlying sinus and plates needed to be planned. The old midline scar and two sinuses were excised. Two hemi-forehead flaps were elevated based on the FBSTA on the left side and on the OBSOA on the right side. An old scar was visible in the right temporal area where the FBSTA was injured. The OBSOA communication with the FBSTA at the LORV was therefore exploited. A W-incision was used in the hairline to make the scars as inconspicuous as possible. It was possible to preserve both STrA's and the adjacent supra-trochlear nerves. The plates and screws were removed and the left frontal sinus duct cleaned and plugged with a myoperiosteal graft from the superior frontal area.

<u>Discussion</u>:

The sensation of the forehead was intact from the first post-operative day. The close association of the STrA and nerve made the preservation easy. There was no flap necrosis and the knowledge of the OBSOA was essential in the success of the right hemi-forehead flap where the FBSTA was previously injured. The assumption of FBSTA was based on the suggestion of extensive overlying scarring.

CASE 9: Mr J. L

<u>History</u>:

A 64-year old man presented with a growing ulcerative lesion of the right cheek. No previous excision or biopsies were done on the lesion.

<u>Pathology</u>:

This patient had basal cell carcinoma on the cheek. Excision was done with a 5 mm margin and a few of the infra-orbital nerve fibres were included with the specimen. The lesion was completely excised. The defect involved the medial lower lid, the lateral nose, the lateral ala and the medial cheek on the right side.

<u>Reconstruction</u>:

A piece of ribbon from a swab was used to measure the defect, the flap and pedicle. Exact measurement of the pedicle was done and a midline forehead flap could be used without superior tilting of the flap. It was difficult to see the CV. The extent of the excision so close to the AA on the right made the only option for the pedicle on the left side where the AA was intact. No scars were seen in the vicinity of the pedicle and hint of a CV could be seen in the superior third of the forehead draining to the left supero-medial orbit.

<u>Discussion</u>:

The exact measurement of the pedicle length and its low rotation point just above the MCH made it possible that the entire flap be designed in the midline of the forehead. This *midline flap* has a satisfactory reach low down on the contralateral cheek. The CV incorporation into the pedicle assured a robust flap. The knowledge of the landmarks for the CA-DNA-AA axis allowed a very narrow pedicle base. The exact pedicle measurement is a result of the cadaver studies (five) for the refinement of the one-stage midline forehead flap. Although the forehead flap is not classically used for medial cheek reconstruction it is a useful and reliable flap and avoids the lower lid ectropion, advancing beard onto the lower lid and nose and the possibility of marginal flap necrosis that cheek advancement flaps might cause. The donor site of the midline forehead flap is also very acceptable.

CASE 10: MRS K (49 years old)

History:

This patient was referred to me by a general surgeon for wider excision of an incompletely excised basal cell carcinoma of the right lateral forehead.

Reconstruction: Limburg Flap. This flap is based on the cadaveric study and more details are given by McClean et al 1982.

Discussion:

The tumour was directly over the oblique branch of the SON (OBSON)(also known as the deep branch). It also overlies the TFA or FBSTA. The most important structure to preserve in this case would be the OBSON. Excision of the lesion was therefore kept anterior to the frontalis muscle as the nerve is deep to the muscle in the forehead. Bleeding from the FBSTA, TFA and AFA can be expected in this area because the blood vessels are anterior to the frontalis muscle.

Further Post-operative surveillance by high frequency ultrasound:

Because the patient was young with the initial reccurance of a basal cell carcinoma (BCC) on examination of the forehead (initially incompletely excised), she was subjected to high frequency dermal ultrasound examination to detect “solar damage”, dermal atrophy and collagen stock loss. Facial scanning was done (non-invasive technique) and the control area was the left forearm (ventral surface). Areas scanned included the forehead, glabellar zone, zygomatic prominences and supralabial zones. Significant solar damage was evident on the forehead and reflects previous solar damage at a very young age. Sun screens and an anti-aging cream, containing vitamin A, were prescribed. This is a unique component to this plastic surgery study, as this is the first case with a BCC undergoing flap surgery and post-flap surveillance for collagen stock loss by high frequency ultrasound. Further details regarding the application of this important technology can be gleaned from: Serup 1992, Gniadecka 2001, Seidenari et al, 1994, Schou et al, 2003, Troilus et al, 2000, Rippon et al, 1998. The typical B-mode scan of the skin shows the membrane, gel, epidermis, subcutis and fascia. Schou et al, 2003, regarding the Dermascan C®, show that the mechanism of imaging is as follows, “It uses an arbitrary scale of intensity of reflection from each pixel ranging from 0 to 255 and pixels with an intensity < 30 have been defined as low echogenic pixels”. The same authors have confirmed that high frequency ultrasound (HFU) is an accurate and reproducible method for assessment of the thickness of the cutis with reported intra- and inter observer variations of < 6% and 2% respectively. From the literature, it appears to be a useful instrument as "the subcutis consists of randomly organised type I and III collagen, fat, polysaccharides and water which is mainly bound to polysaccharides" (Schou et al, 2003). From our experience, in particular this patient with skin cancer, we have found HPU to be a valuable examination because it is non-invasive (Rippon et al, 1998). We think its great value lies in monitoring and evaluating wound healing. We utilized the apparatus in our patient because the Dermascan (Cortex, Denmark) provides two dimensional real time images of skin and wounds (Rippon et al, 1998). "The transducer for this instrument utilizes ultrasound at a frequency of 20mHz, allowing viewing of the tissue down to a depth of approximately 20mm, with a scanning field of 22.4mm" (Rippon et al, 1998). Previous studies show good correlation between HPU and histology (Rippon et al, 1998). The attraction for further use of this apparatus is described by Rippon et al, 1998, of the Wound Healing Institute, Deeside, England, "the technique allows visualization and quantification of wound healing components such as collagen accumulation, re-epithelialization and wound volume". One drawback at the moment is that HFU cannot accurately differentiate between BCC and melanoma. However, of interest to us is that HBU can identify skin atrophy (as in our patient), in addition to evaluating the physical properties of skin. We have used the guidelines of Sedenari et al, of the University of Modena, Italy, who have provided amplitude values for the forehead and cheek. This information has been proven useful in our patient, who has developed BCC in a solar damaged area at a young age. Predicting recurrent cancer or development of new satellite cancers in the region of the local forehead flap is important. The information provided by HBU in this patient allows us to focus post-flap turnover surveillance, assess ongoing or progressive collagen stock loss and the application of anti-aging creams containing vitamin A (Renova®) together with sun screens. In our patient, solar damage and photo-aging is important, due to development of skin cancer at a young age, requiring re-excisional and flap reconstruction. We are sensitive to the development of new cancers in other facial fields of growth such as the ala of the nose, epicanthus of the eye, nasolabial folds and after lip adjustment to the nostril.

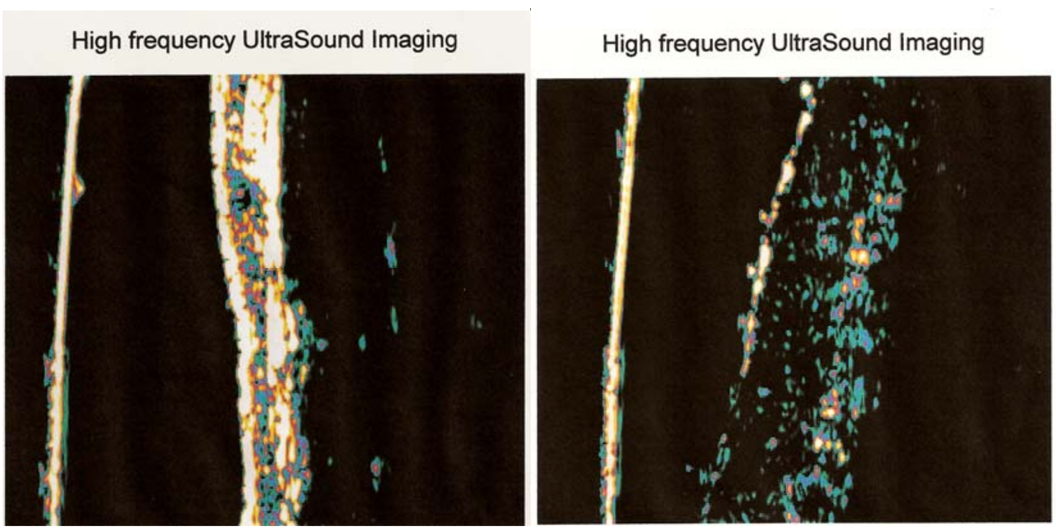


Fig 10: High frequency ultrasound of the skin in this patient showing solar damage. A. Control (forearm), B. Forehead.

CASE 11: Mr D

History: The patient requested brow lift and forehead rejuvenation.

Pathology:

He had low eyebrows and a prominent supra-orbital rim as well as prominent forehead wrinkles.

Reconstruction:

An endoscopic brow lift was done. Lipo-infiltration of autogenous fat harvested from the flanks was used to fill in the supra-orbital concavity.

Discussion:

Placement of incisions in the direction of the hair (vertically) has a smaller chance of neurovascular injury than transverse scars in the frontal area. The plane of dissection for the brow lift has been a hot topic in the past. The subperiosteal plane would avoid injury to the SOA and SON. Visualization via the endoscope is good. The SOA and STrA have muscular and superficial branches and these may be injured during excision of the corrugator muscles. Meticulous dissection can avoid neurovascular injury. Only in a small group of patients a supra-orbital foramen may be present and the origin of the nerve or artery may be higher than the supra-orbital rim. It may be helpful to map the main arteries of the forehead with a hand-held Doppler apparatus in order to avoid vessel injury during lipofilling of the forehead. This is useful to define anatomical landmarks, especially arteries, before using fillers that could compromise blood supply.

CASE 12: M. M

History: This nine year old boy was referred from the Eastern Cape for the management of severe facial disfigurement.

<u>Pathology</u>: Cutaneous tuberculosis was diagnosed at a hospital in the Eastern Cape after the child was suffering from this condition for 5 years. There were bilateral submandibular scars suggestive of Noma and then possibly a secondary tuberculosis infection. Severe facial scarring with bilateral ectropion was present.

<u>Reconstruction</u>:

After 6 months of treatment for the Mycobacterium infection, reconstruction of the lower eyelids and nose was undertaken. A *midline forehead flap* based on the *central vein method* of planning and landmarks developed from the anatomy study was chosen for the nasal reconstruction. Additional procedures had to be done to provide for nasal lining and the creation of a nasal framework for structural support. Local skin turnaround flaps were used for lining. A septal hinge flap was used for dorsal projection and auricular cartilage was used for additional nasal structural support. The contracted lower eyelids were released and lateral based Tripier flaps were set into the defects. The pedicle length was planned as for the one-stage midline forehead flap with no excess length. The *inverted kite design* of pedicle modification was not used, although it could have been employed. The right side of the face was more scarred than the left and the mobility of the adjacent tissue was poor, resulting in a higher ala on the right side. At the second stage operation two weeks later, the superior area of the flap was thinned and most of the pedicle was left intact. No evidence of venous congestion or partial flap necrosis was seen. The child was discharged happy with his new face and eager to attend school like other children.

<u>Discussion</u>:

If a design was considered in this patient, the forehead would have been too short and the flap would have to be tilted or tissue expansion would have been considered. The development of the *one-stage forehead flap* was almost perfected with this case. The courage to perform the inverted Kite design of the pedicle base was lacking because the effect of the scarring and infection on the vasculature was difficult to assess. There wasn't excess pedicle tissue as seen normally with these flaps and minimal tissue was removed at the second stage two weeks later. Pre-operative hand-held Doppler assessment confirmed the presence of a paracentral artery. It was difficult to see the central vein in the lower third of the forehead and compression of the glabella between fingers helped only a little bit. Overall the benefits of the *midline forehead flap* with the refinements developed are:

1) Less tissue is needed for the reconstruction and the pedicle is shorter.

2) No need for tissue expansion.

3) No additional scarring of the forehead by tilted flaps.

4) A midline vertical scar is produced for exceptional scar camouflage.

5) The amount of secondary revisional surgery is minimized.

6) Satisfactory results can be obtained with only two stages for nasal reconstruction.

7) A very robust flap is produced that can withstand mild pressure insults, even in heavy smokers.

A criticism against the flap in this patient is that the nose appears a little bit short and that the initial pedicle could have been a bit longer. One would expect though that with the future facial growth there is the possibility that the nose would have needed a later lengthening procedure in spite of an initial perfect length anyway. The scarring of the cheeks and nasal area caused decreased mobility of the tissue and this was the cause for the shorter appearing nose. The effect of the scarring was thus underestimated and is a lesson taken to heart for similar future reconstructions. The recommendation would be to add at least one centimeter of pedicle length to compensate for local tissue immobility.

APPENDIX 2

CASE STUDIES

CASE 1

EYE LID RECONSTRUCTION WITH MIDLINE FOREHEAD FLAP AND CENTRAL VEIN CONCEPT

Fig 1. Pre-op BCC defect

Fig 2. Midline forehead flap

Fig 3. Cartilage graft

Fig 4. Post-op result

CASE 2

ALA RECONSTRUCTION WITH A PARAMEDIAN FOREHEAD FLAP

Fig 5. Ala defect and 'Swallow tail' flap

Fig 6. Cheek advancement flap

Fig 7. Donor site

Fig 8. Donor site closure

Fig 9. Flap D2 pedicle intact

Fig 10. Pedicle before division and inset

Fig 11. Pedicle division and inset

Fig 12. Final result

CASE 3

NASAL RECONSTRUCTION WITH MIDLINE FOREHEAD FLAP

AND CENTRAL VEIN CONCEPT

Fig 13. Exploring transverse design

Fig 14. Median flap design fits best

Fig 15. Donor site closure,
expansion with clamps

Fig 16. Result prior to donor site closure

CASE 4

NASAL RECONSTRUCTION WITH THE SNAKE FOREHEAD FLAP

Fig 17. Nasal defect

Fig 18. Hand-held Doppler

Fig 19. Snake flap design

Fig 20. Flap pre-elevation

Fig 21. Flap transposition

Fig 22. Active bleeding viability assessed

Fig 23. Flap sutured

Fig 24. Day 1 post: excellent

Fig 25. D 2 Flap ischemia

Fig 26. Leeches applied

Fig 27. Secondary healing

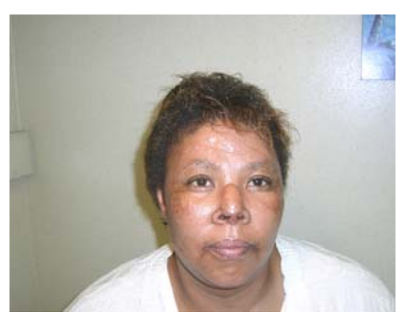


Fig 28. Final result

CASE 5

<u>LOWER LID RECONSTRUCTION WITH MIDLINE FOREHEAD FLAP AND CENTRAL VEIN METHOD</u>

Fig 29. Melanoma recurrence

Fig 30. Lower lid defect

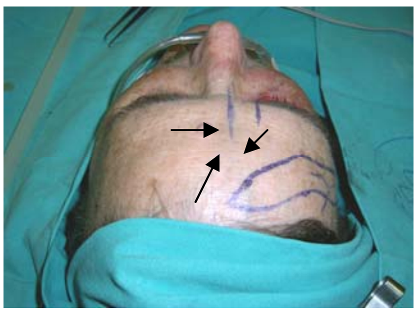


Fig 31. Central vein marked

Fig 32. Flap elevation

Fig 32. Periosteum used as lining

Fig 33. Flap post operatively

Fig 34. Before debulking

Fig 35. Final result

CASE 6

NASAL RECONSTRUCTION WITH A 'ROLLING' TEMPORAL BASED FOREHEAD FLAP

Fig 36. Massive nasal defect

Fig 37. Skin graft defect and forehead

Fig 38. Temporal flap transfer

Fig 39. Day 7 venous congestion

Fig 39. Lateral to medial rolling D 14

Fig 40. Final result

CASE 7

NASAL RECONSTRUCTION WITH A MIDLINE FOREHEAD FLAP AND CENTRAL VEIN METHOD

Fig 41. Nasal defect

Fig 42. Central vein method used

Fig 43. Flap elevation narrow low base

Fig 44. Towel clamp donor site closure

Fig 44. Non-compliance, yet flap survival

Fig 45. Red compression line at pedicle base

Fig 46. Final result D 14

CASE 8

FRONTAL SINUS DEFECT RECONSTRUCTION WITH BILATERAL TEMPORAL HEMI-FOREHEAD FLAPS

Fig 47. Frontal sinus and defects

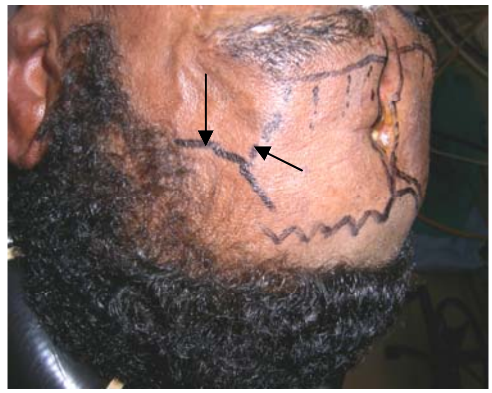


Fig 48. FBSTA and OBSOA marked

Fig 49. Temporal scar; FBSTA poor

Fig 50. Titanium plates the culprits

Fig 51. STrA & N preserved

Fig 52. Sinus defect plugged

Fig 53. Final result

CASE 9

CHEEK RECONSTRUCTION WITH MIDLINE FOREHEAD FLAP AND CENTRAL VEIN METHOD

Fig 54. Doppler confirmation of PCA

Fig 55. Flap elevation; donor site closure

Fig 56. Cheek defect

Fig 57. D 5 post-op

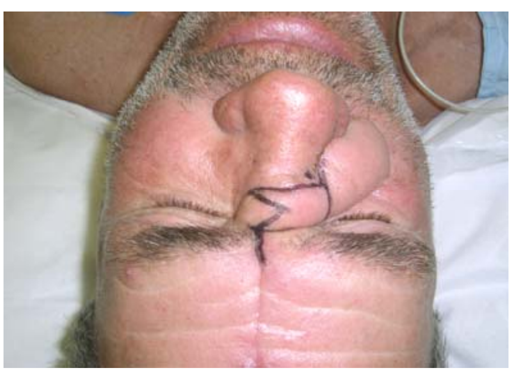


Fig 58. Before pedicle division and inset

Fig 59. Lateral view

CASE 10

<u>LIMBURG FOREHEAD FLAP FOR LOCAL BCC DEFECT RECONSTRUCTION</u>

Fig 60. Flap based on TFA

Fig 61. Anterior view 2weeks post-op

Fig 62. Lateral brow elevation

CASE 11

ENDOSCOPIC FOREHEAD LIFT AND LIPOFILLING

Fig 64. Endoscopic screen/ view

Fig 64. Creating a subperiosteal plane

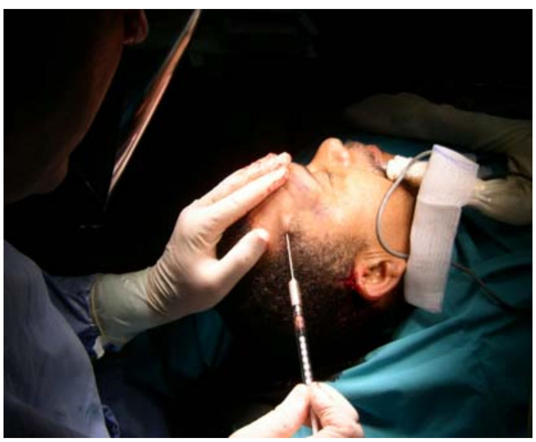


Fig 65. Autogenous lipo-infiltration

Fig 66. Immediate post-operative result

CASE 12

NASAL RECONSTRUCTION WITH THE CENTRAL VEIN MIDLINE FOREHEAD FLAP

Fig 66. Central vein marked

Fig 67. Flap planned around vein

Fig 68. Nasal turnover flaps for lining

Fig 69. Ectropion release

Fig 70. Cartilage grafts

Flap template

Fig 71. Result

Notice little excess pedicle

Fig 72. D 5 post-op

DOPPLER CLINICAL STUDY

- Study design
- Material and Methods
- Relevance for forehead flap transfer
- Conclusions

DOPPLER STUDY DESIGN:

A random prospective study was undertaken at the plastic surgery ward, Tygerberg Hospital, investigating the arteries of the forehead with a Doppler probe (*Mini-Dopplex, Model D900; Hunt Leigh Diagnostics*). No exclusion criteria were included in the study and any patients who volunteered were investigated.

Use of the apparatus is refelected in Fig. 1.

Fig 1. Use of a pocket Doppler to determine the arterial flow in the pedicle area of the desired forehead flap.

MATERIAL AND METHODS:

A hand-held Doppler apparatus was used to note the presence of the following arteries of the forehead: the angular artery and paracentral artery, the dorsal nasal and central artery, the supratrochlear artery and the transverse frontal artery or frontal branch of the superficial temporal artery. KY-jelly was used to lubricate the area to be investigated. The position of the central vein was noted and if it was not visible, compression over the glabella area by pinching the skin against the supero-medial orbital rim, between the thumb and index finger, was applied, to occlude the central vein and make it more visible. Based on the clinical experience gained by cadaver dissections of the arterial supply of the forehead and the knowledge that the central vein is closely associated with the central and paracentral artery, it is a useful landmark to start looking for the central and paracentral arteries. A total of 24 hemi-foreheads (twelve patients) were investigated. No patients were excluded from the study and their ages ranged from 10 to 65 years. The average age was 31.5 years. All the patients were of mixed or Black origin. Demographic data is reflected in Table XIX. Results are shown in Table XX.

TABLE XIII: DEMOGRAPHICS OF DOPPLER STUDY

Patient	Race	Age	Sex	Central Vein	STrV	STrA	TFA/ FBSTA	AA	PCA	DNA	CA	SOA
1	Black	23	F	No	No	yes	Yes	No	No	no	no	no

2	Black	17	F	yes; left	No	yes	Yes	No	Yes	no	no	no
3	Black	65	M	No	No	No	Yes	Yes	No	no	no	no
4	Mixed	16	M	yes; right	yes	yes	Yes	Yes	No	no	no	no
5	Black	14	M	No	No	yes	Yes	No	No	no	no	no
6	Mixed	37	M	yes; right	yes	yes	Yes	No	No	no	no	no
7	Mixed	36	F	yes; right	No	yes	Yes	Yes	Yes	no	no	no
8	Mixed	47	M	yes; left	No	yes	Yes	No	No	no	no	no
9	Black	32	F	yes; left	No	yes	Yes	No	No	no	no	no
10	Mixed	48	F	yes; right	No	No	No	No	No	no	no	no
11	Mixed	33	F	yes; right	No	yes	Yes	No	No	no	no	no
12	Black	10	M	yes; left	No	yes	Yes	Yes	Yes	no	no	no

RESULTS:

TABLE XIX: RESULTS OF DOPPLER STUDY: According to branches		
Branches	Incidence (n=24)	Percentage (%)
TFA	21	49%
STrA	13	30%
PCA	4	9%
AA	5	12%
DNA	0	0%
CA	0	0%

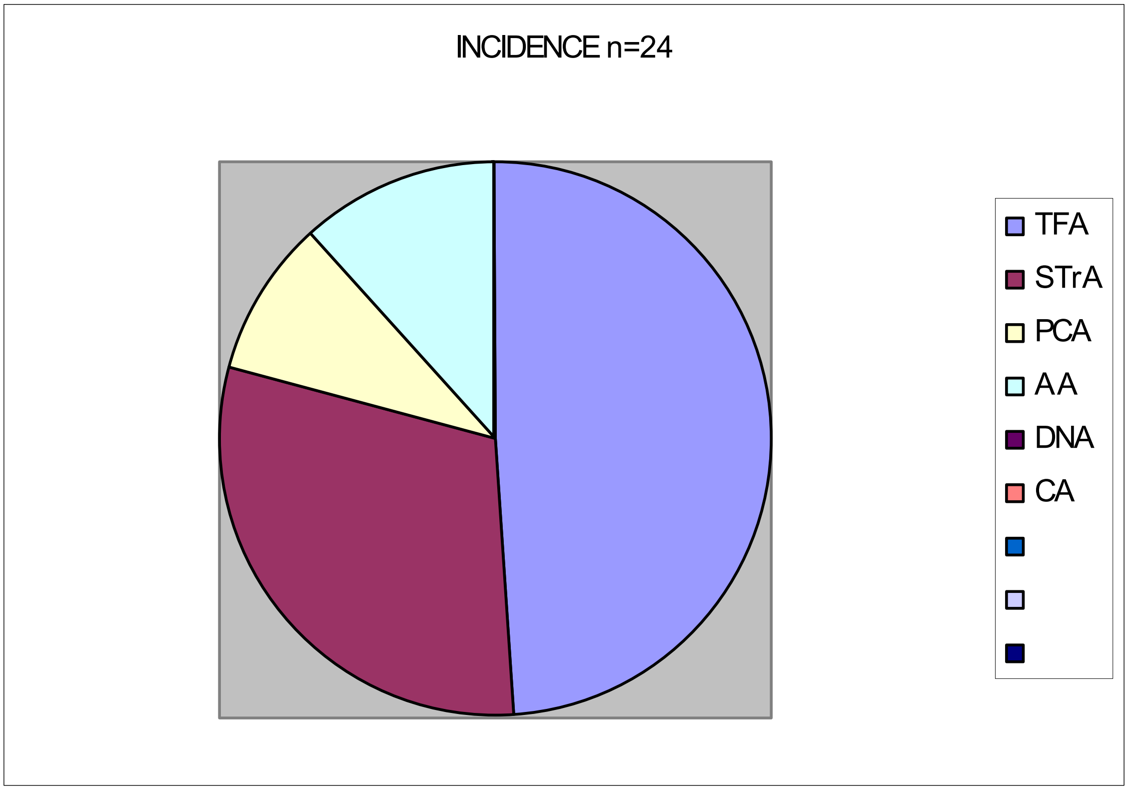


Fig 2. Pie chart illustrating the incidence of arterial branches of the forehead identified by hand-held Doppler apparatus and assessment.

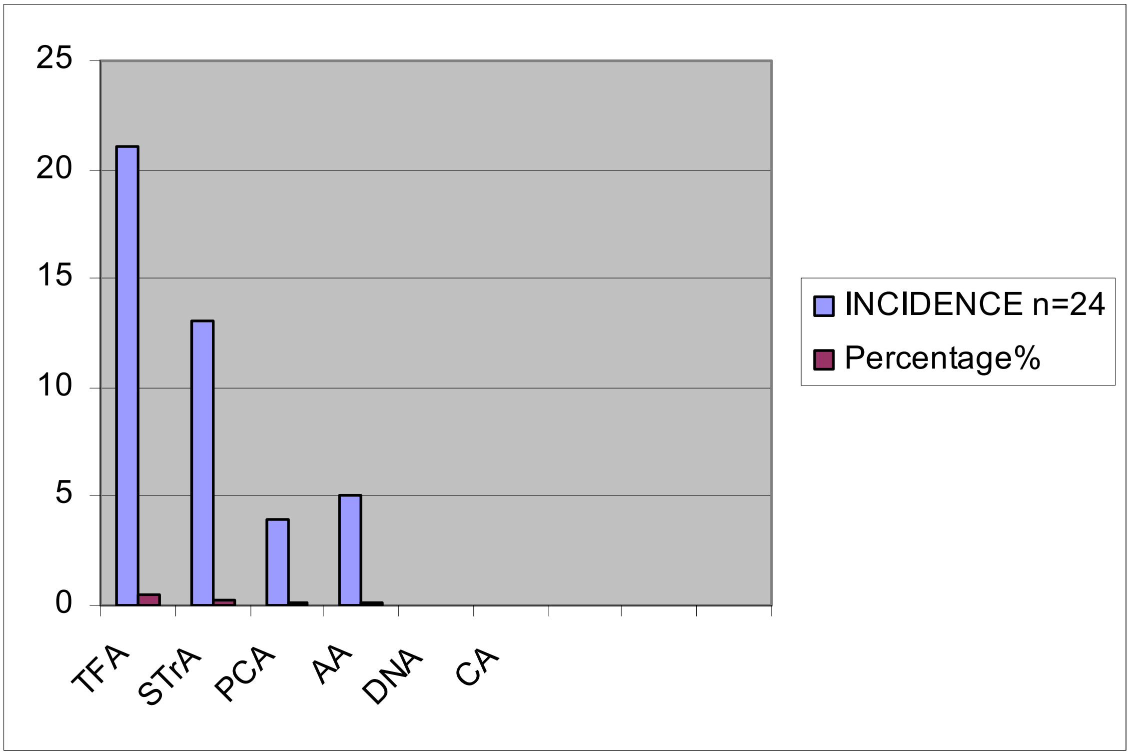


Fig 3. Bar chart of the branches identified with the hand-held Doppler.

The central vein (CV) was seen in nine of the twelve patients. However, the procedure is operator dependent. It was a prominent single unilateral vein in six of the twelve patients. Supratrochlear veins were seen in two of the twelve patients. The frontal branch of the superficial temporal artery is easily palpable without a Doppler, but it may be absent or not enter the forehead. The transverse frontal artery (TFA) was detectable in 21 hemi-foreheads (85 %), while the supratrochlear artery (STrA) was detectable in 13 hemi-foreheads (65 %). The paracentral artery (PCA) was detectable in 4 hemi-foreheads (20 %) and the angular artery (AA) in 5 hemi-foreheads (25 %). When the angular artery was detectable by the Doppler, the paracentral artery was present 3 times (60%).

In all the cases where the paracentral artery was present, the central vein was just medial to the angular artery vertical line. It was difficult to identify the dorsal nasal artery and central artery and it was not found in any patient.

TABLE XX: THE INCIDENCE OF THE FOREHEAD VEINS SEEN		
Branches	Incidence (N =12)	Percentage (%)
CV	9	75%
STrV	2	17%

Fig 4. The central vein and supra-trochlear vein was identified in the 12 patients by macroscopic inspection.

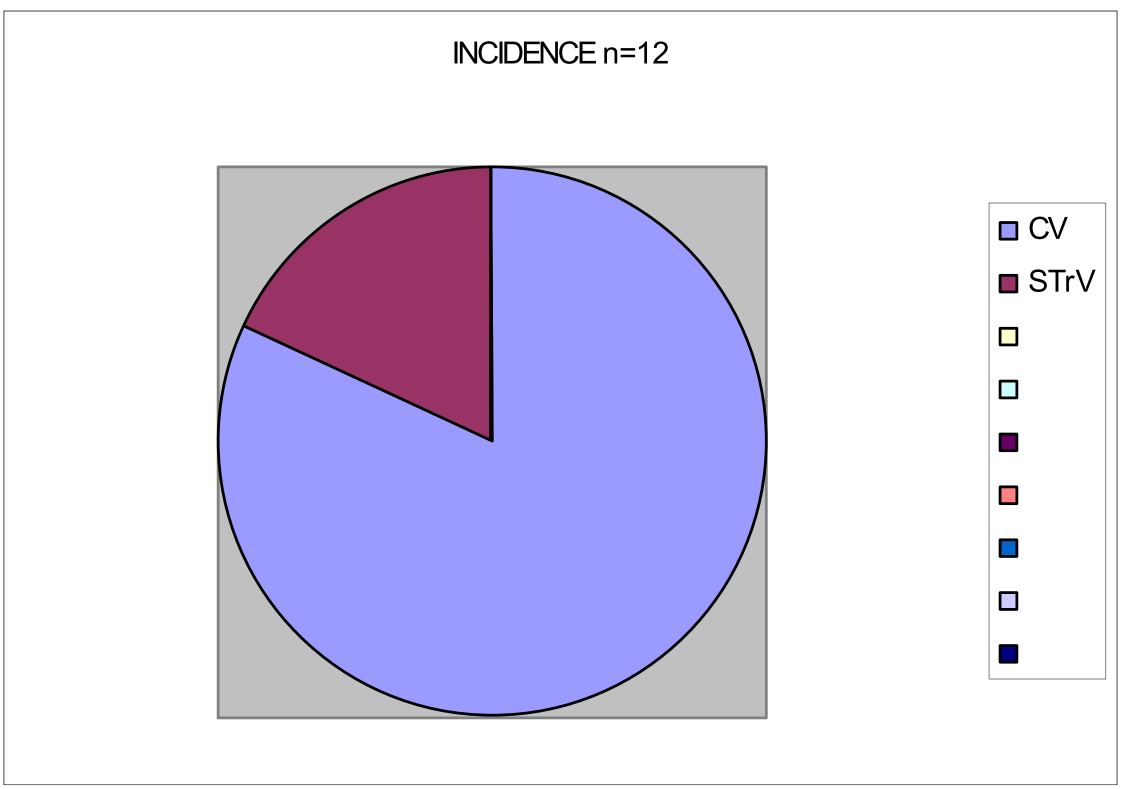


Fig 5. Pie chart of the forehead veins identified macroscopically.

CONCLUSIONS OF DOPPLER STUDIES: END-POINT ANALYSIS

1. The use of pocket Doppler in this setting is operator dependent and not 100% accurate. This is the Achilles heel of this apparatus.
2. This apparatus, although relatively insensitive, could detect small arterial branches in the forehead (sensitivity and specificity were not tested).
3. Regarding the small forehead midline arteries, side branches could be detected in about 50% of cases (range 9 - 49%). Therefore, the apparatus can detect small arteries in the flap pedicle.
4. The hand-held Doppler apparatus is a useful, non-invasive tool to assess vasculature in a proposed forehead flap, but the technique does have limitations. This all has to be taken into account when assessing the patient and doing pre-operative flap planning.
5. **The macroscopic visibility of the central vein is possibily a more sensitive indicator of small artery variations of the central forehead than the hand-held Doppler.**

GENERAL DISCUSSION OF CLINICAL RESULTS AND FLAP SURGERY

- **Overview of flaps**
- **New flaps**
- **New techniques uncluding central vein and pedicle base**
- **Temporal based flaps**

CLINICAL CONTRIBUTION: ORIGINAL FLAPS AND METHODS

ORIGINAL FLAPS

ii. SNAKE FOREHEAD FLAP

iii. SOA FRONTAL BONE FLAP

ORIGINAL METHODS

i. CENTRAL VEIN MIDLINE FOREHEAD FLAP

ii. ROLLING TEMPORAL FOREHEAD FLAP FOR NASAL RECONSTRUCTION

THE ORIGINAL FLAPS AND METHODS DEVELOPED ARE SUMMARIZED.

All the patients felt subjectively that they had an improved result. Subjective improvement was graded (SEE Material and Methods) and 11/12 patients felt that they had good results. Only one patient (8.3%) felt that her result was average. Although her result could be improved by debulking the flap and dermabrasion, she was quite satisfied with the result obtained and was not sure whether she wanted further improvement.

Objective flap assessment (see Material and Methods) showed good results in general and was graded according to venous congestion, partial and complete necrosis and lastly the need for revisional surgery. No complete flap necrosis occurred. With the midline forehead flaps no partial or complete necrosis occurred. One case of partial necrosis occurred in a patient with a temporal based forehead flap ('Snake' forehead flap). The pedicle was based on the patient's favourite sleeping side and she couldn't resist sleeping on the pedicle side. Although this could have been the only factor leading to the 'venous congestion' in the flap, other possibilities such as erroneous flap design must be considered. The fact that the flap was fine for more than 24 hours, and right up until the evening before she slept on the pedicle, makes it a fair assumption that no partial flap necrosis would have occurred, had she not compressed the pedicle as she slept on her arm. Although the venous congestion was mentioned as preceding the partial flap necrosis, ischemic flap injury as a result of arterial compression was probably the causative factor. One could also argue that it was the only factor contributing to the partial flap necrosis, because there wasn't any venous dark blood in the flap when pricked with a needle, and leech therapy was unsuccessful. In fact there wasn't any sign that there was an outflow problem. Therefore, the insult to the flap was most likely ischemic injury related to the compression of the pedicle by the patient. Poor flap choice was considered and possibly the midline flap may have rendered a better result. The incidence of partial or complete necrosis related to flap design can therefore be considered zero. Venous congestion seen with the full transverse forehead flap is a well known occurrence and it is not surprising considering that there is no transverse vein across the forehead (Adamson, 1988; Bunkis et al., 1982; Burget, 1988; Chiarelli, 2001; Kavarana, 1975).

The need for revisional surgery has been included as a measure for objective flap assessment. Only two patients had flap debulking at a later stage. Ultimately, the goal of any reconstruction would be to obtain an excellent result with the minimum amount of operations. It would not be possible to never require revisional operations, as the standard, set by reconstructive surgeons, are quite high and often higher than that of most patients treated. Although two patients could have benefited from revisional surgery, they refused and were satisfied with the result obtained. Two original flaps were developed from the anatomic study of which one was used in clinical practise with partial success. Five original methods of flap design or surgical techniques have been demonstrated. The landmarks developed from the cadaver study have been applied successfully in clinical practise. The forehead landmarks described in Material and Methods is reflected on page 184.

NEW FLAPS:

1) **SNAKE FOREHEAD FLAP**

   The Snake forehead flap was developed based on the arterial axis of the FBSTA/ TFA and transmidline anastomosis with the opposite STrA. This flap is a new method that provides an alternative if central pedicles (based on CA; PCA; STrA) are not available. **It is recommended that a delay procedure be used for this flap and a broader pedicle. This flap is not recommended as a standard option.**

1) **SOA FRONTAL BONE FLAP**

   The close relationship of the SOA to the bone could be exploited by developing a vascularized frontal bone flap for orbital or cranial base defects. Sensation to the central forehead can be preserved by identifying the STrA. As the STrN is closely associated with the artery, dissection should be careful performed close to the artery. To preserve the SON branches dissection should preferably be subperiosteal. If not it will require meticulous dissection not to injure the SON branches. Again the arteries can be used as an intra-operative guide to find the nerves and vice versa. In 2003 Dvivedi and Dvivedi showed a clinical case where a rectangular frontal bone flap was hinged on its periosteal attachments in the reconstruction of a post-traumatic frontal bone deformity. Evidence that the periosteum can be used to create a vascularized frontal bone outer table flap was presented by Cutting et al. (1984) and Casanova et al. (1986).

<u>NEW TECHNIQUES</u>:

4. <u>THE CENTRAL VEIN MIDLINE FOREHEAD FLAP: CENTRAL VEIN AND PEDICLE BASE:</u>

The CV is in most patients easily identified by macroscopic inspection. In some individuals it can be seen from a meter away if the lighting in the room is good. It is often single and more to one side of the midline. By using this prominent central vein as a landmark for pedicle planning one can maintain a narrow pedicle and ensure optimal venous drainage and arterial inflow. The landmarks for identification of the DNA and AA are used to ensure arterial inflow. A pedicle width that extends 5 mm medial and lateral to the CV ensures arterial inflow on both sides of the vein. The STrA can reliably be identified with a hand held Doppler (Yeatts et al, 1996; Shumrick & Campbell, 1998). If it cannot be identified with Doppler (Shumrick; Campbell, 1998), a PCA will more than likely be present. The inferior transverse incision at the base is at the medial canthus horizontal (MCH) line and should not be closer than 5 mm to the MCV line. The robustness of this method is demonstrated by a patient who insisted and persisted to wear his glasses postoperatively, compressing the pedicle at its base, and the flap not even giving a hint of any venous obstruction. The pedicle base at the MCH is quite low and allows one the opportunity of still using the central forehead in the event of a short forehead and thereby negating the need for alternative flap designs or tissue expansion. It must be emphasized that in spite of the venous-arterial relationship in the central forehead not being realised, surgeons throughout the past were able to do forehead flaps successfully, even with pedicles as narrow as 0, 5 cm (Kobayashi, 1995; Eisenberg, 1982; Shumrick, 1998). The significance and identification of the central vein (CV) can certainly help to ensure additional safety against venous congestion and partial flap necrosis (Menick, 2002). It is also an easy way to select the side of the forehead flap and it is easy to design the pedicle around it (Shumrick, 1998; Giugliano, 2004; Boyd, 2000). In the past forehead flaps often had high pedicles and the pedicle had to be divided at a second stage (Gaze, 1980; Kroll, 1981). Daver and Antia (1975) found that the ancient midline forehead flap technique with the pedicle based on terminal branches of the facial artery was as reliable in their hands as it was for thousands of years before (Daver and Antia, 1975). The Indian forehead flap pedicle design as they demonstrated would exactly fit the safe design to provide both arterial inflow and venous drainage as found in this anatomical study. Based on the vessel locations the landmarks provided, that were not specified previously, can be used to avoid vessel injury (Daver and Antia, 1975; Shumrick, 1998; McCarthy, 1985). The pedicle base thus ensures arterial inflow from the AA, DNA, CA and if present the PCA, while venous drainage is via the CA. The base of the flap should thus not extend below the MCH line. This pedicle base design is similar to that used by Labat (1834), Dieffenbach (1845) and others (Campbell, 1997; Mazzola 1983) *with the important difference that the position of the central vein (CV) is considered the axis of the flap design.*

This low pedicle design has the additional advantage that flap length is gained and more essential tissue is utilised compared to a high-based paramedian design. The ancient surgeons were aware of the fact that the shortest distance between two points is a straight line. This is an ideal advantage to exploit in the short forehead and makes certain techniques like temporary alar suspension techniques and *tissue expansion* unnecessary (Campbell, 1997). Friduss et al. (1995) used a mathematic model and computer animation to show that the pedicle base at the medial canthus allowed for a significant increase in flap reach. Even though many modern surgeons studied the forehead anatomy, the ‘obvious’ significance of the CV was not appreciated. When comparing Indian plastic surgeons (Daver and Antia, 1975) understanding of the blood supply of the midline forehead flap with that of their *Western* counterparts, a certain degree of anatomical ignorance is noticeable. It seems like American plastic surgeons continued to believe Blair and Kazanjian's description of the midline forehead flap where the pedicle base is at the eyebrow level and blood supply is from the paired STrA's and SOA's (Gaze, 1980; Campbell, 1987; Park, 2002). Ten years after Daver and Antia's publication in the *Plastic and Reconstructive Surgery Journal*, McCarthy and Lorenz showed that the facial artery via the AA also supplied the median forehead (McCarthy, 1985). This provides further evidence for the origin of the AA. Yet this did not convert the "paramedian forehead surgeons" to the midline (Campbell, 1987; Shumrick, 1998; Millard, 1976; Rohrich, 2004; Menick, 2002; Friduss, 1995).

5. <u>TEMPORAL-BASED FOREHEAD FLAP FOR NASAL RECONSTRUCTION:</u>

Although the rolling transverse forehead flap of nasal reconstruction doesn't rely on structural support, it would be unwise to ignore the importance thereof and nasal valve collapse may result later. If not using additional structural support, this technique should only be used for the patient who has a poor life expectancy or in whom additional surgery would be risky. Lessons learned from the past shouldn't be forgotten.

<u>RECOMMENDATIONS: PREVIOUS FLAPS</u>

The comprehensive findings of this study can now be used to delineate the arterial anatomy of various previously described forehead flaps (Oguz, 1999;

Ohtsuka, 1982; Daver, 1975; Chiu, 1994; Goncalves, 2001). The study also sheds new light on why certain flaps have a greater propensity to develop venous problems (Chiarelli, 2001). The arterial landmarks demonstrated can also be used to refine the execution and application of other existing flaps (Wee, 1991; Dhawan, 1974; Baker, 1985).

RECOMMENDATIONS: FLAP REFINEMENTS

The common practise of de-fatting the superior third of the paramedian forehead flap could be quite risky (from a thrombosis point of view), if not done under direct vision since a variation was seen where the STrA dived to a periosteal level in the MTT of the forehead and continued superiorly at the periosteal level (Friduss, 1995; Quatela, 1995). An increased necrosis risk can be expected in smokers and therefore primary defatting in these patients should be avoided (Sherris, 2002). The mechanism is not fully understood, but thought to be related to secondary polycythaemia and vasoconstriction. Dissecting most of the paramedian forehead flap in the subcutaneous plane is logically also with risk and Ullmann et al. had a six percent incidence of flap necrosis (Ullmann, 2004). If one wants to avoid any possible risk of tip or distal partial necrosis or epidermolysis then the superior flap defatting should not be done at the first stage (Campbell, 1997). In the event of damage to the STrA or absent STrA on Doppler examination, an arterial pulse should be sought more medial in the vertical axis of the angular artery. A PCA will more than likely be present. The

CV can act as an additional guide in flap planning. When the STrA, PCA and CA are not available as pedicles as a result of scars then the FBSTA and TFA can be considered as an alternative pedicle. The SOA branches were on a periosteal level and significant superficial branches were only seen in 2 cadavers. Therefore this artery should rarely be used as basis for cutaneous forehead flaps. The difficulty of identifying this artery with a hand-held Doppler is evidence of its deep anatomical course. The SOA is the primary arterial supplier of the galea-periosteal layer in the forehead and galea-periosteal flaps. Only minor periosteal branches from the STrA were seen not extending more than 3 cm superiorly. Sensation to the central forehead can be preserved by identifying the STrA. As the STrN is closely associated with the artery, dissection should be careful and performed close to the artery. To preserve the SON branches, dissection should preferably be subperiosteal. If not, it will require meticulous dissection not to injure the SON branches. Again the arteries can be used as an intra-operative guide to find the nerves and vice versa.

EVOLUTION OF FOREHEAD FLAP SURGERY:

Forehead flaps started with the *midline forehead flap* and then later the paramedian forehead flap became the standard flap based on a known vessel. Now we have gone back to the midline forehead flap, but theoretically it is "better" than before and possibly superior to paramedian forehead flap.

FOREHEAD FLAP EVOLUTION IN NASAL RECONSTRUCTION			
Surgeon	**Year**	**Technique**	**Advantages**
Sushruta	500 BC	Midline forehead flap, no vein concept	reliable, necrosis seen though
Gillies; Millard	1966; 1976	Paramedian forehead flap, arterial based	reliable, minimal necrosis seen
Kleintjes	2005	Midline forehead flap, central vein concept	reliable, no necrosis even with pedicle insult shorter pedicle needed; one-stage possibility

Other new contributions such as the *“Snake” forehead flap* and *“Rolling” temporal forehead flap* are alternative options for nasal reconstruction when standard flaps are not available.

CONCLUSIONS:

Clinical outcome end-point analysis

1. The clinical results obtained were subjectively and objectively compared to other gold standards in the literature. A low complication rate related to flap planning was obtained. The *central vein method* of midline forehead planning has produced clinically robust flaps.

2. <u>One-stage end-point analysis</u>: The search for a <u>one-stage method</u> for of performing a forehead flap has facilitated the *midline forehead flap* based on the central vein and artery with an inverted kite pedicle base modification.

3. <u>End-point analysis: Novel flaps based on anatomy:</u> New forehead flaps and techniques introduced were based on the results of the cadaveric dissection study.

4. <u>End-point analysis: Clinical recommendations based on anatomy</u>: Clinical recommendations regarding previous flaps, defatting, alternative pedicles and forehead sensation were all based on the results of the cadaveric anatomical study.

5. <u>End-point analysis: alternative nasal reconstructive options</u>: The armamentarium of the plastic and reconstructive surgeon has been increased further by novel alternative nasal reconstruction options: the *“snake” forehead flap* and *“rolling” temporal forehead flap*.

<u>End-point analysis: Forehead flap based on central vein</u>: Finally, the “missing link” of the understanding of the midline forehead flap has been defined. The <u>central vein concept</u> gives a fresh and scientific approach to the midline forehead

flap and can be seen as a re-appreciation of our most ancient plastic and reconstructive operation. Although the ‘missing link’ was a coincidental finding, it is one of great clinical importance.

CHAPTER 6

GENERAL SUMMARY

- **Relevance of research project**
- **Problem addressed (anatomical, clinical)**
- **Relevance of new terminology**
- **Flap feasibility**
- **Clinical proof –of-principle**
- **Recommendations**

RELEVANCE:

There is no in-detailed study in the literature that was performed specifically to investigate the vascular variations of the forehead. This information is vital for the development of different flaps in the forehead and also provides a detailed road map for surgeons.

PROBLEM ADDRESSED:

The variations of the arteries of the central and lateral forehead have been poorly and inaccurately described in the literature. A vast amount of information was gained researching the arterial variations of the forehead related to plastic and reconstructive surgery. The arterial variations of the forehead have now been highlighted.

ANATOMY TEXT BOOKS:

Inconsistent descriptions and depictions of the vascular anatomy of the forehead in these text books can know be upgraded and revised.

FOREHEAD FLAPS USED:

The following flaps were used:

Midline forehead flap based on the central vein, central artery and paracentral artery from the angular artery.

Complete transverse forehead flap based on the frontal branch of the superficial temporal artery (FBSTA).

Hemi-forehead transverse flap, based on the FBSTA.

"Snake" forehead flap based on the FBSTA.

<u>DISSECTIONS</u>:

Dissections were done investigating the arterial variations of the forehead and showed the feasibility and potential clinical applicability of the forehead flap arteries. Venous drainage was also investigated, especially data capture on the central vein.

<u>NEW TERMINOLOGY</u>:

"New terminology" had to be introduced to describe the findings of the anatomic study.

<u>CASE STUDIES</u>:

Clinical cases were studied to refine the *anatomical knowledge gained from the dissections* and to incorporate it into flap planning and execution. An evolution in surgical technique based on the anatomy findings is demonstrated.

<u>DOPPLER STUDY</u>:

A hand-held Doppler study assessment was conducted to substantiate the pre-operative diagnosis of the arterial variations of the forehead. Pitfalls are highlighted.

<u>INTEGRATION</u>:

The results of the anatomy study (cadaver and histology) and the clinical study (Doppler and clinical cases) have been successfully integrated and incorporated into clinical practise. The cadaveric study is now evidence-based.

GENERAL CONCLUSIONS:

1) FLAP FEASABILITY:

The central vein method of planning the midline forehead flap has been shown in six (6) consecutive cases to be robust compared to any previous descriptions of a forehead flap. Even compression of the pedicle by wearing glasses in an elderly heavy smoker was not enough to cause a hint of venous congestion or partial flap necrosis. Alternative forehead flap designs such as the *snake forehead flap* design can be used, because of adequate arterial flow, but then with a *delay procedure* to compensate for the lack of venous drainage in the flap when a narrow base is used.

2) CLINICAL ANATOMY & PROOF-OF-PRINCIPLE THAT ANATOMY DISSECTIONS ARE CORRECT

The Doppler study has confirmed the presence of the arterial variations. The case reports show that the evolution of the planning of the midline forehead flap (from arterial to venous as a primary consideration) that is based on the anatomy study result is clinically accurate and successful.

RECOMMENDATIONS:

1) Revision of anatomy and surgery text books regarding the blood supply terminology of the forehead.
2) Acceptance of new terminology for accurate description of arterial variations of the forehead (to benefit surgeons planning reconstructive nasal flaps.

3) The midline forehead flap based on the central vein can be considered as the primary consideration for reconstruction of the nose and the flap.
4) Delay procedures for narrow-based flaps, where primary venous drainage from a known venous axis is not included (especially if Doppler assessment is not available).
5) Further investigation of: 1) the supraorbital bone flap; 2) one-stage midline forehead flap without island; 3) periosteal incisions to avoid supraorbital nerve injury.

SUMMARY OF ORIGINAL CONTRIBUTIONS FROM THIS STUDY:

New anatomy terminology: The naming of unnamed vessels and structures.

Vessels (8):

i. Central artery

ii. Central vein

iii. Paracentral artery

vi. Ascending temporal artery

vii. Transverse frontal artery

viii. Ascending temporal arteries

ix. Descending temporal arteries

Arterial branches (6):

i. Lateral rim branch of the supra-orbital artery

ii. Medial deep branch of the supra-orbital artery

iii. Vertical deep branch of the supra-orbital artery

iv. Oblique deep branch of the supra-orbital artery

v. Oblique branch of the supratrochlear artery - new.

vi. Brow artery originating from either the STrA or the SOA

Structures/ Vessel patterns (5):

i. Supra-orbital ligament

ii. Genu of the supra-trochlear artery

iii. The plane difference and branching pattern of the superficial vs. the deep branches of the supra-orbital artery.

iv. Illustration of the above fig. 24. = original.

v. Arteries never described before: median artery and median vein.

Arterial variations (many):

i. Most arterial variations described of the FBSTA are new

ii. Most arterial varations of the STrA are new

iii. Most arterial variations of the SOA are new

iv. All arterial variations of the PCA are new

v. All variations of the CA are new

vi. Characteristics of the CV are all original

Central forehead venous drainage:

i. Mostly to left orbit.

Nerves:

i. Naming the SON branches according to their corresponding arteries.

ii. V-periosteal incision.

Histology:

i. New information that has been forthcoming from this study is the arterial luminal sizes, which are not unexpected. There is however nothing reported in the anatomy or histological literature referring to arteriolar diameter in the glabella region.

Landmarks:

i. Classification of transverse thirds of the forehead for flap planning.

ii. Horizontal and vertical lines for flap planning. MCV, MCH, LORV.

New flaps:

i. SOA- bone flap.

ii. Snake forehead flap: An example of what not to do. A learning experience.

New technical flap refinements:

i. The central vein forehead flap: advantages in robustness, good reach, low pedicle and narrow pedicle. Exclusion of the STrA. Flap centered on vein unlike other forehead flap methods where primary planning is based on the arteries!

ii. One-stage forehead flap with pedicle: The inverted- kite modification.

iii. Islanded forehead flap: Possible repopularization of old flap with central vein.

iv. Dangers of primary fat defatting with regards to STrA variations.

v. Standardization of midline forehead flap pedicles based on the constant landmarks provided for safe dissection.

vi. Rolling temporal flap for nasal reconstruction.

Arterial axis for flap planning:

i. AA – DNA- CA

ii. AA- PCA

iii. AA- CB- CA

iv. OBSOA- TFA- STrA

v. OBSOA- AFA

vi. AFA- TFA- STrA

Nasal aesthetic reconstructive units:

i. Dorsal triangle

ii. Alar beans

iii. Tip-lobule handle

Hand-held Doppler value in:

i. Arterial variation identification of the small arteries of the forehead previously unnamed.

ii. Comparison of hand-held Doppler to macroscopic central vein visibility as indicator of central forehead arterial variations.

Dermascan: Technology in objective flap changes.

Reference value:

i. Many incidences of flap necrosis in the literature can be explained based on the detailed anatomy of this dissertation (**Lari et al 2002, Potparic et al 1996, Fukuta et al, 1994**).

ii. Better analysis of the bloodsupply of existing flaps is possible **(Shiau-Duen-hern 2003).**

iii**.** Other surgeons can avoid pitfalls of new flap inventions on the forehead (i.e. the Snake forehead flap), because of a detailed anatomic reference and recommendations from this dissertation.

iv. Some original previous flap designs by the author are validated by this study and many are not. Ironically the concept of a central venous flap investigated turned out to be arterial as well as venous, and of practical value.

CHAPTER 7

LITERATURE CITED

- **General: (1963 – 2005)**
- **By Theme**
  - **History of flaps and flap reconstruction**
  - **Forehead anatomy**
  - **Venous drainage**
  - **Brow and forehead lifts**
  - **Clinical application**
  - **Vasculature**
  - **Terminology**
  - **Plastic reconstructive surgery**

Adamson J.E. Nasal reconstruction with expanded forehead flap. *Plast Reconstr Surg* 81 (1): 12-20, 1988.

Adamson PA, Cormier R, McGraw BL. The coronal forehead lift-modifications and results. *J of Otolaryngology* 21 (1): 25-29, 1992.

Adamson PA, Johnson CM, Anderson JR et al. The forehead lift. *Arch Otolaryngol* 111: 325-329, 1985.

Adamson PA. The forehead lift: refinements in surgical technique. *J Otolaryngol* 15 (2): 89-93. 1986.

Adant J-Ph, Bluth Fr. Endoscopic Supraorbital Nerve Neurolysis. *Acta Chir Belg* 99: 182-184, 1999.

Ahn M.S., Monhian N, Maas C.S.; Bikhazi N.B. Total Nasal Reconstruction with Alloplastic and Autogenous Grafts. *Facial Plastic Surgery* 14(2):145-150, 1998.

Appiani E, Delfino MC. Observations on orbitofrontal rhytidectomy. *Ann Plast Surg* 18 (5): 398-408, 1987.

Baker SR, Swanson NA. Oblique Forehead Flap for Total Reconstruction of the Nasal Tip and Columella. *Arch Otolaryngol* 111: 425-429, 1985.

Blandini D., Tremolada C., Beretta M. et al. Use of a versatile axial dorsonasal musculocutaneous flap in repair of the nasal lobule. *Plast Reconstr Surg* 98 (2): 260-268, 1996.

Boyd CM, Baker SR, Fader DJ, et al. The Forehead Flap for Nasal Reconstruction. *Arch Dermatol* 136: 1365-1370, 2000.

Bunkis J, Mulliken J.B., Upton J, Murray J.E. The evolution of techniques for reconstruction of full-thickness cheek defects. *Plast Reconstr Surg* 70 (3): 319-327, 1982.

Burget GC, Menick FJ. Nasal support and lining: the marriage of beauty and blood supply. *Plast Reconstr Surg* 84 (2): 189-203, 1989.

Burget B.L, Panje W.R, Krause C.J. Nasopharyngeal defect following fibrosarcoma excision and radiotherapy. *Head & Neck Surgery*: 350-356, 1988.

Campbell J. The Temporary Alar Suspension Stitch: A Refinement in Forehead Flap Reconstruction of Nasal Defects. *Plast Reconstr Surg* 100 (6): 1587-1591, 1997.

Capizzi PJ, Eaves FF, Kane WJ. The Transverse Orbicularis Oculi Myocutaneous Flap: its use as nasal lining. *Plast Reconstr Surg* 104: 1419-1423, 1999.

Carstens M.H, Greco R.J, Hurwitz D.J, Tolhurst D.E. Clinical Applications of the Subgaleal Fascia. *Plast Reconstr Surg* 87 (4): 615-626, 1991.

Cheney ML, Gliklich R, Li KK et al. Midforehead Incision: An Approach to the Frontal Sinus and Upper Face. *J Craniofacial Surg* 6 (5): 408-411, 1995.

Chiarelli A, Forcignano R, Boatto D. et al. Reconstruction of the inner canthus region with a forehead muscle flap: a report of three cases. *Br J Plast Surg* 54: 248-252, 2001.

Chiu LD, Hybarger CP, Todes- Taylor N. The Rintala flap revisited. *Plast Reconstr Surg* 94 (6): 801-807, 1994.

Converse J.M., Wood-Smith D. Experiences with the forehead island flap with a subcutaneous pedicle. *Plast Reconstr Surg* 31 (6): 521-527, 1963.

Conway H, Stark R and Kavanaugh JD. Variations of the Temporal Flap. Plast Reconstr Surg.1952: 9:410-423.

Cormack G.C., Lamberty B.G.H. *The arterial anatomy of skin flaps*. 2nd Ed 7: 443-454, 1994.

Cruse CW, Blevins PK, Luce EA. Naso-ethmoid-orbital fractures. *J Trauma* 20 (7): 551-556, 1980.

Daver B.M.; Antia N.H. Large Indian Forehead Rhinoplasty. *Plast Reconstr Surg* 55 (3): 360-362, 1975.

De Greef A. Tissue expansion in reconstructive surgery. *S Afr Med J* 69: 705-707, 1986.

Dhawan IK, Aggaewal SB, Hariharan S. Use of an off-midline forehead flap for the repair of small nasal defects. *Plast Reconstr Surg* 53 (5):537-539, 1974.

Dvivedi S, Dvivedi J. Unusual Frontal Bone Injury. *Nepal Medical College Journal* 5 (2): 105-106, 2003.

Dzubow LM. Subcutaneous Island Pedicle Flaps. *J Dermatol Surg Oncol* 12 (6): 591-596, 1986.

Eiseman G . Bitemporal Flap Reconstruction of Forehead. *J Trauma* 18 (5): 355-359, 1978.

Eisenberg I. History of Medicine. A history of rhinoplasty. *SA Med J* 62: 286-292, 1982.

Fan J. A New technique of scarless expanded Forehead Flap for Reconstructive Surgery. *Plast Reconstr Surg* 106(4): 777-785, 2000.

Fatah M.F. Innervation and functional reconstruction of the forehead. *Br J Plast Surg* 44: 351-358, 1991.

Field L. The Midline Forehead Island Flap. *J Dermatol Surg Oncol* 13 (3): 243-246, 1987.

Field L. Two-stage correction of depressed glabella and nasal root scar contracture utilizing subcutaneous tissue advancement flaps and a layered soft tissue/procerus muscle transposition flap. *J Dermatol Surg Oncol* 19: 962-966, 1993.

Friduss M, Dagum P, Mandych A et al. Forehead Flap in Nasal Reconstruction. *Otolaryngol Head & Neck Surg* 113 (5): 740-747, 1995.

Fukuta K., Potparic Z., Sugihara T, et al. A Cadaver Investigation of the Blood Supply of the Galeal Frontalis Flap. *Plast Reconstr Surg* 94(6): 794-800, 1994.

Gaze N.R. Reconstructing the nasal tip with a midline forehead flap. *Br J Plast Surg* 33: 122-126, 1980.

Giugliano C, Andrades PR and Benitez S. Nasal reconstruction with a forehead flap in children younger than 10 years of age. *Plast Reconstr Surg* 114 (2): 316-325, 2004.

Gniadecka M. et al. Age-related diurnal changes of dermal oedema: evaluation by high-frequency ultrasound. *Br J Dermatol* 131: 849-855, 1994.

Gniadecka M. et al. Effects of aging on dermal echogenicity. *Skin Research and Technology* 7: 204-207, 2001.

Goncalves J, Patenotre P, Martinot V. et al. Rhinopoieses etendues par lambeau frontal. A propos d'une serie de 12 cas chez l' adulte. *Ann Chir Plast Esthet* 46: 617-628, 2001.

Grab and Smiths, *Plastic Surgery*, 5th ed., Lippincot-Raven, 1997.

Gupta AK, Jacob V. An absolute milieu for primary bone graft in aesthetic nasal reconstruction. *Aesth Plast Surg* 28: 177-180, 2004.

Guzel MZ. The turnover subdermal-periosteal median forehead flap. *Plast Reconstr Surg* 111 (1): 347-350, 2003.

Gruber S, Papp C and Maurer H. Reconstruction of damaged forehead with bilateral fasciocutaneous temporal V- Y advancement island flaps. *Br J Plast Surg* 52: 74-75, 1999.

Guerrerosantos J. Frontalis musculocutaneous island flap for coverage of forehead defect. *Plast Reconstr Surg* 105 (1): 18-22, 2000.

Haeseker B. Digital surgery revisited. On the origin of digital transfer in reconstructive surgery. *Br J Plast Surgery* 52: 495-499, 1999.

Hauben D.J. Ernst Blasius's contribution to Plastic Surgery. *Plast Reconstr Surg* 74 (4): 561-570, 1984.

Hayes H. Skin Marking for the forehead flap. *Plast Reconstr Surg* 80 (4): 649, 1987.

Herbert D. A subcutaneous pedicled cheek flap for reconstruction of alar defects. *Br J Plast Surg* 31: 79-92, 1978.

Hinderer UT, Urriolagoitia F, Vildosola R. The Blepharo-periorbitoplasty: Anatomic basis. *Ann Plast Surg* 18 (5): 437-453, 1987.

Houseman ND, Taylor GI, Pan W. The Angiosomes of the Head and Neck: Anatomic Study and Clinical Applications. *Plast Reconstr Surg* 105 (7): 2287-2313, 2000.

Ida N and Ogawa T. Exposed artificial bone in the forehead covered with a transverse orbicularis oculi myocutaneous flap. *Scand J Plast Reconstr Surg Hand Surg* 36: 100-102, 2002.

Ida N, Ohsumi N, Tonegawa M, et al. Repair of full thickness defect of the nose using an expanded forehead flap and a glabella flap. *Aesth Plast Surg* 25: 15-19, 2001.

Iida N, Ohsumi N and Tsutsumi Y. Use of bilateral retroangular flaps for reconstruction of the glabella and nose. *Br J Plast Surg* 54: 451-454, 2001.

Islam ZU, Rehman HU and Khan MD. Frontalis muscle flap advancement for jaw-winking ptosis. *Ophthal Plast and Reconstr Surg* 18 (5): 365-369, 2002.

Iwahira Y, Maruyama Y. Expanded unilateral forehead flap (Sail Flap) for coverage of opposite froehead defect. *Plast Reconstr Surg* 92 (6): 1052-1056, 1993.

Kaufman AJ. Moulage: The Forehead flap. *Dermatol Surg* 29: 402-403, 2003.

Kiyokawa K, Tai Y, Inoue Y et al. Efficacy of temporal musculopericranial flap for reconstruction of the anterior base of the skull. *Scand J Plast Reconstr Hand Surg* 34: 43-53, 2000.

Knize D. Reassessment of the Coronal Incision and Subgaleal Dissection for Foreheadplasty. *Plast Reconstr Surg* 102 (2): 478-489, 1998.

Kobayashi S, Yoza S, Kakibuchi M et al. Retroauricular Hairline Flap Transfer to the Face. *Plast Reconstr Surg* 96 (1): 42-47, 1995.

Kroll SS. Forehead flap Nasal Reconstruction with Tissue Expansion and Delayed Pedicle Separation. *Laryngoscope* 99: 448-452, 1989.

Lascaratos J, Cohen M, Dionyssios V. Plastic Surgery of the Face in the Fourth Century. *Plast Reconstr Surg* 102(4): 1274-1280, 1998.

Leonard A.G. The Forehead flap: minimising the secondary defect by preservation of the frontalis muscle. *Br J Plast Surg* 36: 322-326, 1983.

Mangold U, Lierse W, Pfeifer G. Die Arterien der Stirn als Grundlage des Nasenersatzes mit Stirnlappen. Acta Anat.1980; 107: 18-25.

Marten T. Hairline Lowering during Foreheadplasty. *Plast Reconstr Surg* 103 (1): 224-236, 1999.

Mazzola R.F., Marcus S. History of Total Nasal Reconstruction with Particular Emphasis on the Folded Forehead Flap Technique. *Plast Reconstr Surg* 72 (3): 408-414, 1983.

McCarthy JG, Lorenc ZP, Cutting C, et al. The Median Forehead Flap Revisited: The Blood Supply. *Plast Reconstr Surg* 76 (6): 866-869, 1985.

McCarthy J. E. *Plastic Surgery* W.B. Saunders, 1990.

Menick FJ. A 10-year experience in nasal reconstruction with the three-stage forehead flap. *Plast Reconstr Surg* 109 (6): 1839-1855, 2002.

Menick F.J. Nasal Reconstruction: Forehead Flap. *Plast Reconstr Surg* 113 (6): 100-111, 2004.

Metaf M. et al. Tissue expansion assisted by prefabrication of the forehead flap for nasal reconstruction. *Ann Plast Surg* 34: 478-487, 1995.

Micalli G. The Italian Contribution to Plastic Surgery. *Ann Plast Surg* 31: 566-571, 1993.

Millard D.R., Jr. Reconstructive Rhinoplasty for the lower two-thirds of the nose. *Plast Reconstr Surg* 57 (6): 722-728, 1976.

Miller P.J., Hertler C., Alexiades G. et al. Replantation of the Amputated Nose. *Arch Otolaryngol H&N Surg* 124: 907-910, 1998.

Mommaerts MY, Abeloos JSV, De Clercq CAS et al. Brow and forehead lift with cranial suspension. *J Cranio-Maxillo-Facial Surg* 22: 33-36, 1994.

Morris S.F., MacGill K.A., Taylor G.I. Scalp replantatio by arterialised venous network flow-through. *Br. J. Plast Surg* 45: 187-192, 1992.

Motomura H, Muraoka M, Nose K. Eyebrow reconstruction with intermediate hair from the hairline of the forehead on the pedicled temporoparietal fascial flap. *Ann Plast Surg* 51 (3): 314-318, 2003.

Muenker R. Nasal reconstruction with Tissue Expansion. *Facial Plast Surg* 5 (4): 328-337, 1998.

Oguz YM. Axial pattern bilobed flap for the reconstruction of the midline forehead defects. *Plast Reconstr Surg* 103(2): 737, 1999.

Ohtsuka H, Miki Y; Shioya N. Trilobed flap in facial reconstruction. *Br J Plast Surg* 35: 493-497, 1982.

Ortiz-Monasterio F. Labat and the three-lobed forehead flap. *Plast Reconstr Surg* 73 (4): 705, 1984.

Park D, Ahn K, Han D et al. Blepharoptosis Repair by Use of Superiorly Based Muscle Flaps. *Plast Reconstr Surg* 101 (3): 592-603, 1998.

Park SS. The Single-Stage Forehead Flap in Nasal Reconstruction. An alternative with advantages. *Arch Facial Plast Surg* 4: 32-36, 2002.

Park SS. Reconstruction of Nasal Defects Larger than 1,5 Centimeters in Diameter. *The Laryngoscope* 110: 1241-1250, 2000.

Pinho C, Choupina M, Silva P et al. A new retroauricular flap for facial reconstruction. *Br J Plast Surg* 56: 599-602, 2003.

Pittet B, Montandon D. Nasal Reconstruction in Children: A Review of 29 Patients. *J Craniofacial Surg* 9 (6): 522-528, 1998.

Potenza A.D., Glenn R.C. Late conversion of a broad-pedicled forehead flap to an island flap. *Plast Reconstr Surg* 63 (4): 271-272, 2002.

Potparic Z, Fukuta K, Colen LB et al. Galeo-pericranial flaps in the forehead: a study of blood supply and volumes. *Br J Plast Surg* 49: 519-528, 1996.

Psillakis JM, Rumley TO, Camargos A. Subperiosteal Approach as an Improved Concept for Correction of the Aged Face. *Plast Reconstr Surg* 82 (3): 383-392, 1988.

Quatela VC, Sherris DA, Rounds MF. Esthetic Refinements in Forehead Flap Nasal Reconstruction. *Arch Otolaryngol Head Neck* 121: 1106-1113, 1995.

Ramirez O. Endoscopic Techniques in Facial Rejuvenation: An Overview. Part 1. *Aesth Plast Surg* 18: 141-147, 1994.

Riggio E. The Hazards of Contemporary Forehead Flap and Neck Dissection in Smokers. *Plast Reconstr Surg* 112 (1): 346-347, 2003.

Riggio E, Spano A, Nava M. The Forehead Zygomatico-Orbital Artery-Based Island Flap. *Plast Reconstr Surg* 115 (1): 226-233, 2005.

Rippon M.G. et al. Ultrasound assessment of skin and wound tissue: comparison with histology. *Skin Res and Techn* 4: 147-154, 1998.

Rudolph R, Miller SH. Do Forehead Lifts Lift or Unfurl? *Aesth Plast Surg* 16: 1-9, 1992.

Rohrich RJ, Griffin JR, Ansari M, et al. Nasal Reconstruction- Beyond Aesthetic Subunits: A 15- year Review of 1334 Cases. *Plast Reconstr Surg* 114 (6): 1405-1406, 2004.

Sakai S, Soeda S and Matsukawa A. Refinements of the island median forehead flap for reconstruction of the medial canthal area. *J Dermatol Surg Oncol* 15: 524-530, 1989.

Savage R.C. Orbital Exenteration and Reconstruction for Massive Basal Cell and Squamous Cell Carcinoma of Cutaneous Origin. *Ann Plast Surg* 10 (6): 458-466, 1983.

Sawhney C.P. Use of a larger midline forehead flap for Rhinoplasty, with new design for donor site. *Plast Reconstr Surg* 63 (3): 395-397, 1979.

Schou A.J. et al. Ultrasound of skin in prednisone-induced short term growth suppression. *J Pre Endoc and Metals* 16: 973-980, 2003.

Schwartz R.J., MacDonald M. A rationale approach to nasal reconstruction in leprosy. *Plast Reconstr Surg* 114 (4): 876-882, 2004.

Seidenari S. et al. Echographic evaluation with image analysis of normal skin: variations according to age and sex. *Skin Pharmacol* 7: 201-209, 1994.

Serup J. Ten years' experience with high-frequency ultrasound examination of the skin: development and refinement of technique and equipment. *Ultrasound in Dermatology* 41-53, 1992.

Sherris DA, Fuerstenberg J, Danahey D, et al. Reconstruction of the Nasal Columella. *Arch Facial Plast Surg* 4: 42-46, 2002.

Shipkov H, Anastassov YK, Djambazov KB, et al. Nasal reconstruction with vascularized forehead flap. *Folia Medica* XLVI, 1/2004: 23-25, 2004.

Shumrick K.A., Campbell A. Improvements in forehead flap design for nasal reconstruction. *Facial Plast Surg* 14(2): 165-171, 1998.

Shumrick K.A, Smith T.L. The Anatomic Basis for the design of forehead flaps in Nasal Reconstruction. *Arch Otolaryngol Head Neck Surg* 118: 373-379, 1992.

Siegle RJ. Forehead Reconstruction. *J Dermatol Surg Oncol* 17: 200-204, 1991.

Stucker FJ, Daube D. Reflections on Total and Near Total Nasal Reconstruction. *Facial Plast Surg* 10 (4): 374-381, 1994.

Summers BK and Siegle RJ. Facial cutaneous reconstructive surgery: Facial Flaps. *J Am Acad Dermatol* 29: 917-941, 1993.

Sykes J and Tolen CJ. Subtotal nasal reconstruction using a bi valved forehead flap. *Facial Plast Surg* 14 (2): 159-164, 1998.

Terranova W. The use of periosteal flaps in the scalp and forehead reconstruction. *Ann Plast Surg* 25 (6): 450-456, 1990.

Thatte R.L., Raibagkar S.C., Mokal N. Two flag flaps based on the supratrochlear vessels for nasal reconstruction. *Ann Plast Surg* 25 (3): 197-199, 1990.

Tolhurst DE, Carstens MH, Greco RJ et al. The surgical anatomy of the scalp. *Plast Reconstr Surg* 87 (4): 603-612, 1991.

Troilius A. et al. Ultrasound investigation of portwine stains. *Acta Derm venereal* 80: 196-199, 2000.

Ullmann Y, Fodor L, Shoshani O et al. A novel approach to the use of the forehead flap for nasal reconstruction. *Plast Reconstr Surg* 115 (5): 1372-1378, 2004.

Utley D.S., Koch R.J., Good R.L. The Failing Flap in Plastic and Reconstructive Surgery: Role of the Medicinal Leech. *Laryngoscope* 108 (8): 1129-1135, 1998.

Vural E, Batay F, Key JM. Glabella frown lines as a reliable landmark for the supratrochlear artery. Otolaryngol. *Head & Neck Surg* 123 (5): 543-546, 2000.

Wee SS, Hruza GJ, Mustoe TA. The Frontonasal Flap: utility for lateral nasal defects and technical refinements. *Br J Plast Surg* 44: 201-205, 1991.

Wild T., Hybarger P. Triple-Flap Technique for Reconstruction of Large Nasal Defects. *Arch Facial Plast Surg* 3:17-21, 2001.

Winslow C.P., Cook T.A., Burke A, Wax M.K. Total Nasal Reconstruction. Utility of the free radial fascial flap. *Arch Facial Plast Surg* 5, Mar/Apr: 159-163, 2003.

Yeatts RP, Newsom RW, Matthews BL. Doppler-assisted vascular pedicle flaps in eyelid and periorbital reconstruction. *Arch Ophthalmol* 114: 1149-1152, 1996.

Yenidunya MO. Axial pattern bilobed flap for the reconstruction of the midline forehead defects. *Plast reconstr Surg* 103 (2): 737, 1999.

Zilinsky I, Winkler E, Jacobs DI, et al. Turnover Forehead Flap Combined with Composite Crus of Helix Graft for Partial Nasal Reconstruction. *Plast Reconstr Surg* 103 (1): 192-196, 1999.

Zuker R.M., Capek L., De Haas W. The expanded forehead scalping flap: A new method of total nasal reconstruction. *Plast Reconstr Surg* 98 (1): 155-159, 1996.

CRITICAL LITERATURE BY THEME:

A. HISTORY OF NASAL RECONSTRUCTION:

Ahn M.S., Monhian N, Maas C.S.; Bikhazi N.B. Total Nasal Reconstruction with Alloplastic and Autogenos Grafts. *Facial Plastic Surgery* 14(2):145-150, 1998.

Bunkis J, Mulliken J.B., Upton J, Murray J.E. The evolution of techniques for reconstruction of full-thickness cheek defects. *Plast Reconstr Surg* 70 (3): 319-327, 1982.

Corso P.F. Variations of the arterial, venous and capillary circulation of the soft tissues of the head by decades (methyl methacrolate). *Plast Reconstr Surg* 27: 160-171, 1961.

Eisenberg I. History of Medicine. A history of rhinoplasty. *SA Med J* 62: 286-292, 1982.

Haeseker B. Digital surgery revisited. On the origin of digital transfer in reconstructive surgery. *Br J Plast Surgery* 52: 495-499, 1999.

Hauben D.J. Ernst Blasius's contribution to Plastic Surgery. *Plast Reconstr Surg* 74 (4): 561-570, 1984.

Hayes H. Skin Marking for the forehead flap. *Plast Reconstr Surg* 80 (4): 649, 1987.

Lascaratos J, Cohen M, Dionyssios V. Plastic Surgery of the Face in the Fourth Century. *Plast Reconstr Surg* 102(4): 1274-1280, 1998.

Mazzola R.F., Marcus S. History of Total Nasal Reconstruction with Particular Emphasis on the Folded Forehead Flap Technique. *Plast Reconstr Surg* 72 (3): 408-414, 1983.

Micalli G. The Italian Contribution to Plastic Surgery. *Ann Plast Surg* 31: 566-571, 1993.

Ortiz-Monasterio F. Labat and the three-lobed forehead flap. *Plast Reconstr Surg* 73 (4): 705, 1984.

Thatte R.L., Raibagkar S.C., Mokal N. Two flag flaps based on the supratrochlear vessels for nasal reconstruction. *Ann Plast Surg* 25 (3): 197-199, 1990.

Winslow C.P., Cook T.A., Burke A, Wax M.K. Total Nasal Reconstruction. Utility of the free radial fascial flap. *Arch Facial Plast Surg* 5, Mar/Apr: 159-163, 2003.

B. <u>FOREHEAD ANATOMY AND FLAPS:</u>

Adamson J.E. Nasal reconstruction with expanded forehead flap. *Plast Reconstr Surg* 81 (1): 12-20, 1988.

Adamson PA. The forehead lift: refinements in surgical technique. *J Otolaryngol* 15 (2): 89-93, 1986.

Adamson PA, Cormier R, McGraw BL. The coronal forehead lift-modifications and results. *J of Otolaryngology* 21 (1): 25-29, 1992.

Appiani E, Delfino MC. Observations on orbitofrontal rhytidectomy. *Ann Plast Surg* 18 (5): 398-408, 1987.

Baker SR, Swanson NA. Oblique Forehead Flap for Total Reconstruction of the Nasal Tip and Columella. *Arch Otolaryngol* 111: 425-429, 1985.

Blandini D., Tremolada C., Beretta M. et al. Use of a versatile axial dorsonasal musculocutaneous flap in repair of the nasal lobule. *Plast Reconstr Surg* 98 (2): 260-268, 1996.

Boyd CM, Baker SR, Fader DJ,et al. The Forehead Flap for Nasal Reconstruction. *Arch Dermatol* 136: 1365-1370, 2000.

Burget GC, Menick FJ. Nasal support and lining: the marriage of beauty and blood supply. *Plast Reconstr Surg* 84 (2): 189-203, 1989.

Burget B.L, Panje W.R, Krause C.J. Nasopharyngeal defect following fibrosarcoma excision and radiotherapy. *Head & Neck Surgery* 350-356, 1988.

Campbell J. The Temporary Alar Suspension Stitch: A Refinement in Forehead Flap Reconstruction of Nasal Defects. *Plast Reconstr Surg* 100 (6): 1587-1591, 1997.

Carstens M.H, Greco R.J, Hurwitz D.J, Tolhurst D.E. Clinical Applications of the Subgaleal Fascia. *Plast Reconstr Surg* 87 (4): 615-626, 1991.

Cruse CW, Blevins PK, Luce EA. Naso-ethmoid-orbital Fractures. *J Trauma* 20 (7): 551-556, 1980.

Dhawan IK, Aggaewal SB, Hariharan S. Use of an off-midline forehead flap for the repair of small nasal defects. *Plast Reconstr Surg* 53 (5):537-539, 1974.

Daver B.M.; Antia N.H. Large Indian Forehead Rhinoplasty. *Plast Reconstr Surg* 55 (3): 360-362, 1975.

Dvivedi S, Dvivedi J. Unusual Frontal Bone Injury. *Nepal Medical College Journal* 5 (2): 105-106, 2003.

Dzubow LM. Subcutaneous Island Pedicle Flaps. *J Dermatol Surg Oncol* 12 (6): 591-596, 1986.

Fan J. A New technique of scarless expanded Forehead Flap for Reconstructive Surgery. *Plast Reconstr Surg* 106(4): 777-785, 2000.

Fatah M.F. Innervation and functional reconstruction of the forehead. *Br J Plast Surg* 44: 351-358, 1991.

Field L. The Midline Forehead Island Flap. *J Dermatol Surg Oncol* 13 (3): 243-246, 1987.

Field L. Two-stage correction of depressed glabella and nasal root scar contracture utilizing subcutaneous tissue advancement flaps and a layered soft tissue/procerus muscle transposition flap. *J Dermatol Surg Oncol* 19: 962-966, 1993.

Friduss M, Dagum P, Mandych A et al. Forehead Flap in Nasal Reconstruction. *Otolaryngol Head & Neck Surg* 113 (5): 740-747, 1995.

Fukuta K., Potparic Z., Sugihara T, et al. A Cadaver Investigation of the Blood Supply of the Galeal Frontalis Flap. *Plast Reconstr Surg* 94(6): 794-800, 1994.

Gaze N.R. Reconstructing the nasal tip with a midline forehead flap. *Br J Plast Surg* 33: 122-126, 1980.

Giugliano C, Andrades PR and Benitez S. Nasal reconstruction with a forehead flap in children younger than 10 years of age. *Plast Reconstr Surg* 114 (2): 316-325, 2004.

Gruber S, Papp C and Maurer H. Reconstruction of damaged forehead with bilateral fasciocutaneous temporal V-Y advancement island flaps. *Br J Plast Surg* 52: 74-75, 1999.

Guerrerosantos J. Frontalis musculocutaneous island flap for coverage of forehead defect. *Plast Reconstr Surg* 105 (1): 18-22, 2000.

Herbert D. A subcutaneous pedicled cheek flap for reconstruction of alar defects. *Br J Plast Surg* 31: 79-92, 1978.

Houseman ND, Taylor GI, Pan W. The Angiosomes of the Head and Neck: Anatomic Study and Clinical Applications. *Plast Reconstr Surg* 105 (7): 2287-2313, 2000.

Ida N and Ogawa T. Exposed artificial bone in the forehead covered with a transverse orbicularis oculi myocutaneous flap. *Scand J Plast Reconstr Surg Hand Surg* 36: 100-102, 2002.

Ida N, Ohsumi N, Tonegawa M, et al. Repair of full thickness defects of the nose using an expanded forehead flap and a glabella flap. *Aesth Plast Surg* 25: 15-19, 2001.

Iida N, Ohsumi N and Tsutsumi Y. Use of bilateral retroangular flaps for reconstruction of the glabella and nose. *Br J Plast Surg* 54: 451-454, 2001.

Islam ZU, Rehman HU and Khan MD. Frontalis muscle flap advancement for jaw-winking ptosis. *Ophthal Plast and Reconstr Surg* 18 (5): 365-369, 2002.

Kiyokawa K, Tai Y, Inoue Y et al. Efficacy of temporal musculopericranial flap for reconstruction of the anterior base of the skull. *Scand J Plast Reconstr Hand Surg* 34: 43-53, 2000.

Kobayashi S, Yoza S, Kakibuchi M et al. Retroauricular Hairline Flap Transfer to the Face. *Plast Reconstr Surg* 96 (1): 42-47, 1995.

Kroll SS. Forehead flap Nasal Reconstruction with Tissue Expansion and Delayed Pedicle Separation. *Laryngoscope* 99: 448-452, 1989.

Leonard A.G. The Forehead flap: minimising the secondary defect by preservation of the frontalis muscle. *Br J Plast Surg* 36: 322-326, 1983.

Mangold U, Lierse W, Pfeifer G. Die Arterien der Stirn als Grundlage des Nasenersatzes mit Stirnlappen. Acta Anat.1980; 107: 18-25.

Mazzola R.F., Marcus S. History of Total Nasal Reconstruction with Particular Emphasis on the Folded Forehead Flap Technique. *Plast Reconstr Surg* 72 (3): 408-414, 1983.

McCarthy JG, Lorenc ZP, Cutting C, et al. The Median Forehead Flap Revisited: The Blood Supply. *Plast Reconstr Surg* 76 (6): 866-869, 1985.

Menick FJ. A 10-year experience in nasal reconstruction with the three-stage forehead flap. *Plast Reconstr Surg* 109 (6): 1839-1855, 2002.

Menick F.J. Nasal Reconstruction: Forehead Flap. *Plast Reconstr Surg* 113 (6): 100-111, 2004.

Millard D.R., Jr. Reconstructive Rhinoplasty for the lower two-thirds of the nose. *Plast Reconstr Surg* 57 (6): 722-728, 1976.

Miller P.J., Hertler C., Alexiades G. et al. Replantation of the Amputated Nose. *Arch Otolaryngol H&N Surg* 124: 907-910, 1998.

Mommaerts MY, Abeloos JSV, De Clercq CAS et al. Brow and forehead lift with cranial suspension*. J Cranio-Maxillo-Facial Surg* 22: 33-36, 1994.

Ohtsuka H, Miki Y; Shioya N. Trilobed flap in facial reconstruction. *Br J Plast Surg* 35: 493-497, 1982.

Park SS. Reconstruction of Nasal Defects Larger than 1, 5 Centimeters in Diameter. *The Laryngoscope* 110: 1241-1250, 2000.

Park SS. The Single-Stage Forehead Flap in Nasal Reconstruction. An alternative with advantages. *Arch Facial Plast Surg* 4: 32-36, 2002.

Pinho C, Choupina M, Silva P et al. A new retroauricular flap for facial reconstruction. *Br J Plast Surg* 56: 599-602, 2003.

Potparic Z, Fukuta K, Colen LB et al. Galeo-pericranial flaps in the forehead: a study of blood supply and volumes. *Br J Plast Surg* 49: 519-528, 1996.

Quatela VC, Sherris DA, Rounds MF. Esthetic Refinements in Forehead Flap Nasal Reconstruction. *Arch Otolaryngol Head Neck* 121: 1106-1113, 1995.

Riggio E, Spano A, Nava M. The Forehead Zygomatico-Orbital Artery-Based Island Flap. *Plast Reconstr Surg* 115 (1): 226-233, 2005.

Sakai S, Soeda S and Matsukawa A. Refinements of the island median forehead flap for reconstruction of the medial canthal area. *J Dermatol Surg Oncol* 15: 524-530, 1989.

Savage R.C. Orbital Exenteration and Reconstruction for Massive Basal Cell and Squamous Cell Carcinoma of Cutaneous Origin. *Ann Plast Surg* 10 (6): 458-466, 1983.

Sawhney C.P. Use of a larger midline forehead flap for Rhinoplasty, with new design for donor site. *Plast Reconstr Surg* 63 (3): 395-397, 1979.

Shipkov H, Anastassov YK, Djambazov KB, et al. Nasal reconstruction with vascularized forehead flap. *Folia Medica*, XLVI, 1/2004: 23-25, 2004.

Shumrick K.A., Campbell A. Improvements in forehead flap design for nasal reconstruction. *Facial Plast Surg* 14(2): 165-171, 1998.

Shumrick K.A, Smith T.L. The Anatomic Basis for the design of forehead flaps in Nasal Reconstruction. *Arch Otolaryngol Head Neck Surg* 118: 373-379, 1992.

Stucker FJ, Daube D. Reflections on Total and Near Total Nasal Reconstruction. *Facial Plast Surg* 10 (4): 374-381, 1994.

Summers BK and Siegle RJ. Facial cutaneous reconstructive surgery: Facial Flaps. *J Am Acad Dermatol* 29: 917-941, 1993.

Sykes J and Tolen CJ. Subtotal nasal reconstruction using a bi-valved forehead flap. *Facial Plast Surg* 14 (2): 159-164, 1998.

Terranova W. The use of periosteal flaps in the scalp and forehead reconstruction. *Ann Plast Surg* 25 (6): 450-456, 1990.

Tolhurst DE, Carstens MH, Greco RJ et al. The surgical anatomy of the scalp. *Plast Reconstr Surg* 87 (4): 603-612, 1991.

Vural E, Batay F, Key JM. Glabella frown lines as a reliable landmark for the supratrochlear artery. Otolaryngol. *Head & Neck Surg* 123 (5): 543-546, 2000.

Wee SS, Hruza GJ, Mustoe TA. The Frontonasal Flap: utility for lateral nasal defects and technical refinements. *Br J Plast Surg* 44: 201-205, 1991.

Whetzel TP, Mathes SJ. Arterial anatomy of the face: An analysis of vascular territories and perforating cutaneous vessels. Plast Reconstr Surg. 1992; 89 (4): 591- 605.

Wild T., Hybarger P. Triple-Flap Technique for Reconstruction of Large Nasal Defects. *Arch Facial Plast Surg* 3:17-21, 2001.

Yeatts RP, Newsom RW, Matthews BL. Doppler-assisted vascular pedicle flaps in eyelid and periorbital reconstruction. *Arch Ophthalmol* 114: 1149-1152, 1996.

Yenidunya MO. Axial pattern bilobed flap for the reconstruction of the midline forehead defects. *Plast Reconstr Surg* 103 (2): 737, 1999.

C. <u>VENOUS DRAINAGE:</u>

Converse J.M., Wood-Smith D. Experiences with the forehead island flap with a subcutaneous pedicle. *Plast Reconstr Surg* 31 (6): 521-527, 1963.

Drisco B.P., Baker S.R. Reconstruction of nasal alar defects. *Arch Facial Plast Surg* 3 APR-JUNE: 91-99, 2001.

Eiseman G . Bitemporal Flap Reconstruction of Forehead. *J Trauma* 18 (5): 355-359, 1978.

Epstein et al. The vertebral venous plexus as a major cerebral venous outflow tract. Anesthesiology. 32 (4): 332-7, 1970.

Goncalves J, Patenotre P, Martinot V. et al. Rhinopoieses etendues par lambeau frontal. A propos d'une serie de 12 cas chez l' adulte. *Ann Chir Plast Esthet* 46: 617-628, 2001.

Iwahira Y, Maruyama Y. Expanded unilateral forehead flap (Sail Flap) for coverage of opposite forehead defect. *Plast Reconstr Surg* 92 (6): 1052-1056, 1993.

Kavarna N.M. Use of a folded forehead flap for reconstruction after a large excision of the full thickness of the cheek. *Plast Reconstr Surg* 56 (6): 629-632, 1975.

Miller P.J., Herler C., Alexiades G. et al. Replantation of the Amputated Nose. *Arch Otolaryngol H&N Surg* 124: 907-910, 1998.

Morris S.F., MacGill K.A., Taylor G.I. Scalp replantatio by arterialised venous network flow-through. *Br. J. Plast Surg* 45: 187-192, 1992.

Motomura H, Muraoka M, Nose K. Eyebrow reconstruction with intermediate hair from the hairline of the forehead on the pedicled temporoparietal fascial flap. *Ann Plast Surg* 51 (3): 314-318, 2003.

Potenza A.D., Glenn R.C. Late conversion of a broad-pedicled forehead flap to an island flap. *Plast Reconstr Surg* 63 (4): 271-272, 2002.

Riggio E. The Hazards of Contemporary Forehead Flap and Neck Dissection in Smokers. *Plast Reconstr Surg* 112 (1): 346-347, 2003.

Rohrich RJ, Griffin JR, Ansari M, et al. Nasal Reconstruction- Beyond Aesthetic Subunits: A 15- year Review of 1334 Cases. *Plast Reconstr Surg* 114 (6): 1405-1406, 2004.

Sherris DA, Fuerstenberg J, Danahey D, et al. Reconstruction of the Nasal Columella. *Arch Facial Plast Surg* 4: 42-46, 2002.

Utley D.S., Koch R.J., Good R.L. The Failing Flap in Plastic and Reconstructive Surgery: Role of the Medicinal Leech. *Laryngoscope* 108 (8): 1129-1135, 1998.

Williams J.Z., Evans G.R.D., Ainslie N.B. Cutaneous nasal malignancies: Is primary reconstruction safe? *Plast Reconstr Surg* 94 (8): 57-61, 1998.

Zilinsky I, Winkler E, Jacobs DI, et al. Turnover Forehead Flap Combined with Composite Crus of Helix Graft for Partial Nasal Reconstruction. *Plast Reconstr Surg* 103 (1): 192-196, 1999.

D. <u>BROW AND FOREHEAD LIFTS:</u>

Cheney ML, Gliklich R, Li KK et al. Midforehead Incision: An Approach to the Frontal Sinus and Upper Face. *J Craniofacial Surg* 6 (5): 408-411, 1995.

Knize D. Reassessment of the Coronal Incision and Subgaleal Dissection for Foreheadplasty. *Plast Reconstr Surg* 102 (2): 478-489, 1998.

Marten T. Hairline Lowering during Foreheadplasty. *Plast Reconstr Surg* 103 (1): 224-236, 1999.

Park D, Ahn K, Han D et al. Blepharoptosis Repair by Use of Superiorly Based Muscle Flaps. *Plast Reconstr Surg* 101 (3): 592-603, 1998.

Psillakis JM, Rumley TO, Camargos A. Subperiosteal Approach as an Improved Concept for Correction of the Aged Face. *Plast Reconstr Surg* 82 (3): 383-392, 1998.

Ramirez O. Endoscopic Techniques in Facial Rejuvenation: An Overview. Part 1. *Aesth Plast Surg* 18: 141-147, 1994.

Rudolph R, Miller SH. Do Forehead Lifts Lift or Unfold? *Aesth Plast Surg* 16: 1-9, 1992.

E. <u>FOREHEAD AESTHETICS AND LANDMARKS:</u>

Hinderer UT, Urriolagoitia F, Vildosola R. The Blepharo-periorbitoplasty: Anatomic basis. *Ann Plast Surg* 18 (5): 437-453, 1987.

Siegle RJ. Forehead Reconstruction. *J Dermatol Surg Oncol* 17: 200-204, 1991.

G. <u>FOREHEAD SENSATION:</u>

Adamson PA, Johnson CM, Anderson JR et al. The forehead lift. *Arch Otolaryngol* 111: 325-329, 1985.

Adant J-Ph, Bluth Fr. Endoscopic Supraorbital Nerve Neurolysis. *Acta Chir Belg* 99: 182-184, 1999.

Cheney ML, Gliklich R, Li KK et al. Midforehead Incision: An Approach to the Frontal Sinus and Upper Face. *J Craniofacial Surg* 6 (5): 408-411, 1995.

Marten T. Hairline Lowering during Foreheadplasty. *Plast Reconstr Surg* 103 (1): 224-236, 1999.

Park D, Ahn K, Han D et al. Blepharoptosis Repair by Use of Superiorly Based Muscle Flaps. *Plast Reconstr Surg* 101 (3): 592-603, 1998.

Psillakis JM, Rumley TO, Camargos A. Subperiosteal Approach as an Improved Concept for Correction of the Aged Face. *Plast Reconstr Surg* 82 (3): 383-392, 1988.

Ramirez O. Endoscopic Techniques in Facial Rejuvenation: An Overview. Part 1. *Aesth Plast Surg* 18: 141-147, 1994.

<u>E. ETIOLOGY OF NASAL DEFECTS:</u>

Schwartz R.J., MacDonald M. A rationale approach to nasal reconstruction in leprosy. *Plast Reconstr Surg* 114 (4): 876-882, 2004.

Zuker R.M., Capek L., De Haas W. The expanded forehead scalping flap: A new method of total nasal reconstruction. *Plast Reconstr Surg* 98 (1): 155-159, 1996.

F. REFERENCES FROM CLINICAL APPLICATIONS:

Andaluz Norberto et al. The one-piece orbitopterional approach. *Skull base: An interdisciplinary approach*. Volume 13(4): 241-245, 2003.

Arole FO, Olaitan AA and Fatusi OA. Giant frontal sinus mucocoele with intracranial extension and orbital displacement in an elderly Nigerian. *WAJM* Volume 21 (3):262-264, 2002.

Bailey M. Hugh and Jackson Ian T. Vascularized galeal frontalis flap to reduce craniofacial infection. *Plast and Reconst Surg* Volume 81 (4): 642-643, 1988.

Bajaj MS and Sethi Anita. Complicated eyelid reconstruction after an Unusual glabellar flap repair. *Acta Ophthalmologica Scandinavica* 599-600, 2000.

Baroudi Issa F. Obliteration of decompressed frontal sinus by means of a deepithelialized island forehead flap. *Plast and Reconstr Surg* Volume 77 (5): 824-827, 1986.

Bennet Simon PH, Richard Bruce M, Graham Kenneth E. Median forehead flaps for eyelid reconstruction. *BJPS* 733-734, 2001.

Blackwell Keith E. Reconstruction of massive defects in the head and neck: the role of simultaneous distant and regional flaps. *Head and Neck* 620-628, 1997.

Chiarelli A, Forcignano R, Boatto F et al. Reconstruction of the inner canthus region with a forehead muscle flap: a report on three cases. *BJPS* Volume 54: 248-252, 2001.

Field Laurence M. Suggestions for improving the axial frontonasal flap. *Plast. and Reconstr. Surg* Volume 78(2): 263-264, 1986.

Furuta S, Hayashi M and Shinohara H. Nasal reconstruction with an expanded dual forehead flap. *Br J Plast Surg* Volume 53:261-264, 2000.

Gabriel A et al. Unlined repairs of defects following oral cancer ablation*. Br J Plast Surg* Volume 29: 165-169, 1976.

Gullane Patrick J. et al. Minor and major lip reconstruction. *The Journal of Otolaryngology* Volume 12(2): 75-82, 1983.

Han Kihwan, Kang Jingsung. Tripartite frontalis muscle flap transposition for blepharoptosis. *Brown and Company* Volume 30(3): 224-232, 1993.

Hay David. Reconstruction of both eyelids following traumatic loss. *BRJ Plastic Surgeon* Volume 24: 361-364, 1971.

Hurwitz JJ and Nik N. The role of the browplasty rotational flap in lower eyelid reconstruction. *Ophthalmic Surgery* Volume 15(5): 382-385, 1984.

Jung Dong-hak, Moon Hyoung-Jin, Choi Seung-Ho and Lam Sameul M. Secondary rhinoplasty of the Asian nose: correction of the contracted nose. *Aesth. Plast. Surg* Volume 28: 1-7, 2004.

Kiyokawa Kensuke, Tai Yoshiaki, Inoue Yojiro t al. Efficacy of temporal musculopericranial flap for reconstruction of the anterior base of the skull. *Scand J Plast Reconstr Hand Surg* Volume 34: 43-53, 2000.

Kobayashi Seiichiro. Reconstruction of a short nose by full-thickness tissue transfer with osteotomy. *Lippincott-Raven Publishers* Volume 39(6): 628-632, 1997.

Lari A.R, Kanjoor J.R, Vulvoda M. et al. Orbital reconstruction following sino-nasal mucormycosis. *Br J Plast Surg* Volume 3: 72-75, 2002.

Lee James L and Zimbler Marc S. forehead flap for reconstruction of large nasal defects. *Ear, Nose & Throat Journal* Volume 83(5): 322, 2004.

Marsh Jeffrey L et al. Lacrimal gland adenoid cystic carcinoma: intracranial and extracranial en bloc resection. *Plastic and Reconstructive Surgery* Volume 68 (4): 577-585, 1981.

Mavili Mehmet Emin. Further experience with upper lip flaps for reconstruction of the ala nasi and alar base defects. *Lippincott-Raven Publishers*: 600-605, 1998.

Mclean Neil.R, Watson Anthony C.H. Reconstruction of a defect of the ala nasi following trigeminal anaesthesia with an innervated forehead flap. *Br J Plast Surg* Volume 35: 201-203, 1982.

Noorman van der Dussen Frans M. Utilization of the pedicle of the temporal-forehead-flap to close defects in the maxilla after tumour surgery. *J. Max.-Fac. Surg* Volume 11: 204-206, 1983.

Ohmori Kitaro. Total rhinoplasty with a free osteocutaneous flap. *Plas Reconstr Surg* Volume 63(3): 387-394, 1979.

Ohtsuka Hisashi. Eye socket and eyelid reconstruction using the combined island frontal flap and retroauricular island flap: a preliminary report. *Annals of Plastic Surgery* Volume 20(3): 244-248, 1988.

Putterman Allen M. Reconstruction of nasal fistulas of the medial canthus. *American Journal of Ophtalmology* Volume 108: 68-74, 1989.

Rapidis Alexander D, Liarikos Sotiris. Malignant orbital and orbitomaxillary tumors: surgical consideration. *Orbit* Volume 17(2): 77-88, 1998.

Rebeiz Elie E et al. Surgical management of life-threatening epistaxis in Osler-Weber-Rendu disease. *Brown and Company* 208-213, 1995.

Shiau Duen-hern. Reversed temporal artery island flap for forehead reconstruction. *Plast. Reconstr. Surg* Volume 112(6): 1649-1651, 2003.

Smalley John J. et al. Forehead flap rotation to protect the carotid artery. *Plastic and Reconstructive Surgery* Volume 49(1): 96-97, 1972.

Snow, Stephen N. Rotation flaps to reconstruct nasal tip defects following Mohs surgery. *Dermatologic Surgery* Volume 23(10): 916-919, 1997.

Speculand, B. The origin of the temporalis muscle flap. *British Journal of Oral & Maxillofacial Surgery* Volume 30: 390-392, 1992.

Stal Samuel et al. Reconstruction of calvarial defects. *Southern Medical Journal* Volume 8 (5): 812-819, 1992.

Sutton, Andrew F and Quatela, Vito C. Bilobed flap reconstruction of the temporal forehead. *Arch Otolaryngol Head Neck Surgery* Volume118: 978-982, 1992.

Szaslay L. Reconstruction of a cheek defect with a forehead flap in one stage. *Plast. Reconstr. Surg* 1106-1107, 1994.

Van Der Meulen. The use of mucosa-lined flaps in eyelid reconstruction: A new approach*. Plast Reconstr Surg* Volume 70(2): 139-146, 1982.

Van Der Woerdt. Adnexal surgery in dogs and cats. *Veterinary Ophthalmology* Volume 7(5): 284-290, 2004.

Wallis Andrew and Donald Paul J. Frontal sinus fractures: A review of 72 cases*. Laryngoscope* Volume 98: 593-598, 1988.

Wolfe S, Anthony R. Lengthening the nose: a lesson from craniofacial surgery applied to posttraumatic and congenital deformities. *Plast. Reconstr. Surg* volume 94(1): 87-78, 1993.

Yanaga Z., Hiroko Y. and Mori S. and Seiichiro X. Eyelids and eye socket reconstruction using the expanded forehead flap and composite grafting. *Plast. Reconstr. Surg* Volume 108(1): 8-16, 2001.

Zhou Li-Yun and Hu Qun-Yin. Median forehead island skin flap for the correction of severely collapsed nose. *Annals of Plastic Surgery* Volume 22(6): 516-522, 1989.
