

THE OSTRICH AS MEAT ANIMAL -
ANATOMICAL AND MUSCLE CHARACTERISTICS

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Francois Mellett

INTRODUCTION

The domestication of ostriches and commercial ostrich breeding has a long and interesting history. [Ostriches were successfully domesticated in Algeria during 1857 and also successfully bred in Italy during 1859. * In South Africa the domestication of wild ostriches started in the Cape Colony with 80 tame birds during 1865. This number increased to 32 247 birds within ten years (De Mosenthal, 1877). Ostrich farming reached a peak during 1913 with 757 000 birds (De Jager, 1985, personal communication). Currently (1985) there are approximately 120 000 domesticated ostriches in South Africa.

The commercial production of ostrich meat started in 1958 and the first abattoir was built in 1964. * At the present moment 85 000 birds are slaughtered annually. Although the income from the carcass of a 14 month old ostrich comprise only 15% of the total income of a 14 month old bird (with the hide comprising 65% and the first harvest feathers 20%), the subjects of carcass characteristics and meat quality has long been neglected. Very little is known about the anatomy of the skeleton and muscles of the ostrich, the *post mortem* reactions of these muscles and the effects of different slaughtering, chilling and deboning practices. The necessity of the above mentioned have proved very usefull in the beef, sheep, pork and poultry industries.

* With this present study we described the essential skeletal and muscular anatomy and included well known practices to the meat industry, such as electrical stimulation of the carcasses, *post mortem* pH monitoring of certain muscles, different deboning practices and vacuum packed ageing of selected cuts of ostrich meat. The obtained results are in agreement with general meat science, with expected inter-*species* variation, e.g. where the final pH-values of pork is relatively low at approximately 5,5; that of beef is higher at 5,7 and ostrich meat even higher at 6,0.

Certain other fields of essential research are pointed out in this study, such as the growth and development of the ostrich, as well as certain basic biochemical research on the meat of the ostrich.

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1 GENERAL

1.1 THE ZOOLOGICAL POSITION OF THE OSTRICH

During the nineteenth and first half of the twentieth centuries the class *Aves* was subdivided into three orders, or sometimes called subclasses, namely *Saururae* (lizard-tailed birds of which only fossils exist), *Ratitae* (flat breastbone) and *Carinatae* (modern birds with a keel on the breastbone). Such references are De Mosenthal (1877), Stark (1900), and Bradley and Grahame (1950). In this classification the ostrich was considered as a member of the subclass *Ratitae*, order *Struthionales*, family *Struthionidae*, genus *Struthio* and further differentiated into four species, namely *S. australis*, *S. camelus*, *S. massaicus* and *S. molybdophanes* (Stark and Sclater, 1906). It has since been established that there is only one species, namely *S. camelus*.

The current zoological classification of the ostrich is presented in Table 1.1. This classification is in agreement with McLachlan and Liversidge (1978), Getty (1975) and Welty (1975).

Table 1.1 Zoological position of the ostrich

Class	<i>Aves</i>
Subclass	<i>Neornithes</i>
Superorder	<i>Neognathae</i>
Order	<i>Struthioniformes</i>
Family	<i>Struthionidae</i>
Genus	<i>Struthio</i>
Species	<i>camelus</i>

In this classification system all living birds are members of the subclass *Neornithes* and superorder *Neognathae*, while the fossil birds are classified in another subclass *Archaeornithes*, although a few New World fossil birds are members of the subclass *Neornithes* and superorder *Odontognathae* (Welty, 1975). The ostrich and other flightless birds with a flat sternum are not members of the same order.

X1.2 THE OSTRICH AS DOMESTICATED FARM ANIMAL

X Although ostriches were hunted for their meat centuries ago (De Mosenthal, 1877), the real motivation for the domestication of the ostrich was the production of feathers during the second half of the nineteenth century. Since then the demand for feathers declined somewhat, but the leather articles made from the treated hides are still very popular. De Mosenthal (1877) referred to the use of ostrich meat and recognized the potential of ostrich meat with remarks like "seeing the present prices charged for beef and mutton, that ostrich-meat may one day form an important item in our food supply "and "the meat is said to be palatable, and in flavour not unlike young beef". He also mentioned the "long and muscular neck" and the "extremely muscular thighs" which, today sell as products resembling oxtail and beef steaks.

X The optimal age of slaughtering ostriches for maximum utilization of the hides, feathers and feed conversion efficiency is when the birds are fourteen months old (De Waal, 1984, personal communication). At this age the animals are not fully matured physiologically and the meat thus produced can indeed be very succulent and palatable.

1.3 TERMONOLOGY

In order to carry out a study on the relative aspects of any meat, the muscles must be anatomically identified, as mentioned by Naudé, Van Rensburg, Smit, Stiemie, Dreyer, Rossouw and De Jager (1979). This present study deals with the anatomical nomenclature and description of the skeleton and the muscles of the hind limb, as well as the mass distribution of these muscles and some commercial, retail and technological aspects of the meat of the ostrich. The terminology applied is the latest available terms in accordance with *Nomina Anatomica* (1977), although this publication does not deal with the ostrich.

1.4 LIST OF ABBREVIATIONS USED IN THE TEXT AND FIGURES

acc.	=	accesorius
art.	=	articulatio
caud.	=	caudalis
cm	=	centimeter
cran.	=	cranialis
crur.	=	cruris
ext.	=	externus
fem.	=	femoris
flex.	=	flexor
for.	=	foramen
fov.	=	fovea
g	=	gram
h	=	hour
int.	=	internus
intm.	=	intermedius
kg	=	kilogram
lat.	=	lateralis
m.	=	muscularis
med.	=	medius
medi.	=	medialis
min.	=	minimus
proc.	=	proximalis
s.	=	seu
ventr.	=	ventralis

In the plural form the last letter of the abbreviation is duplicated.

2 SKELETON OF THE OSTRICH

2.1 GENERAL CONSIDERATIONS

The skeleton of the ostrich (Figure 2.1) is typically avian, with a few remarkable exceptions. The forelimb is underdeveloped in comparison to that of flying birds. The length of the *radius* (Figure 2.1/13), *metacarpus* (Figure 2.1/16) and *digiti manus* (Figure 2.1/17) together is far less than the length of the *humerus* (Figure 2.1/12). In birds like the fowl and goose (Nickel, Schummer & Seifërle, 1977) the length of the humerus is about equal to that of the radius as well as that of the metacarpal and digital bones. Furthermore the legs are very long and powerful, which is characteristic of many terrestrial birds. A *pubic symphysis* is found only in the ostrich (George & Berger, 1966)

2.2 SKELETON OF THE HEAD (*ossa cranii*)

The *neurocranium* (Figure 2.1/1) and the *splanchnocranium* (Figure 2.1/2) are clearly separated by very large orbital cavities in the ostrich as in all other birds. In the fourteen month old ostrich the individual bones are clearly separated, but in the adult bird the individual bones of both parts succumb to fusion which completely obliterates the sutures. Pneumatization of almost all bones results in a very complicated system of cavities which are ventilated from the nasopharynx.

The neurocranium consists of the occipital bone, the sphenoid bone, the parietal bones, the frontal bones and the temporal bones. The ethmoid bone is displaced nasally and not part of the neurocranium (Nickel, *et al.* 1977).

The *os occipitale* (Figure 2.2/1) consists of the fused *basioccipitale*, the paired *exoccipitale* and the *supraoccipitale*. The latter two surround the large *foramen occipitale magnum* (Figure 2.2/A), while the first two participate in the formation of the hemispherical *condylus occipitalis* (Figure 2.2/B). In the ostrich this occipital condyle is very large in comparison to other birds. The occipital bone with its *foramen magnum*

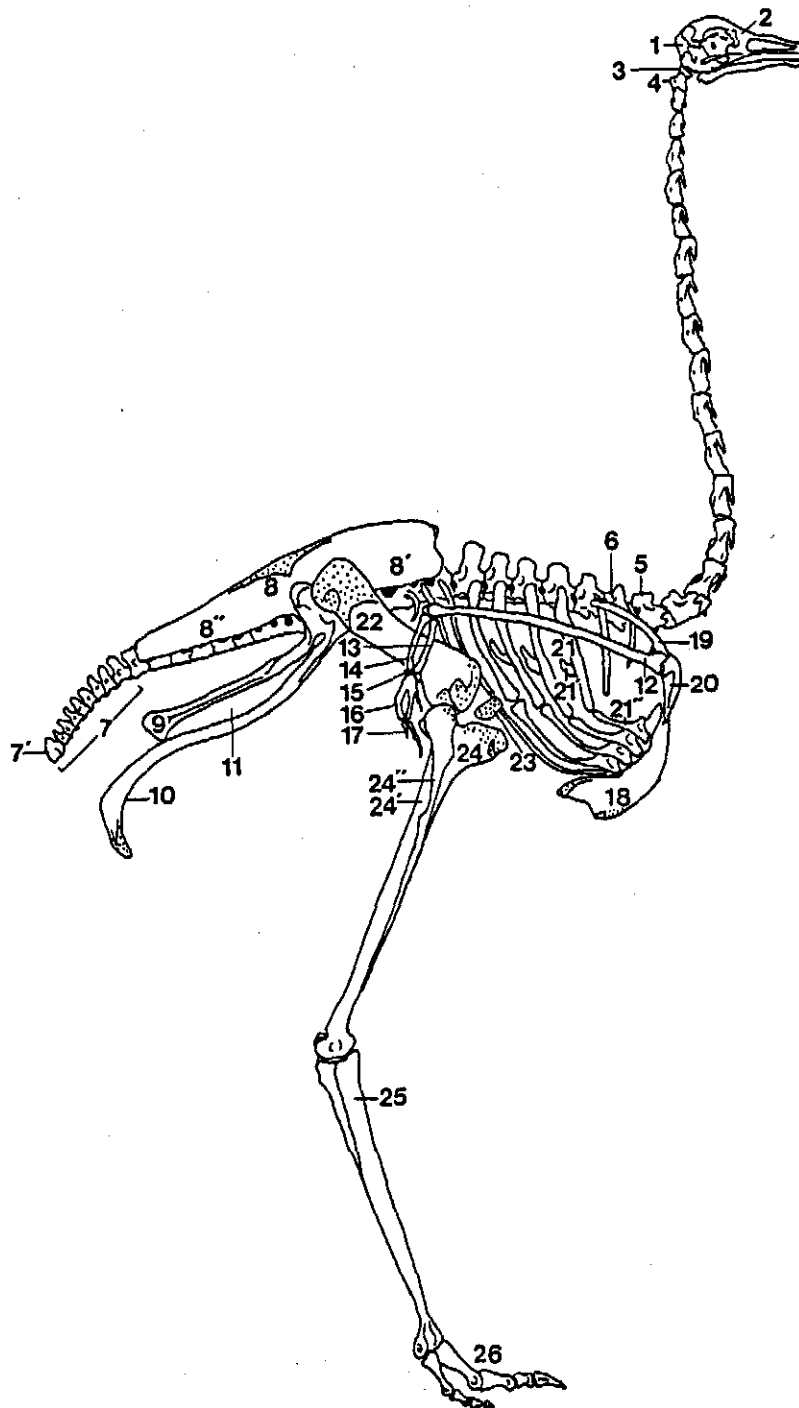


Figure 2.1 Skeleton of the ostrich

1 neurocranium; 2 splanchnocranium; 3 atlas; 4 axis; 5 last cervical vertebra; 6 first thoracic vertebra; 7 coccygeal vertebrae and 7' pygostyle; 8 ilium with its pre-acetabular (8') and post-acetabular (8'') parts; 9 ischium; 10 pubis; 11 incisura puboischiadica; 12 humerus; 13 radius; 14 ulna; 15 carpus; 16 metacarpus; 17 digiti manus; 18 sternum; 19 scapula; 20 caracoid; 21 rib with 21' proc. uncinatus and 21'' sterno-costal bone; 22 femur; 23 patella; 24 ossa cruris with 24' tibia (tibiotalarsus) and 24'' fibula; 25 tarsometatarsus; 26 digiti pedis

is situated basally and horizontally in the pigeon, vertically and nuchally in the duck and goose, whereas in the fowl it takes up a middle position between these two extremes (Nickel, *et al.* 1977). In this respect the ostrich is comparable to the fowl.

The *os sphenoidale* (Figure 2.2/2,2') forms the greater part of the floor of the cranial cavity. The *basisphenoidale* (Figure 2.2/2) is the caudal basilar part and consists of a body and temporal wings. The rostrally directed presphenoidal part or *praesphenoidale* (Figure 2.2/2') consists of a body and orbital wings. The lateral borders of the basisphenoid forms part of the *porus acusticus ext.* (Figure 2.2/D) and the floor of the posterior wall of the ear capsule. The presphenoid is perforated at its root by the Eustachian tube (*tubae auditivae*) (Figure 2.2/C). The articulation surfaces for the pterygoid bones are situated rostrally to these openings. The orbital wings fuse medially to a bony plate and form the *septum interorbitale* (Figure 2.2/E) with the more rostrally situated ethmoid bone.

The *os ethmoidale* (Figure 2.2/3) consists of two parts. The first part is a horizontal plate lying below the processes of the frontal and nasal bones, which corresponds to the *lamina cribrosa* of mammals. The vertically situated part is a bony plate which participates in the formation of the interorbital septum (Figure 2.2/E).

The *ossa parietalia* (Figure 2.2/4) are inserted between the supra occipital and the frontal bones.

The *ossa frontalia* (Figure 2.2/5) are very large and can be differentiated into a *pars frontalis* (Figure 2.2/F), a *pars orbitalis* (Figure 2.2/G) and a *pars nasalis* (Figure 2.2/G). These bones participate in the delineation of the cranium, the orbit and the nasal cavity.

The *ossa temporalia* (Figure 2.2/6,6') consists of the ear capsule (*ossa oticum*) (Figure 2.2/6) and the squamous part (*pars squamosa*) (Figure 2.2/6'). In birds the ear capsule arises by

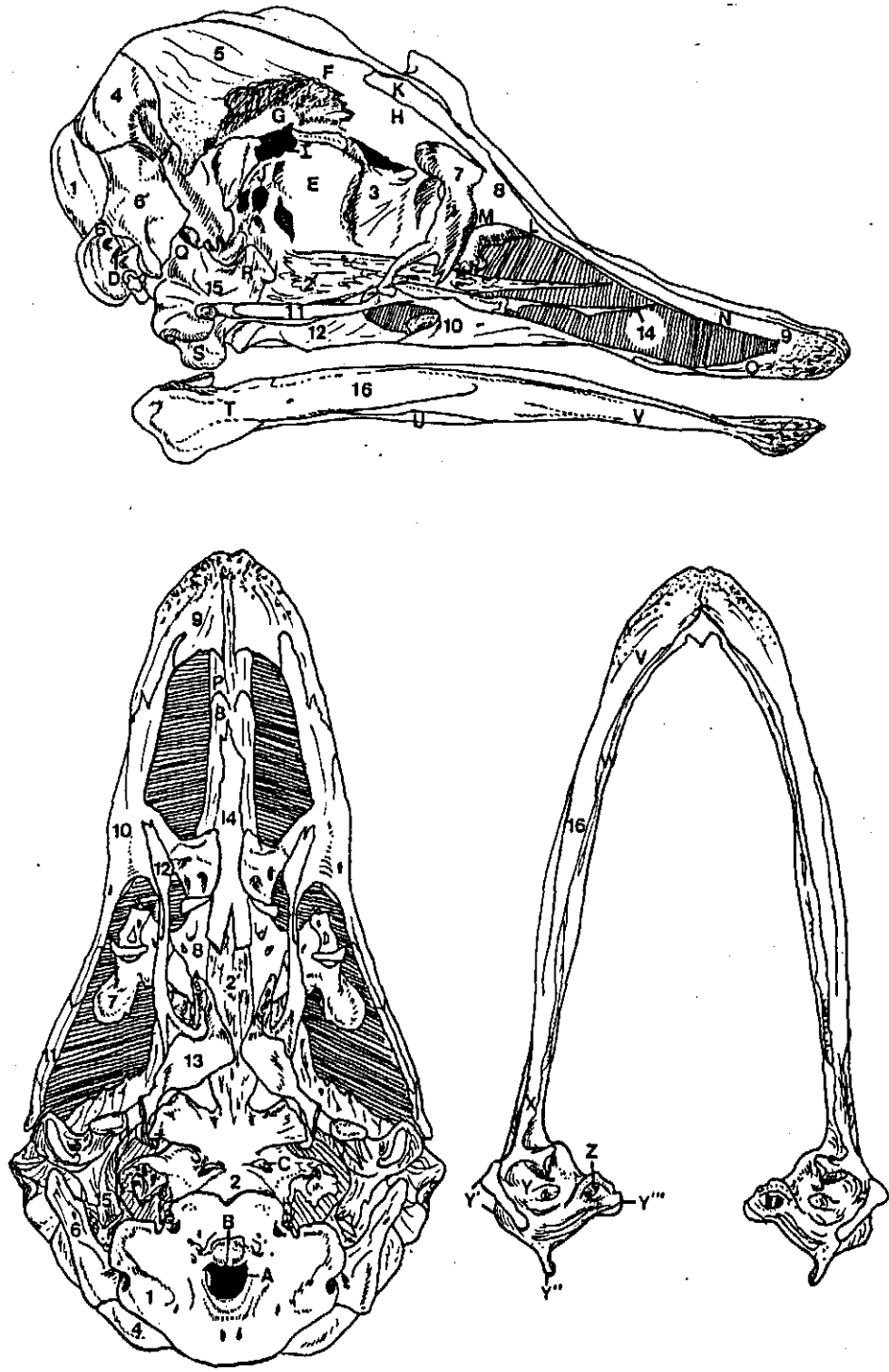


Figure 2.2 Skeleton of the head

1 os occipitale; 2 basisphenoid and 2' presphenoid of the os sphenoidale; 3 os ethmoidale; 4 os parietale; 5 os frontale; 6 os oticum and 6' pars squamosa of the os temporale; 7 os lacrimale; 8 os nasale; 9 os intermaxillare; 10 os maxillare; 11 os zygomaticum; 12 os palatinum; 13 os pterygoideum; 14 vomer; 15 os quadratum; 16 mandible; A for. occipitale magnum; B condylus occipitalis; C Eustachian tube; D porus acusticus ext.; E septum interorbitale; F pars frontalis. G pars orbitalis and H pars nasalis of the os frontale; I for. olfactorium; J for. opticum; K proc. frontalis, L proc. intermaxillaris and M proc. maxillaris of the os nasale; N proc. frontalis, O proc. maxillaris and P proc. palatinum of the os intermaxillare; Q proc. oticus, R proc. orbitalis and S proc. articularis of the os quadratum; T angular bone; U gonial bone; V dentary bone; W splenial bone; X surangular bone; Y articular bone with Y' proc. externus, Y'' proc. retroarticularis and Y''' proc. mandibularis internus; Z for. pneumaticum

fusion of three components, namely the *prooticum*, the *opisthoticum* and the *epioticum*. The ear capsule lies between the lateral part of the occipital bone, the parietal bone and the basisphenoid. The Eustachian tube terminates in the floor of the middle ear cavity, which can be viewed through the *external acoustic orifice*. There is an orobasal articular groove on the ear capsule which articulates with the otic process of the quadrate bone. The squamous part of the temporal bone participates in the formation of the lateral wall of the cranium by occupying the space between the parietal, frontal and sphenoid bones. This part is also involved in the formation of the articular groove for the quadrate bone. In the fowl the squamous temporal bone bears the orbital process (*proc. orbitalis*) and the suprameatal or zygomatic process (*proc. suprameaticus s. zygomaticus*) although in the goose, duck, pigeon (Nickel, *et al.* 1977) and ostrich (Frank, 1953) only the orbital process is found.

The *splanchnocranium* (Figure 2.1/2) (bones of the face) is clearly separated from the *neurocranium* (Figure 2.1/1) by the large orbital cavities. The ethmoid bone is shared by the *neurocranium* and *splanchnocranium*, but the true bones of the face are the lacrimal bones, the nasal bones, the premaxillary bone, the maxillary bones, the zygomatic bones, the palatine bones, the pterygoid bones, the vomer, the quadrate bones and the mandible. The lower beak is the fusion product of five component bones.

The *ossa lacrimalia* (Figure 2.2/F) forms moveable joints with the nasal bones and the zygomatic bones. They form the nasal and ventral borders of the *orbitae*. This bone is very large in the ostrich and small in the fowl.

The *ossa nasalia* (Figure 2.2/8) forms part of the dorsal and lateral borders of the nasal cavity, as well as a large part of the skeleton of the upper beak. The *procc. frontales* (Figure 2.2/K) join the frontal bones, the *procc. intermaxillares* (Figure 2.2/L) join the premaxillary bone ventrally and the *procc. maxillares* (Figure 2.2/M) form the articulation surface with the lacrimal bones.

The *os incisivum* (*premaxillary bone, os intermaxillare*) (Figure 2.2/9) originated as a paired bone and forms the largest part of the upper beak. The *procc. frontales* (Figure 2.2/N) are fused medially and joins the frontal bones, the *procc. maxillares* (Figure 2.2/O) support part of the lateral border of the beak and are fused with the maxillary bones, while the *procc. palatini* (Figure 2.2/P) are degenerated and fused with the *procc. frontales* in the ostrich.

The *ossa maxillaria* (Figure 2.2/10) are fused with the premaxillary bones as well as the palatine and zygomatic bones.

The *ossa zygomatica* (Figure 2.2/11) consist of three fused bones and joins the maxillary, premaxillary and lacrimal bones on the lateral border of the beak, and the quadrate bones caudally.

The *ossa palatina* (Figure 2.2/12) are fused immovable with the maxillary and pterygoid bones.

The *ossa pterygoidea* (Figure 2.2/13) lies between the articulate of the sphenoid and quadrate bones and partially covers the *presphenoid* ventrally.

The *vomer* (Figure 2.2/14) is a very thin bony plate covering the ventral border of the *presphenoid* and joins the *procc. intermaxillares* of the *ossa nasalia* where they meet the *procc. palatinus* of the *os intermaxillare*.

The *ossa quadrata* (Figure 2.2/15) are so called because of their shape. They lie between the *neurocranium* and the maxillopalatine apparatus and exert a considerable influence on the kinetics of the latter. Their *proc. oticus* (Figure 2.2/Q) forms a movable joint with the articular groove of the squamous temporal bone. A second, very strong articular process (*proc. articularis*) (Figure 2.2/5) carries a condyle which articulates with the mandible in the *articulatio quadratomandibularis*. Medially it also forms a joint with the pterygoid bones. A third process, the *proc. orbitalis* (Figure 2.2/R) points towards the orbit and acts as a muscle lever.



The lower jaw or *mandibula* (Figure 2.2/16) conforms to the shape of the upper jaw. The mandible is made up of the dentary (Figure 2.2/V), surangular or suprangular (Figure 2.2/X), splenial (Figure 2.2/W), angular (Figure 2.2/T) and gonial (Figure 2.2/U) bones, as well as the articular bone (Figure 2.2/Y) with its *proc. externus*, *proc. retroarticularis* and *proc. mandibularis* (Figure 2.2/Y', Y'' and Y'''). On the latter process the *fov. pneumaticum* (Figure 2.2/7) is found (Webb, 1956).

The *os hyoideum* (Figure 2.3) of the ostrich differs largely from that of other birds. The only bony part is the rostral part of the rod-like rami or *ceratobranchial* bone (Figure 2.3/4). The part corresponding to the *basihyale* (or *basihyoideum*) (Figure 2.3/2), consists of the rostral *entoglossum* (Figure 2.3/1) and *urohyale* (Figure 2.3/3) and is made up of cartilage only. The caudal part of the rami or *epibranchial* (Figure 2.3/5) is also cartilage and lies laterally against the neurocranium.

2.3 SKELETON OF THE TRUNK

2.3.1 GENERAL

In birds the skeleton of the trunk consists of the vertebral column, the ribs, the sternum and, from a functional point of view, also the pelvis since it shows bony fusion with many vertebrae. The skeleton of the trunk was described by Mivart (1874) in detail. Since this period however the nomenclature of avian anatomy changed considerably and was laid down by the International Committee of Veterinary Anatomical Nomenclature (I.C.V.A.N.), established in 1957. Some reorganization led to the establishment of the International Committee on Avian Anatomical Nomenclature (I.C.A.A.N.) in 1971 (Getty, 1975) which is responsible for this task today. The nomenclature applied in this study is in agreement with Getty (1975), Koch (1973), George and Berger (1966), Lucas and Stettenheim (1972) Nickel, *et al.* (1977) and Ede (1964).

2.3.2 VERTEBRAL COLUMN (*columna vertebralis*)

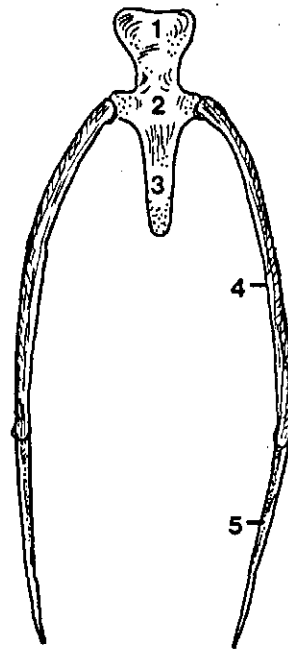


Figure 2.3 The hyoid apparatus

1 entoglossum; 2 basihyale; 3 urohyale; 4 ceratobranchial; 5 epibranchial

As in mammals the vertebral column is differentiated into cervical, thoracic, lumbar, sacral and coccygeal vertebrae. The last two thoracic vertebrae are fused with the lumbar and sacral vertebrae which makes it difficult to delineate the individual regions.

The cervical vertebral column consists of 18 *vertebrae cervicales* (Mivart, 1874, described 17, considering the eighteenth, nineteenth and twentieth vertebrae as cervico-dorsal vertebrae). The first cervical vertebra, the *atlas* (Figures 2.1/3 and 2.3), articulates with the hemispherical occipital condyle in a ball and socket joint, the *art. atlantooccipitalis*, and with the second cervical vertebra, the *axis* (Figures 2.1/4 and 2.5), in the *art. atlantoaxialis*. The ringshaped atlas has on its ventral arch (Figure 2.4/1) an articulation socket for the occipital condyle and a depression for the articulation with the odontoid process or *dens axis* (Figure 2.5/1) of the axis.

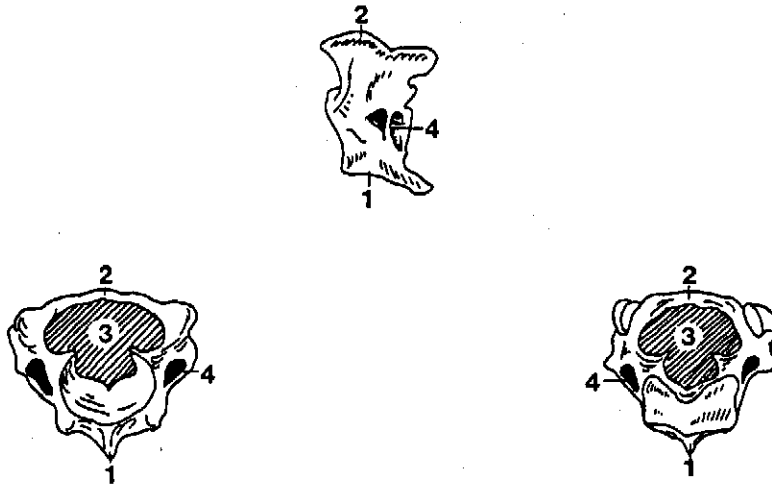


Figure 2.4 The atlas

1 ventral arch; 2 dorsal arch; 3 vertebral foramen; 4 for. transversarium

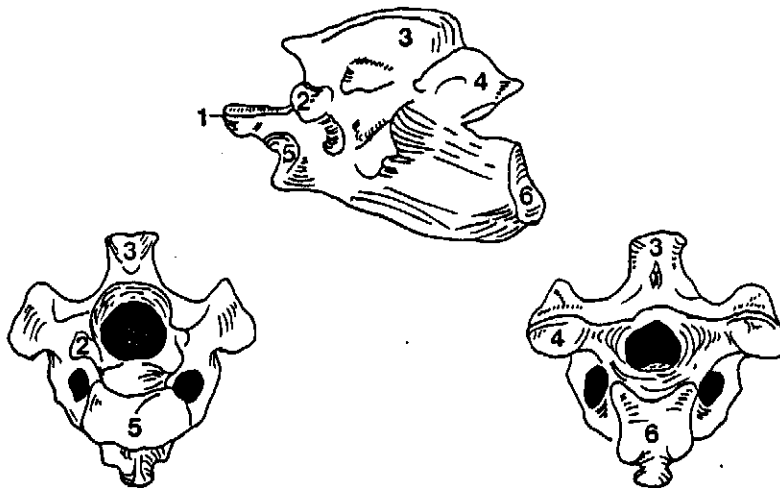


Figure 2.5 The axis

1 dens axis; 2 cranial zygapophyses; 3 proc. spinosus; 4 proc. art. caud.;
5 facies art. cran.; 6 fovea art. caud.

The dorsal arch (Figure 2.4/2) spans the vertebral foramen (Figure 2.4/3) and articulates with the odontoid process as well as with the cranial articular processes or *cranial zygapophyses* (Figure 2.5/2) of the axis. Peculiar to the ostrich, the *for. transversarium* (Figure 2.4/4) is present also in the atlas.

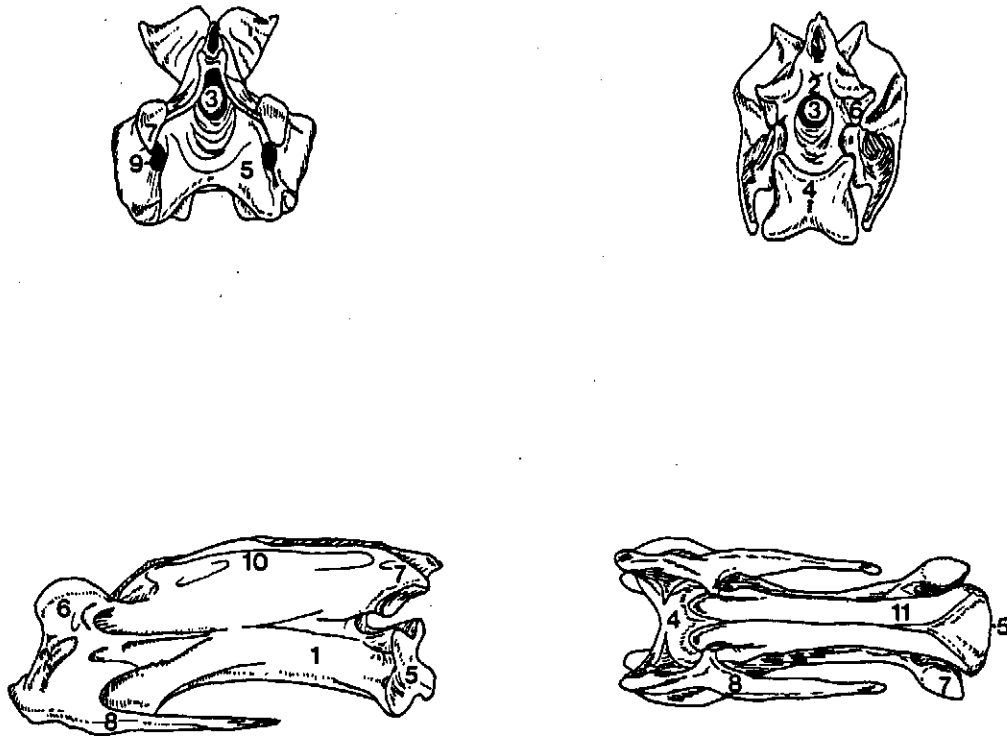


Figure 2.6 Caudal, cranial, lateral and ventral aspects of the seventh cervical vertebra

1 corpus vertebrae; 2 arcus vertebrae; 3 for. vertebrale; 4 facies art. cran.; 5 fovea art. caud.; 6 proc. art. cran.; 7 proc. art. caud.; 8 proc. transversus; 9 for. transversarium; 10 proc. spinosus; 11 crista ventr.

All cervical vertebrae, apart from the atlas, consist of a vertebral body (*corpus vertebrae*) (Figure 2.6/1) and the vertebral arch (*arcus vertebrae*) (Figure 2.6/2). The cranial articular surface of the vertebral body (Figure 2.6/4) is concave in the transverse direction and convex in the dorso-ventral direction, whereas the caudal articular surface (Figure 2,6/5) has the opposite curvatures. Between the caudal and cranial articular surfaces of two adjacent vertebrae there are fibrocartilagenous intervertebral discs (*disci*

intervertebrales). A very strong ligament, attached to the *processus spinosus* (Figure 2.6/10), connects the bodies of adjacent vertebrae. Remnants of the notochord (*pulpy nuclei*) are not found in birds. The cranial and caudal zygapophyses (*processus articulares cran. et caud.*)(Figure 2.6/6,7) form the *artt. processuum articularum s. juncturae zygapophyseales*. The *processus transversi* (Figure 2.6/8) arose from the union of parapophyses and diapophyses as well as a rib rudiment. They are traversed by the *foramen transversarium* (Figure 2.6/9) which collectively form the *canalis transversarius*. These rib rudiments are small on the cranial vertebrae, become progressively larger in a caudal direction on the cervical vertebrae up to the fourteenth vertebra which carries the largest *processus transversi*. Thereafter they become smaller up to the eighteenth and last cervical vertebra. On the ventral surface of the vertebral body there are the paired *cristae ventrales* or *hypapophyses* (Figure 2.6/11). The *incisura vertebralis cran. and caud.* of adjacent cervical participate in the formation of the *lateral vertebral foramen*, through which the spinal nerves pass.

On the basis of descriptive anatomy where the term thoracic vertebrae (*vertebrae thoracicae*) (Figure 2.1/6 and Figure 2.7) only apply to vertebrae which carry well developed ribs, the ostrich has nine thoracic vertebrae, which differ in both shape and size. The first three thoracic vertebrae each has a prominent caudally directed ventral crest (*crista ventr.*) on the ventral body (*corpus vertebrae*) (Figure 2.7/3). The vertebral arch (*arcus vertebrae*)(Figure 2.7/1) has a plate-like spine (*proc. spinalis*)(Figure 2.7/2), which is small in the first thoracic vertebra and becomes progressively larger in a caudal direction. The same accounts for the *proc. transversus* (Figure 2.7/4) with the *fovea costalis transversalis* (Figure 2.7/5), which articulates with the *tuberculum costae* (Figure 2.7/12) of the ipsenumerical rib. On the lateral surfaces of the vertebral body there are the *parapophyses* (Figure 2.7/6) which articulates with the rib heads (Figure 2.7/11). In the ostrich and duck the last two rib-bearing vertebrae and in the goose the last three, form a bony union

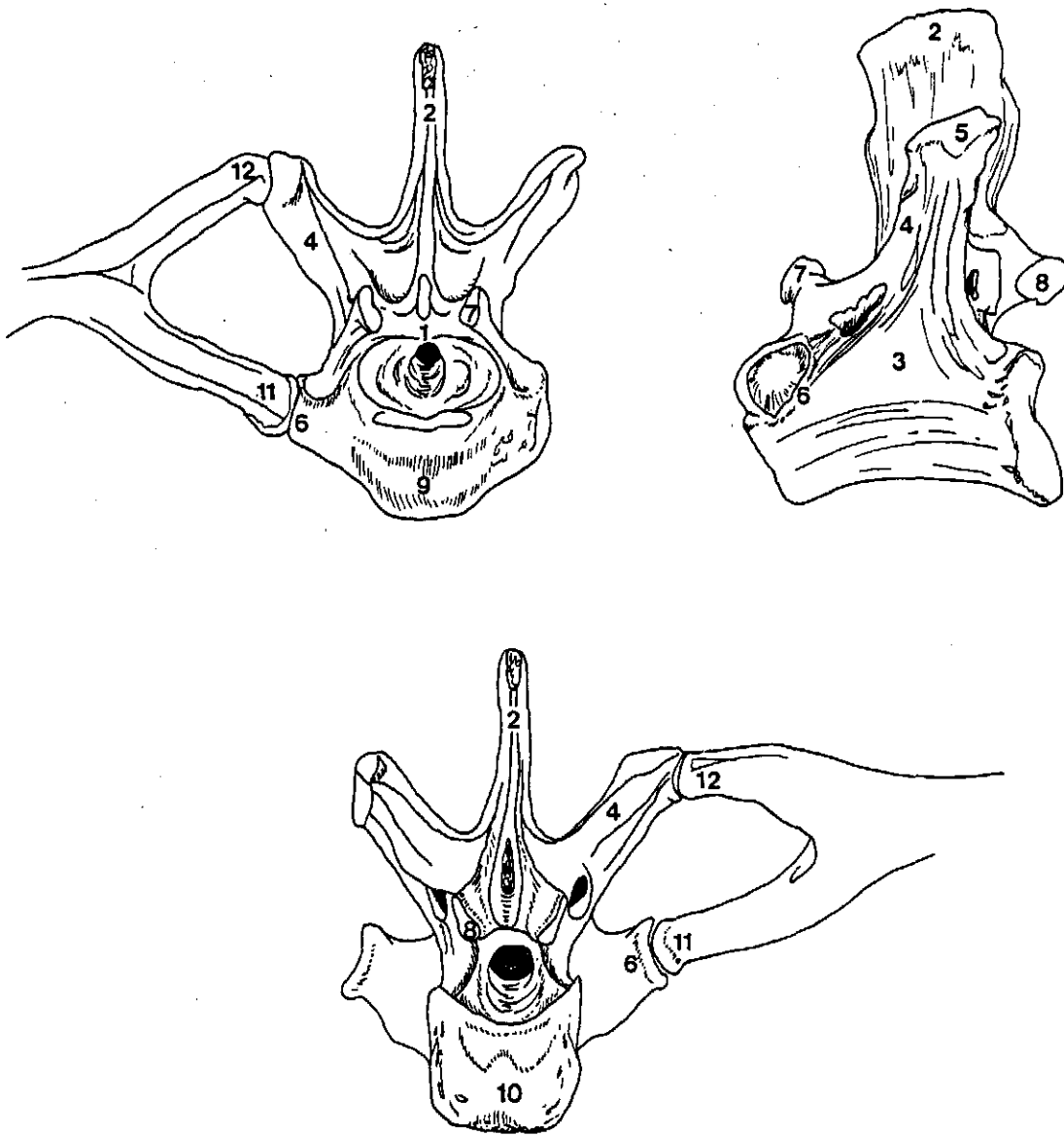


Figure 2.7 Cranial, lateral and caudal aspects of the fourth thoracic vertebra

1 arcus vertebrae; 2 proc. spinalis; 3 corpus vertebrae; 4 proc. transversus;
 5 fovea costalis transversalis; 6 parapophyses with articular cavity for head of
 rib; 7 proc. art. cran. (zygapophysis); 8 proc. art. caud.; 9 facies art. cran.;
 10 facies art. caud.; 11 capitulum costae; 12 tuberculum costae

with the synsacrum (Figure 2.13). In the ostrich the last rib is also fused to the ninth thoracic vertebra. All the other thoracic vertebrae in these three species articulate with each other by means of saddle joints and the *junctionae zygapophysiales*. In the fowl and pigeon the second to fifth thoracic vertebrae are fused into a bony column. The sixth thoracic vertebrae is free and the seventh is fused to the synsacrum (Nickel, *et al.* 1977).

In the adult ostrich the last two thoracic (Figure 2.13/1), all the lumbar and some of the sacral vertebrae are fused together into a bony column, the synsacrum, which is also fused to the medial surface of the ilia. They were identified as eight lumbar, three sacral and eight sacrocaudal vertebrae by Mivart (1874). According to later publications such as Nickel *et al.* (1977), they can not be identified as lumbar or sacral vertebrae by means of their transverse or spinal processes. In this study the views of Mivart, 1874, are accepted as correct. Eight transverse processes are found in the region of the acetabulum, as well as eight openings to allow the passage of nerves. These vertebrae are completely fused and termed lumbar vertebrae (Figure 2.13/2).

The following three vertebrae situated in the postacetabular region differ considerably from the preceding in the sense that they have well developed transverse processes fused together to support the antitrochanter like a wedge. These three vertebrae are termed *sacral vertebrae* (Figure 2.13/3).

Of the eight sacro-caudal vertebrae (Figure 2.13/4) the first five are fused immovably with the preceding vertebrae, while three are free, although immovable due to the contact between the *procc. transversii* with the ventro-medial surface of the ilia as well as fusion of their spinous processes. All the thoracic, lumbar, sacral and sacro-caudal vertebrae have well developed spinous processes. From and including the last thoracic vertebrae to the seventh sacro-caudal vertebrae, the spinous processes are fused, whilst the last sacro-caudal vertebrae is free.

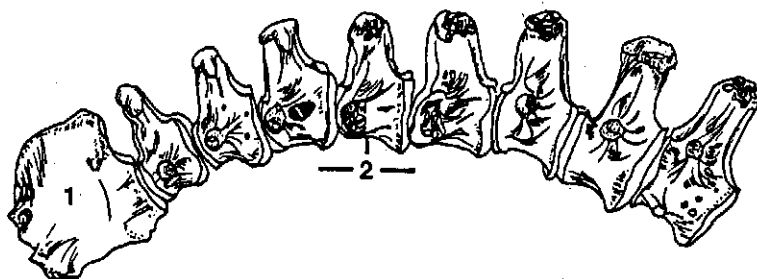


Figure 2.8 Coccygeal vertebrae of the ostrich
1 pygostyle; 2 free coccygeal vertebrae

The ten true *coccygeal vertebrae* (Figures 2.1/7 and 2.8/2) vary in both shape and size. The first to eighth coccygeal vertebrae have strong transverse processes and distinct spines, which are double in the ostrich and fowl. The last member of the coccygeal chain, the ploughshare-shaped *pygostyle* (Figures 2.1/7' and 2.8/1) is the fusion product of two vertebrae. The ostrich is the only domesticated bird with ten coccygeal vertebrae. All other domesticated birds have only five coccygeal vertebrae.

The spinal cord lies unprotected as from the opening between the third and fourth sacro-caudal vertebrae, but reaches into the pygostyle.

Table 2.1 summarizes the nomenclature used to describe the vertebrae of the ostrich.

Table 2.1 Nomenclature applied to the vertebrae of the ostrich

<u>Position</u>	<u>Region</u>	<u>Number of vertebrae</u>	<u>Total length,cm</u>
1 - 18	cervical	18	95
19 - 27	thoracic	9	42
28 - 35	lumbar	8	10
36 - 38	sacral	3	4
39 - 46	sacro-caudal	8	26
47 - 56	coccygeal	10	18
Total		56	195

2.3.3 BREAST BONE (*sternum*)

The breast bone or *sternum* (Figure 2.1/18 and 2.9/5) is a large, dorsally concave and ventrally convex, bony plate which forms a ventral cover to more than half of the body cavity. The *sternum* of the ostrich has no keel, which is characteristic only of flightless birds. There is a deep, convex groove with sharp edges which follows the thickened convex cranial border of the sternum to receive the flat distal ends of the *coracoid* (Figures 2.1/20 and 2.9/3) and *clavicle* (Figure 2.9/2) bones. Lateral to the articular surface of the *coracoid*, a craniolaterally directed *proc. lateralis cran.* (Figure 2.9/6) arises from the *sternum*. Following caudally on the thickened lateral border of the *sternum* are the articular surfaces (Figure 2.9/7) for the sternocostal bones. There are five such articular surfaces in the ostrich and they present as small, vertically positioned half cylinders. Between each pair there is a trough from which air holes (*foramina pneumatica*) lead into the *sternum*.

The sternum is nearly rectangular in outline and on each side there is a caudolaterally directed *processus lat. caud.* (Figure 2.9/8).

2.3.4 RIBS (*costae*)

Like the geese and ducks the ostrich have nine pairs of ribs (Figure 2.1/21). The middle five pairs articulate with the *ossa sternocostalia* (Figure 2.1/21" and Figure 2.9/9). The proximal end of a rib carries the long-necked head or *capitulum* (Figure 2.10/1) and the short protruberance, the *tuberculum costae* (Figure 2.10/2). Both articulate with the thoracic vertebrae of the corresponding number, the head with the *parapophysis* (Figure 2.7/6) and the tubercle with the *diapophysis* (Figure 2.7/5). The body, shaft or *corpus costae* (Figure 2.10/3) is flat and is curved laterally over its whole surface. The third to fifth rib each has a flat *processus uncinatus* (Figure 2.10/4) which rises in a caudodorsal direction and lies against the lateral surface of the next rib.

The *ossa sternocostalia* (Figure 2.9/9 and Figure 2.10/5) are



Figure 2.9 Breast bone and pectoral girdle of the ostrich

1 scapula; 2 clavicle; 3 coracoid; 4 humerus; 5 sternum; 6 proc. lateralis cran.;
7 articulation surfaces for sternocostal bones; 8 proc. lat. caud.; 9 sternocostal
bone

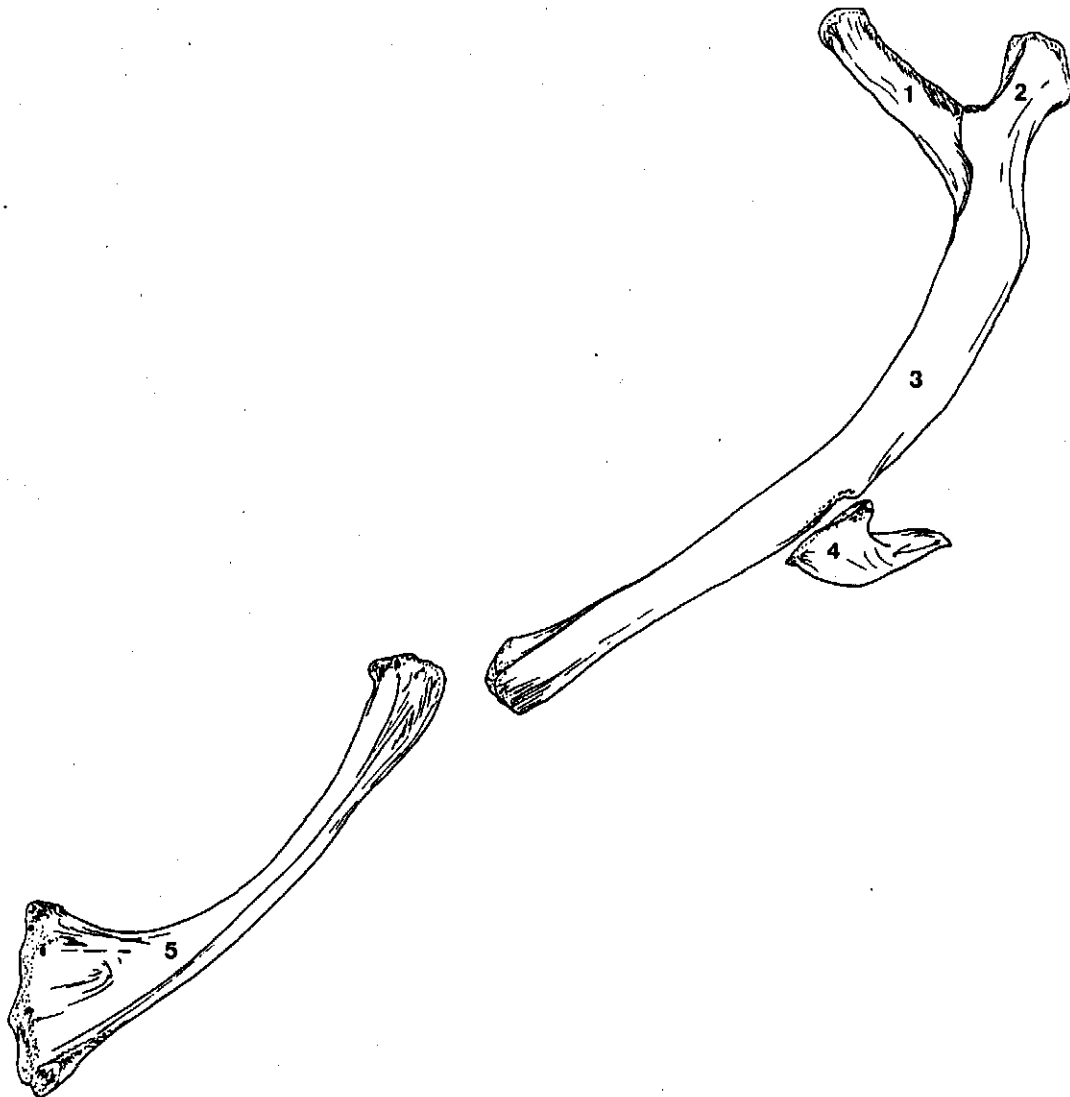


Figure 2.10 Lateral view of fourth, left thoracic rib

1 capitulum costae; 2 tuberculum costae; 3 corpus costae; 4 proc. uncinatus;
5 sternocostal bone

rod-shaped and increase in size and length progressively from first to last. They join to the ribs and *sternum* by moveable articulations. On the thickened distal ends there are transversely situated grooves which articulates with the half cylindrical articular processes (Figure 2.9/7) on the lateral border of the *sternum*.

2.4 SKELETON OF THE FORELIMB (*membri thoracici*)

2.4.1 BONES OF THE PECTORAL GIRDLE (*ossa cinguli membri thoracici*)

The fused bones of the pectoral girdle forms the connection between the trunk and the forelimbs. The pectoral girdle consists of the shoulder blade or *scapula* (Figures 2.1/19 and 2.9/1), the *coracoid* (Figures 2.1/20 and 2.9/3) and the collar bone or *clavicle* (Figure 2.9/2)

The *scapula* is a long, caudally directed, flat bone running parallel with the vertebral column, lying against the thoracic wall.

The strongest bone of the pectoral girdle, the *os coracoide*s is firmly wedged into the groove provided for it in the *sternum*. This bone is triangular in shape and forms the larger part of the articulation surface for the humerus.

The *clavicles* of all birds unite ventrally to form the "wish-bone" or *furcula* (Nickel, *et al.* 1977). This is not the case in the ostrich. The *clavicles* are poorly developed and only partially ossified.

Where the three bones of the pectoral girdle unite, they participate in the formation of the articulation surface for the humerus (Figure 2.9).

2.4.2 BONES OF THE WING (*ossa alae*)

The skeleton of the wing of the ostrich consists, as in all other birds, of the *stylopodium* or upper-arm which comprises the humerus (Figures 2.1/12 and 2.11/1) only, the *zeugopodium* comprising the radius (Figures 2.1/13 and 2.11/7) and ulna (Figures 2.1/14 and 2.11/6) and the *autopodium*, made up of the *basipodium*, which consists of the wrist or carpus, the *metapodium*, which is the metacarpus, and the *acropodium*, which is the fingers or *digiti*.

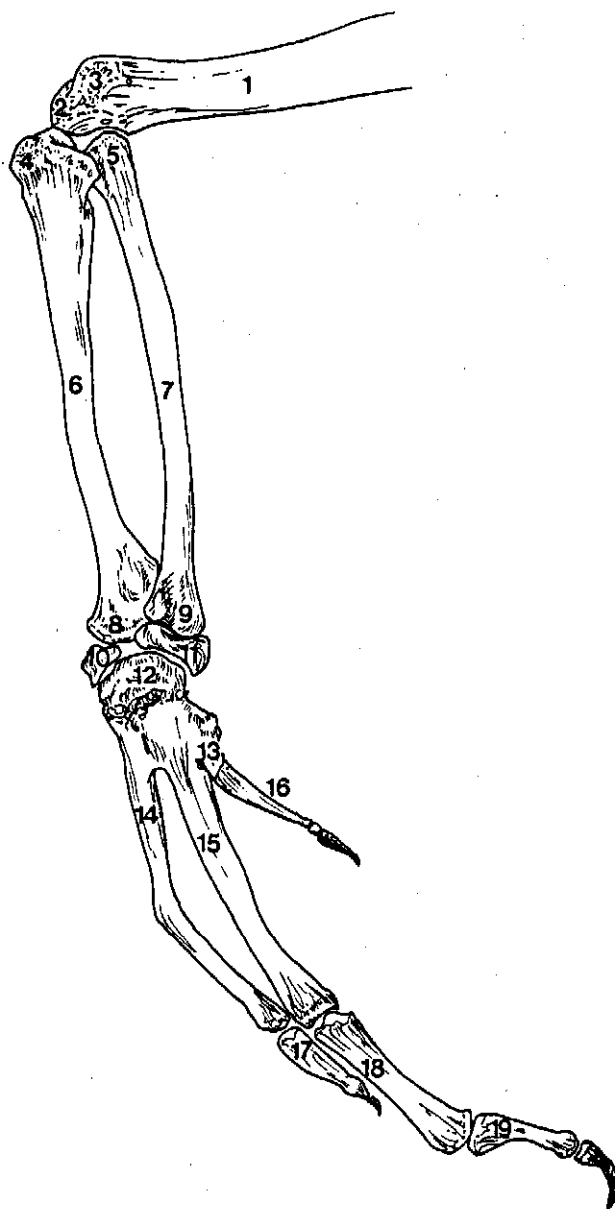


Figure 2.11 Lateral view of the bones of the right wing of the ostrich

1 humerus; 2 condylus ulnaris and 3 condylus radialis of the trochlea humeri;
 4 fovea art. ulnae; 5 capitulum radii; 6 ulna; 7 radius; 8 trochlea art. ulnae;
 9 trochlea art. radii; 10 os carpi ulnare; 11 os carpi radiale; 12 fused centrale
 and carpale; 13 first, 14 third and 15 second carpometacarpale; 16 pollex;
 17 third digit; 18 first and 19 second phalanx of the second digit

The humerus is a long curved, tubular bone with, on the proximal end the *caput humeri*. This head of the humerus forms the shoulder joint with the socket formed by the pectoral girdle. The distal articular surface of the humerus, the *trochlea humeri* (Figure 2.11/2,3) points caudoventrally. The *condylus ulnaris* (Figure 2.11/2) projects further distally than the *condylus radialis* (Figure 2.11/3).

The bones of the forearm (*ossa antebrachii*) (Figure 2.11/6,7) consist of the large *ulna* (Figure 2.11/6) and smaller *radius* (Figure 2.11/7). They are at a 90° angle with the humerus when the wing is folded. These two bones are about equal in length and separated by the *spatium interosseum*. The proximal thickened end of the ulna has an articulation socket to receive the ulnar condyle of the humerus in the *fovea art. ulnae* (Figure 2.11/4). At its distal end the ulna has the *trochlea art. ulnae* (Figure 2.11/8) for articulation with the ulnar and radial carpal bones. The proximal head of the radius bears the *capitulum radii* (Figure 2.11/5) for articulation with the *radial condyle* of the humerus, while on its distal end it bears the *trochlea art. radii* (Figure 2.11/9) for articulation with the radial carpal bone. The ulna and radius also articulate with one another at both the proximal and distal ends.

The wrist or carpus of all birds is made up of two *ossa carpalia*. According to Ede (1964) the *os carpi radiale* (Figure 2.11/11) originated from the fusion of the first centrale, radiale and intermedium, whilst the *os carpi ulnare* (Figure 2.11/10) is formed by the fusion of the ulnare and pisiform. The major articulation surface of the metacarpal bones (Figure 2.11/12) is the fusion product of the second, third and fourth centrale; first, second, third, fourth and fifth carpale; and heads of the metacarpal bones.

The *metapodium* (Figure 2.11/12) consist of the abovementioned fused carpal bones as well as the first (Figure 2.11/13), second (Figure 2.11/15) and third (Figure 2.11/14) carpometacarpal bones or *ossa carpometacarpalia*.

There are three fingers (*digiti manus*) corresponding to the three rays of the metapodium. The first finger, the thumb or *pollex* (Figure 2.11/16) consists of a first and second phalanx, the last covered by a nail. The second digit is the most strongly developed with a first (Figure 2.11/18) second (Figure 2.11/19) and third phalanx, with a nail. The third digit (Figure 2.11/17) has only one phalanx immediately beside the first phalanx of the second digit.

2.5 SKELETON OF THE HINDLIMB (*membra pelvini*)

2.5.1 BONES OF THE PELVIC GIRDLE (*ossa cinguli membri pelvini*)

The pelvic girdle of birds is very large and this is related to their bipedal standing posture because their hind limbs are their only equipment for support and walking. The true pelvic girdle consists of two hip bones (*ossa coxae*), each of which is made up of an ilium (Figures 2.1/8, 2.12/9), an ischium (Figures 2.1/9, 2.12/9 and 2.13/8) and a pubis (Figures 2.1/10, 2.12/11 and 2.13/7), although some of the thoracic, all of the lumbar and sacral, and some of the sacro-caudal vertebrae are immovably fused to these bones.

The *os ilium* can be differentiated into a pre-acetabular (Figure 2.1/8' and 2.1/5") and a postacetabular (Figures 2.1/8" and 2.12/5') part. The ilia are joined dorsally to the spinous and transverse processes of the vertebrae of the synsacrum. The ilia are spearpoint-shaped, with the sharp end pointing in a caudal direction. Together with the cranial parts of the ischium and pubis, the ilium form the ring-shaped *acetabulum* (Figure 2.12/7). The involvement of the pubis is minimal however. The *antitrochanter* (Figures 2.12/6 and 2.13/6) is formed by the ilium and cranial end of the ischium and lies directly caudal to the *acetabulum*.

The *os ischium* is a long bony plate reaching from the *antitrochanter* to the caudal point of the ilium. Its thickened cranial part participates in the formation of the *acetabulum*, while its postacetabular ventral border, together with the dorsal border of the pubis, forms the *incisura puboischiadica* (Figure 2.12/B). Approximately 5 cm from its cranial end, the ischium has a distinct process on the ventral border deviding the *incisura puboischiadica* and thus forming the *foramen obturatum* (Figure 2.12/A).

The *os pubis* is a very long and thin bony plate, reaching from just ventral to the *acetabulum* in a caudoventral direction to form the most caudal point of the body of the ostrich. One quarter from the caudal end of the pubis it forms the synostosis with the ischium resulting in the *incisura puboischiadica*.

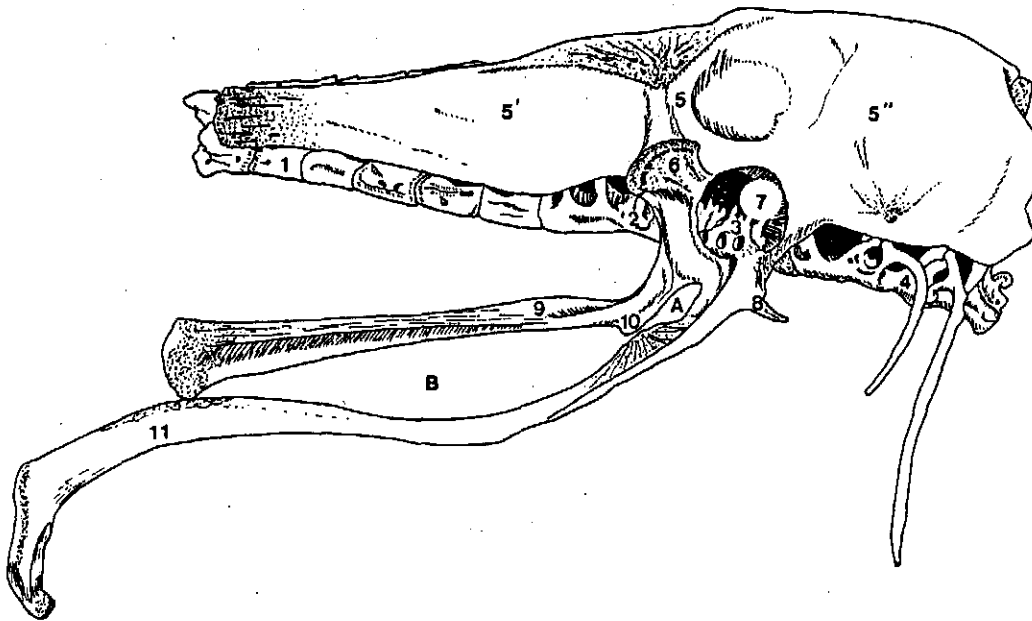


Figure 2.12 Lateral view of the pelvic girdle

1 sacro-caudal vertebrae; 2 sacral vertebrae; 3 lumbar vertebrae; 4 thoracic vertebrae; 5 ilium with its 5' postacetabular and 5'' pre-acetabular parts
6 antitrochanter; 7 acetabulum; 8 proc. pectinealis; 9 os ischium with 10 proc.;
11 pubis; A for. obturatum; B incisura puboischiadica

On the cranial tip of the pubis, the *processus pectinealis* (Figures 2.12/8 and 2.13/5) is very prominent. The pectineal process points in a cranial direction.

The two caudal parts of the pubii articulate with one another in the ostrich. This forms the pubic symphysis (Figure 2.13/10). According to George and Berger (1966) the ostrich is the only bird with a pubic symphysis. The area between the ischium and the pubis is occupied by the *m. obturator internus* (Figure 3.4/4) and not, as in other birds, by a membrane. The space between the ventral border of the ilium and the dorsal border of the ischium is however covered by a strong membrane.

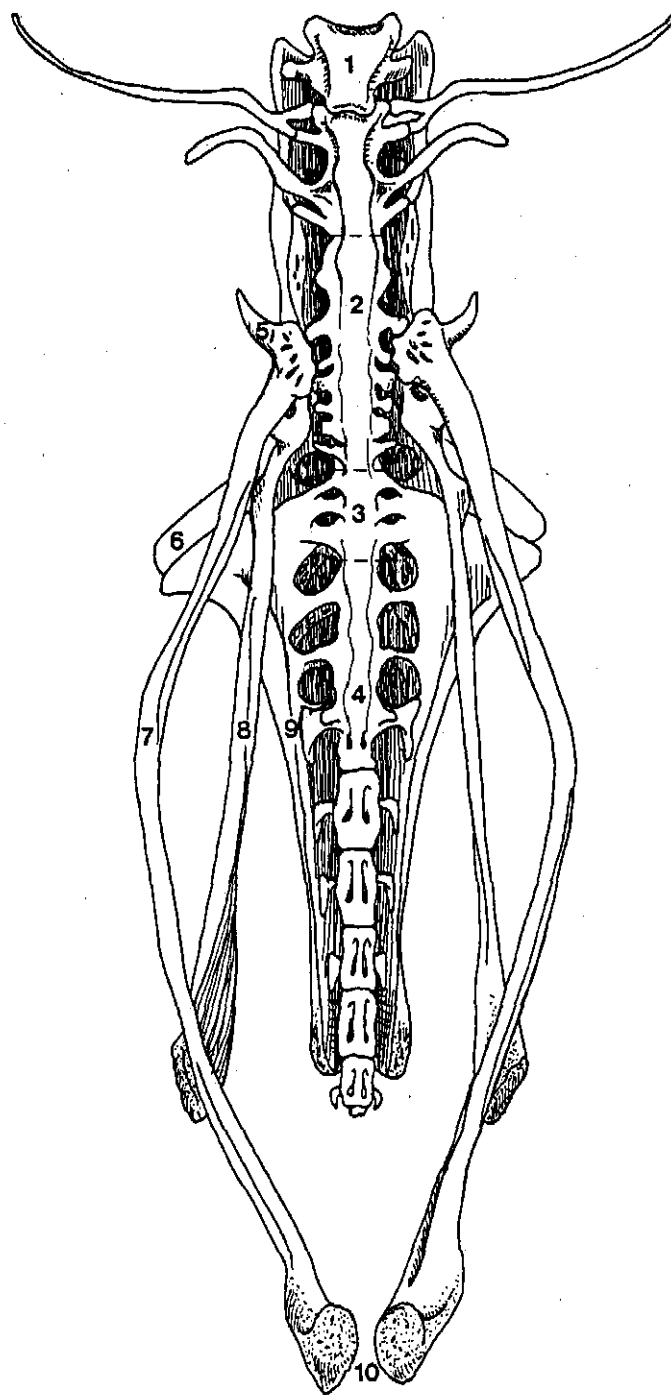


Figure 2.13 Ventral view of the pelvic girdle

1 thoracic vertebrae; 2 lumbar vertebrae; 3 sacral vertebrae; 4 sacro-caudal vertebrae; 5 proc. pectinealis; 6 antitrochantor; 7 pubis; 8 ischium; 9 ilium; 10 pubic symphysis

2.5.2 BONES OF THE PELVIC LIMB (*ossa membri pelvini*)

The *femur* or *stylopodium* (Figures 2.1/22 and 2.14) is a strong tubular bone. The hemispherical *caput femoris* (Figure 2.14/3) is situated on a very short neck which projects medially, almost at a right angle with the proximal end of the femur. The *trochanter major* (Figure 2.14/1) is very large with an articulation surface on the proximal end. This trochanteric surface of the femur articulates with the antitrochanter of the ilium and ischium. The cranial border of the greater trochanter continues distally on the cranial surface of the shaft as a thin bony ledge. On the caudal surface a similar ledge is present which serves as an attachment area of a few postacetabular leg muscles. The lesser trochanter is only a very small protuberance situated medially under the neck. The distal extremity of the femur is more complex than that of other birds as well as many mammals (e.g. the horse, the ox, the sheep and the dog as described by Getty, 1975). On its cranial surface the *trochlea femoris* (Figure 2.14/9) separates the medial (Figure 2.14/8) and lateral (Figure 2.14/10) epicondyles. On the caudal surface the intercondyloid fossa (figure 2.14/6) separates the medial (Figure 2.14/7) and lateral (Figure 2.14/4 & 5) condyles. The lateral condyle has a deep groove for articulation with the fibula. The lateral epicondyle and medial condyle articulates with the tuberosity of the tibia, and the medial condyle with the caudal aspects of the condyle of the tibia.

The patella (Figure 2.1/23) of the ostrich is a small bone enclosed in the tendon of the patella, which covers the anterior surface of the knee joint. The patellar tendon is formed by the joined tendons of the *Mm. iliotibialis* (3.2.1 and 3.3.1), *femorotibialis ext.* (3.4.1), *femorotibialis med.* (e.4.3) and *rectus femoris* (3.4.2), and inserts mainly on the rotular crest of the tibiotarsus.

The *ossa cruris* (Figures 2.1/24 and 2.15) or zeugopodium consists of the tibia and fibula. The tibia (Figures 2.1/24' and 2.15/5) is a very strong, tubular bone, with the proximal

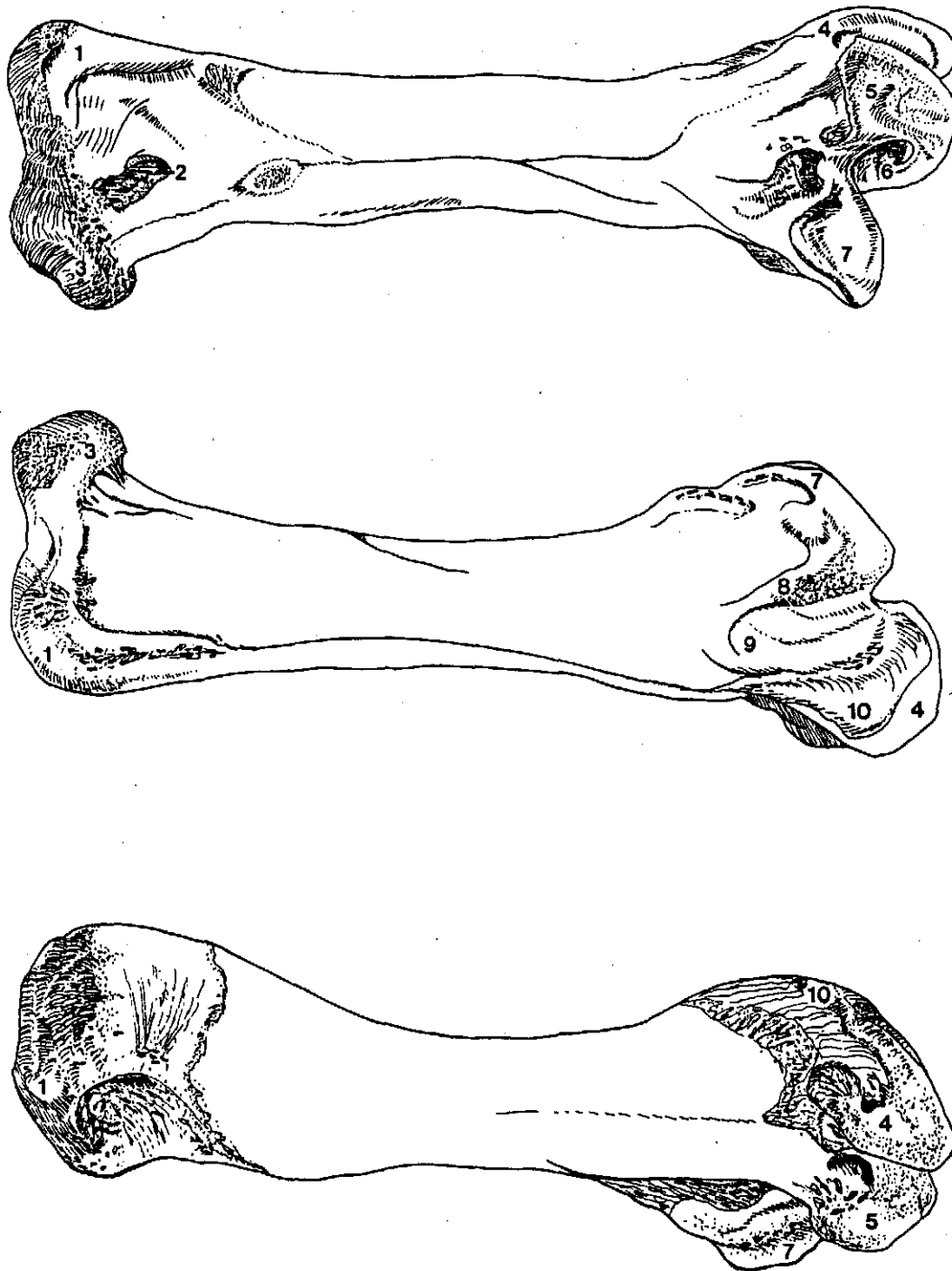


Figure 2.14 Caudal, cranial and lateral aspects of the right femur of the ostrich
 1 trochanter major; 2 nutrient foramen; 3 caput femoris; 4 & 5 condylus lat. with a deep groove for articulation with the fibula; 6 intercondyloid fossa; 7 condylus med.; 8 epicondylus med.; 9 trochlea femoris; 10 epicondylus lat.

row of tarsal bones (*ossa tarsalia*) fused to the proximal end. It is therefore termed tibiotarsus. The proximal end of the tibia bears two caudally directed condyles, as well as a cranially directed tuberosity. The lateral surface of the lateral condyle articulates with the medial surface of the head of the fibula (Figure 2.15/2). The distal extremity of the tibiotarsus is characterised by a symmetrical trochlea (Figure 2.15/6).

The fibula (Figures 2.1/24" and 2.15/2) has a prominent head (Figure 2.15/1) which articulates with the lateral surface of the tibia as well as the lateral condyle of the femur. On the lateral border there is a distinct process (Figure 2.15/3) for attachment of the *Mm. iliotibularis* and *flexor cruris lat. et med.* (Figure 3.8/19). The rest of the body of the fibula is very thin and in close association with the lateral surface of the tibia.

The *tarsometatarsus* (Figure 2.1/25 and 2.15) of the adult ostrich consists of a single bone derived from the fusion of the metatarsal and tarsal bones. The proximal end of the tarsometatarsus bears two concave articular surfaces (Figure 2.15/7) separated by a protruberance. These surfaces articulate with the tibiotarsus in the *art. intertarsia*. The distal end of this bone bears two *trochleae* (Figure 2.15/8 and 9), separated by a deep groove. The trochlea for the first toe is situated medially and is much larger than the lateral trochlea for the second and last toe.

The toes or *digiti pedis* (Figure 2.1/26 and 2.15/10 and 11) each has four phalanges, with the last phalanx of the first toe pointed to form the claw (Figure 2.15/12), covered by a big nail. The other phalanges have a concave articulation surface proximally and a trochlea distally.

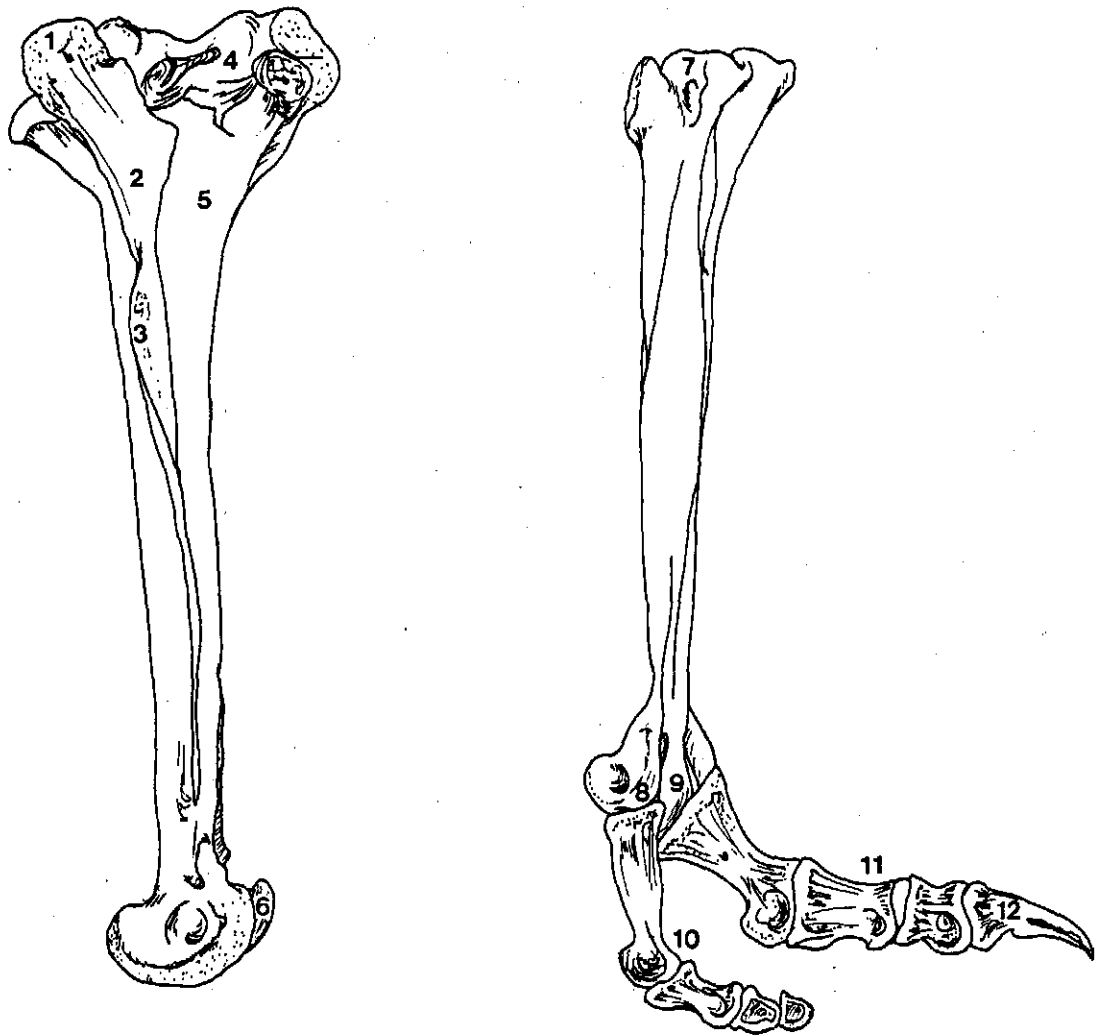


Figure 2.15 Lateral aspects of the right lower leg (tarsometatarsus) and foot of the ostrich
 1 capitulum of 2 fibula; 3 proc. for attachment of *m. iliofibularis* 4 condylus of
 5 tibia; 6 trochlea art.; 7 facies art. prox. of the tarsometatarsus; 8 and 9 trochleae
 artt. for the first phalanges of the second and first toes respectively; 10 second and
 11 first toes; 12 claw

3 MUSCLES OF THE PELVIC LIMB

3.1 GENERAL CONSIDERATIONS

The nomenclature of avian anatomy is still confusing due to the numerous attempts of several authors to apply terms used in human and veterinary anatomy directly to birds, while others invented terms which increased the confusion. In this study the nomenclature used is in agreement, where applicable, with that used by the United States Department of Agriculture (Lucas and Stettenheim, 1972), Getty (1975), Nomina Anatomica (1977), Chamberlain (1943), and George and Berger (1966).

In order to compare the ostrich with other birds, it is necessary to briefly explain the muscle formulations invented by Garrod, modified by Hudson and later by Berger (George and Berger, 1966). Some birds lack certain muscles and this led to the introduction of the muscle formulas of which an applicable extract is presented in Table 3.1 (from: George and Berger, 1966).

Table 3.1 Symbols for formula muscles

<u>Code letter</u>	<u>Name of muscle</u>
A	<i>Pars caudofemoralis, M. caudiliofemoralis</i> ¹
B	<i>Pars iliofemoralis, M. caudiliofemoralis</i> 1
C	<i>M. ilioprochantericus med.</i>
D	<i>M. ilioprochantericus ext. et int.</i> ²
E	<i>M. iliacus</i>
X	<i>M. flexor cruris lat.</i> ³
Y	<i>Pars acc., M. flex. crur. lat.</i>
Am	<i>M. ambiens</i>

1 *M. piriformes* (George and Berger, 1966)

2 *M. gluteus med. et min.* (George and Berger, 1966)

3 *M. semitendinosus* (George and Berger, 1966)

With reference to Table 3.2, the ostrich has A,B,C,D,X,Y and Am, but lacks E. In addition, of all birds the *M. gracilis* is unique to the ostrich, and the femorotibial muscles consists, like in mammals, of four muscles (*M. quadriceps femoris*) whereas it comprises only three muscles (*Mm. femorotibialis*) in all other birds. The nomenclature of the femorotibial muscles of mammals and birds are shown in Table 3.2, together with the chosen terms for the ostrich.

Table 3.2 Descriptive terms of the femorotibial muscles of mammals, the ostrich and birds in general

Region of the thigh	Mammals	Ostrich	Birds
Lateral (external)	<i>M. vastus lat.</i>	<i>M. femorotib. ext.</i>	<i>M. femorotib. ext.</i>
Cranial	<i>M. rectus fem.</i>	<i>M. rectus fem.</i>	} <i>M. femorotib. med.</i>
Caudolateral	<i>M. vastus intm.</i>	<i>M. femorotib. med.</i>	
Medial	<i>M. vastus medi.</i>	<i>M. femorotib. int.</i>	<i>M. femorotib. int.</i>

The chosen terms is in agreement with general avian anatomy nomenclature, although *lateralis*, *intermedius* and *medialis* is still preferred above *externus*, *medius* and *internus* respectively by Nomina Anatomica (1977), dealing with mammals only.

3.2 PRE-ACETABULAR REGION

3.2.1 *M. iliotibialis cranialis*

The *M. iliotibialis cran.* (Figure 3.1/1 and Figure 3.2/1) is a straplike parallel-fibred muscle forming the craniolateral border of the thigh. Most authors refer to this muscle in other birds as the *M. sartorius*, for example Koch (1973), George and Berger (1966), Bradley and Grahame (1950), Ede (1964), Nickel, *et al.* (1977) and Chamberlain (1943), because it resembles this muscle of the mammalian thigh. Getty (1975) suggested however that this muscle be called *M. iliotibialis cran.* since it does not represent a homologue of the *M. Sartorius* of mammals.

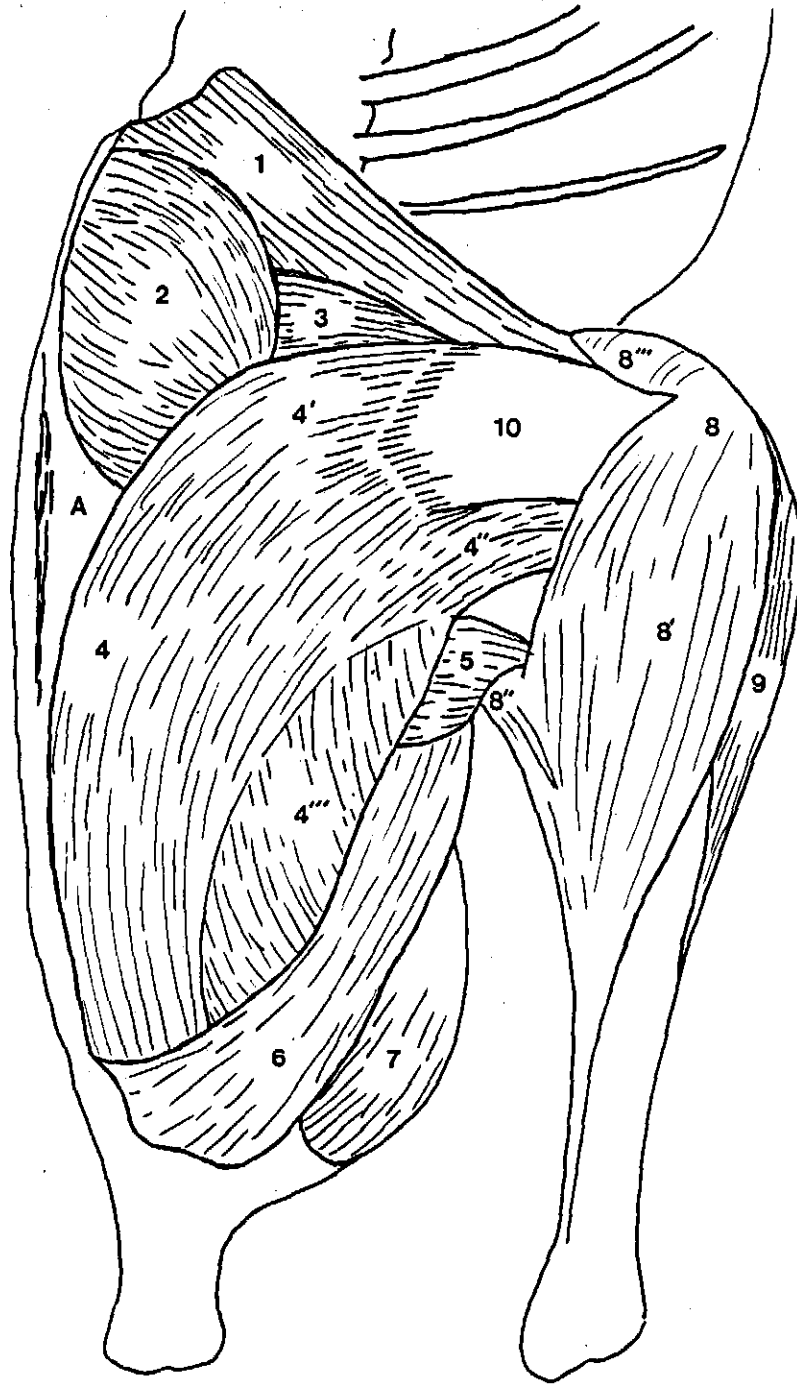


Figure 3.1 Lateral view of the superficial muscles of the right leg of the ostrich
 1 M. iliotibialis cran.; 2 M. ilirotrochantericus ext.; 3 M. ambiens; 4 M. iliotibialis lat. with its 4' cranial, 4'' medial and 4''' caudal parts; 5 M. iliofibularis; 6 M. flexor cruris lat.; 7 M. obturator int.; 8 M. gastrocnemius with 8' pars externus, 8'' pars media and 8''' pars interna; 9 M. peroneus longus; 10 M. femorotibialis ext.; A ilium

This muscle originates from the craniolateral rim of the pre-acetabular iliac crest (Figure 3.8/7) as well as by aponeurotic attachments to dorsal fascia of the caudal thoracic vertebrae. It finds its insertion on the medial surface of the patella and contributes thereby to the medial portion of the patellar ligament to the head of the tibiotarsus.

The action of this muscle is firstly to extend the knee joint and the tibiotarsus, opening the angle between the femur and tibiotarsus, and secondly to flex the hip joint, closing the angle between the cranial part of the ilium and the femur in a non-weightbearing limb.

3.2.2 *M. ilioprochantericus externus* (Figure 3.2/2)

This muscle is a thin, convex muscle covering a large superficial pre-acetabular area of the hip of the ostrich. It is triangular in shape lying over the dorsal aspects of the hip joint and extends distally over the trochanter of the femur. This may be the equivalent of the gluteus maximus of mammals.

The *M. ilioprochantericus ext.* finds its origin on the full length of the pre-acetabular iliac crest (Figure 3.8/1). The belly tapers to a wide, flat tendon inserting on the lateral surface of the trochanter of the femur (Figure 3.8/8) by a common tendon with the internal ilioprochanteric muscle (3.2.3).

The action of this muscle is mainly to govern the rotation of the thigh and it probably plays no significant role in abduction of the thigh.

3.2.3 *M. ilioprochantericus internus* (Figure 3.2/2)

The internal trochanteric muscle is identical in shape and size as its external counterpart (3.2.2), which covers it completely. The only difference is that the internal muscle is concave on its lateral border. It probably corresponds to the gluteus minimus of mammals.

This muscle originates on the full length of the pre-acetabular iliac crest, just ventral to 3.2.2 (Figure 3.8/2). The belly

This muscle originates from the craniolateral rim of the pre-acetabular iliac crest (Figure 3.8/7) as well as by aponeurotic attachments to dorsal fascia of the caudal thoracic vertebrae. It finds its insertion on the medial surface of the patella and contributes thereby to the medial portion of the patellar ligament to the head of the tibiotarsus.

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The *M. ilioprochantericus ext.* finds its origin on the full length of the pre-acetabular iliac crest (Figure 3.8/1). The belly tapers to a wide, flat tendon inserting on the lateral surface of the trochanter of the femur (Figure 3.8/8) by a common tendon with the internal ilioprochanteric muscle (3.2.3).

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This muscle originates on the full length of the pre-acetabular iliac crest, just ventral to 3.2.2 (Figure 3.8/2). The belly

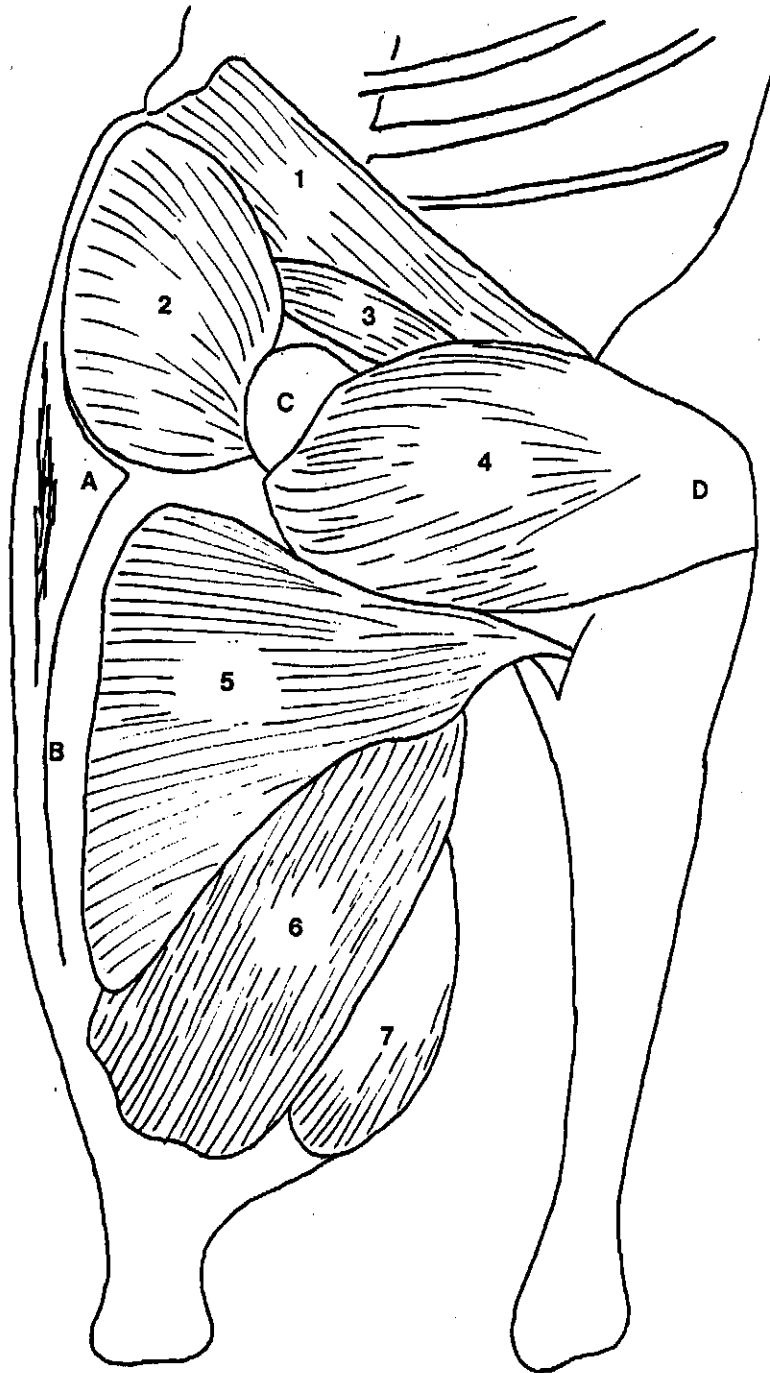


Figure 3.2 Lateral view of the second layer of muscles of the right leg of the ostrich

1 M. iliobtibialis cran.; 2 M. ilirotrochantericus int.; 3 M. ambiens; 4 M. femorotibialis ext.; 5 M. iliofibularis; 6 M. flexor cruris lat.; 7 M. obturator int.; A ilium; B iliac crest; C trochanter major of the femur; D patellar ligament

also tapers to a wide, flat tendon inserting on the lateral surface of the trochanter of the femur (Figure 3.8/8) by a common tendon with 3.2.2.

The external and internal trochanterici governs the rotation of the femur in the acetabulum.

3.2.4 *M. ilioprochantericus cranialis* (Figure 3.3/1)

This is a very small, spear-shaped muscle extending in a caudo-ventral direction to reach the cranio-lateral edge of the trochanter of the femur.

The origin of this muscle is on the lateral surface of the pre-acetabular ilium, ventral to the cranial tip of origin of the two preceding muscles (Figure 3.8/5). The small belly tapers to a thin tendon, inserting on the cranio-lateral edge of the greater trochanter.

The cranial trochantericus is responsible for the medial rotation of the thigh.

3.2.5 *M. ilioprochantericus medius* (Figure 3.3/2)

The medial ilioprochantericus (C in Table 3.1) is very well developed in the ostrich and is very fleshy and triangular-shaped. This muscle covers the entire area between the cranial and caudal ilioprochanterici, and inserts on the femur.

This muscle originates on the surface of the pre-acetabular ilium (Figure 3.8/4) with its tendon inserting on the cranio-dorsal edge of the trochanter of the femur (Figure 3.8/10) between the cranial and caudal ilioprochanterici insertion areas.

The action is a small contribution to the medial rotation of the thigh.

3.2.6 *M. ilioprochantericus caudalis* (Figure 3.3/3)

The shape of the caudal ilioprochantericus is similar to that of the described cranial ilioprochantericus (3.2.4).

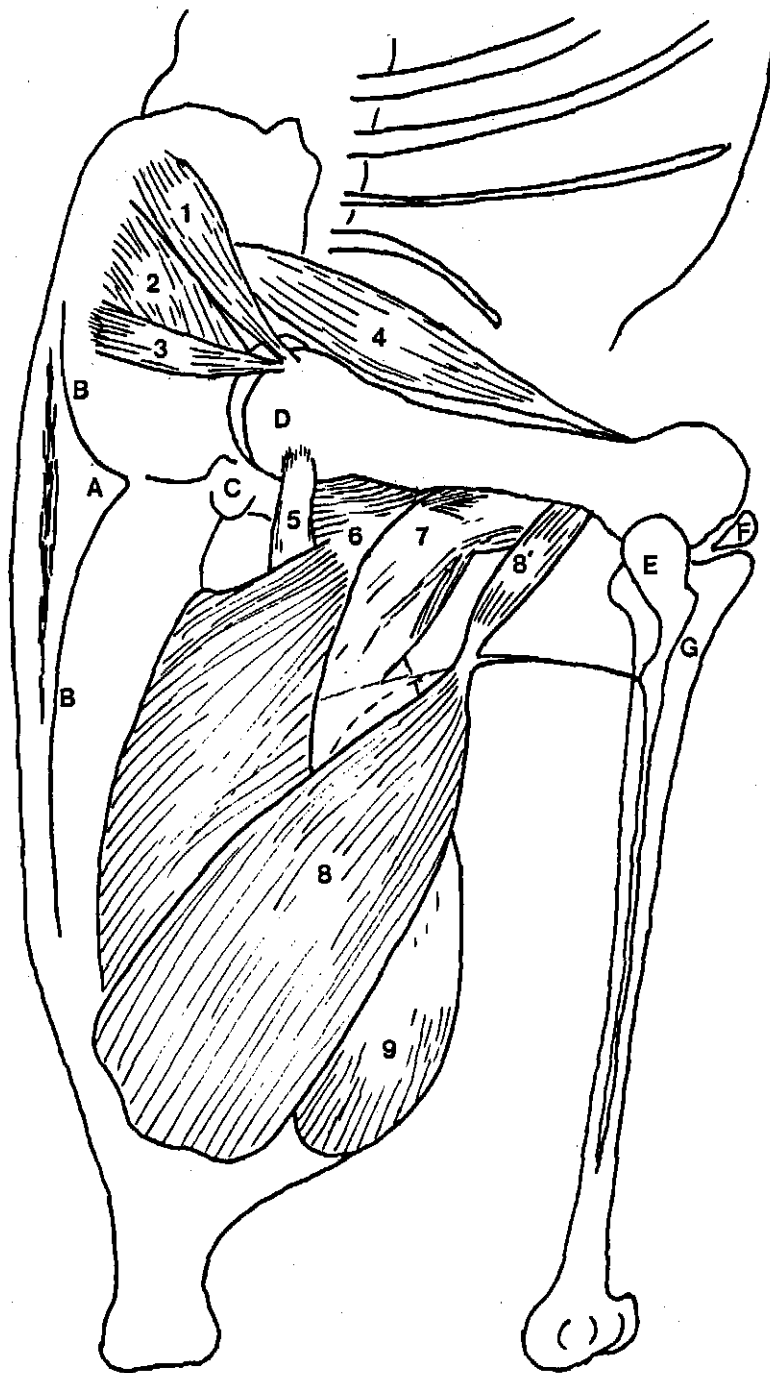


Figure 3.3 Lateral view of the third layer of muscles of the right leg of the ostrich

1 ilirotrochantericus cran.; 2 ilirotrochantericus med.; 3 ilirotrochantericus caud.;
 4 M. ambiens; 5 M. ischiofemoralis; 6 M. caudiliofemoralis; 7 pubischiofemoralis;
 8 M. flexor cruris lat. with 8' part accessorius; 9 M. obturator int.; A ilium; B iliac
 crest; C antitrochanter; D trochanter major; E fibula; F patella; G tibia

It originates on the lateral surface of the pre-acetabular ilium (Figure 3.8/3), ventral to and in the middle of the origin of the external and internal trochanterici. The point of insertion is on the craniolateral edge of the trochanter of the femur, caudally to that of the cranial trochantericus (Figure 3.8/9).

The action of this muscle is to rotate the thigh medially.

3.2.7 *M. ambiens* (Figures 3.2/3, 3.2/3 and 3.3/4)

The ambiens muscle (Am in Table 3.1) is characteristic of birds and reptiles, but has been considered a homologue of the pectineus of mammals (Getty, 1975). In general it can be said that the ambiens arises by a short aponeuroses from the ventral edge of the cranial portion of the pubis ventral to the acetabulum (George and Berger, 1966), or from the pectineal processes of the pubis (Koch, 1973, and Getty, 1975). Its tendon transverses the patellar ligament diagonally and lateral over the cranial aspect of the knee, descends along the cranial surface of the fibula and is continuous with the aponeuroses of origin of one or more of the flexor muscles of the second, third or fourth digits. The ambiens is also claimed to be the most medial muscle in the thigh of birds (George and Berger, 1966). The pectineus of mammals on the other hand originates from the brim of the pubis and inserts on a roughened surface on the inner side of the femur and medial epicondyle (Sisson & Grossman, 1953).

Although Garrod & Darwin (1873) reported a well developed ambiens in *Struthio camelus*, they failed to report that, in the case of the ostrich, the ambiens does not originate on the pubis, and that it is not the most medial muscle of the thigh.

The ambiens muscle in the ostrich is visible on the lateral surface of the thigh just caudally to the cranial iliotibialis muscle. It is cylindrical in shape and tapers to a cord-like tendon in the region of the knee joint.

The ambiens originates on the lateral surface of the pre-acetabular ilium, ventral to the origin of the medial trochantericus.

The tendon passes along the medial surface of the patella, takes a diagonal course (from medial to lateral) within a compartment in the patellar ligament, reaches the lateral surface of the knee, and then continues downward to give rise to the origin of the flexor muscle of the second digit.

The ambiens is responsible for the automatic grasping action as well as extension of the tibiotarsus.

3.2.8 *M. gracilis* (Figure 3.7/2)

As already mentioned, the ambiens normally originates at the pectineal process, but, in the case of the ostrich, the gracilis occupies this attachment area as well as the medial space normally occupied by the ambiens. The gracilis reaches further down than the ambiens and the flat belly tapers to a short tendon on the medial surface of the tibia head.

The gracilis originates by a short aponeurosis on the lateral surface of the pectineal process, reaching well into the cranial edge of the acetabulum. The short tendon inserts on the medial surface of the tibial condyle together with the internal femorotibial muscle (3.4.4).

The gracilis is an adductor and flexes the hip joint, closing the angle between the pre-acetabular ilium and the femur.

3.3 POSTACETABULAR REGION

3.3.1 *M. iliotibialis lateralis* (Figure 3.1/4)

The lateral iliotibial muscle covers almost the entire lateral postacetabular surface of the thigh as well as the femorotibial muscles (3.5). It is triangular in shape and three distinct parts can be identified, namely a cranial (Figure 3.1/4'), medial (Figure 3.1/4'') and caudal (Figure 3.1/4''') section.

The cranial part resembles the *M. tensor fasciae latae* in mammals and is wide and flat, with the muscle fibres ending approximately in the half of the thigh, with only a very thin,

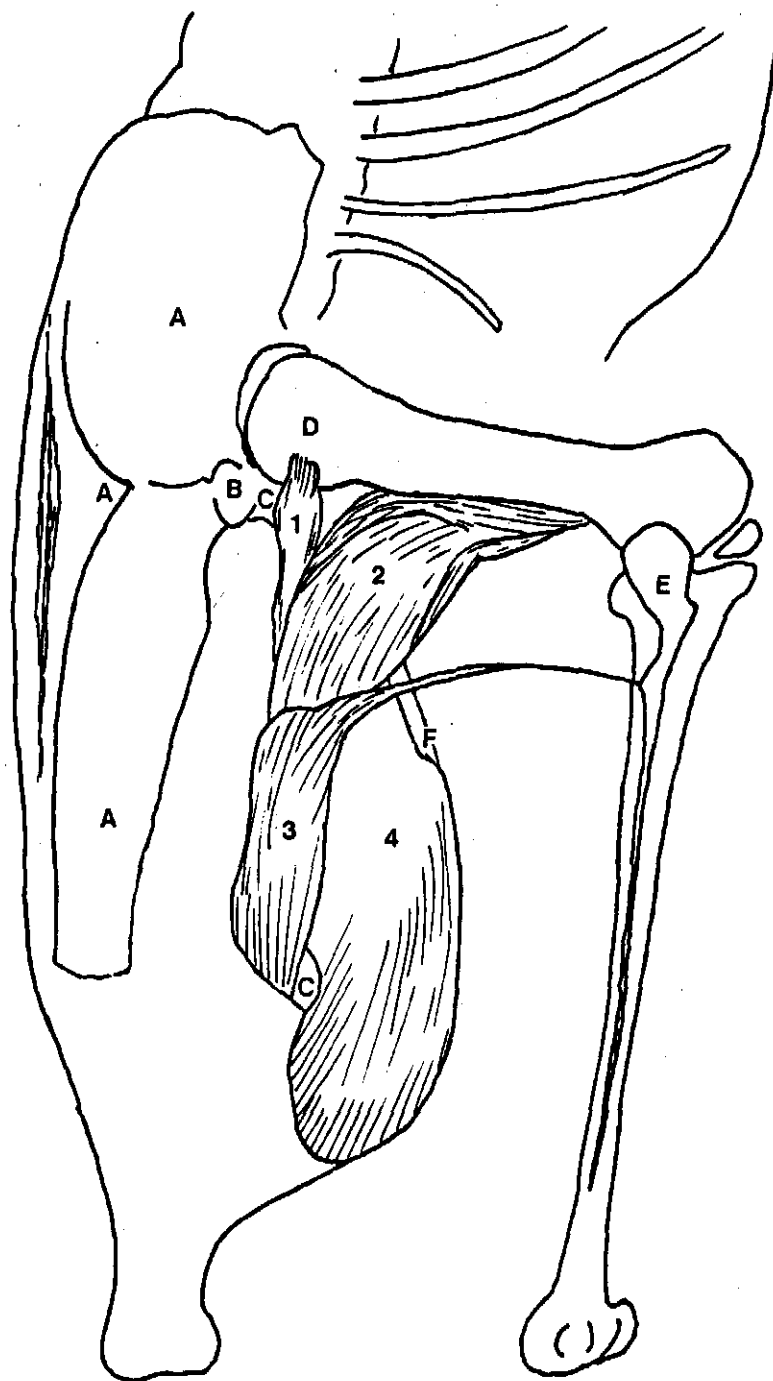


Figure 3.4 Lateral view of the fourth layer of muscles of the right leg of the ostrich

1 M. ischiofemoralis; 2 M. pubischiofemoralis; 3 M. flexor cruris med.; 4 M. obturator int.; A ilium; B antitrochanter; C ischium; D trochanter major; E fibula; F pubis

wide and transparent fascial sheath covering the rest of the upper leg which disappears under both heads of the gastrocnemius muscle in the region of the knee joint.

The medial section of the lateral iliotibial muscle covers the area directly caudal and ventral to the cranial section. The fleshy belly reaches further down than that of the cranial part and disappears under the external part of the gastrocnemius muscle.

The caudal section is almost horizontally fibred and reaches from a ventral position of the cranial section, to join the medial part close to the knee joint.

The origin of the lateral iliotibialis is fleshy on the entire length of the postacetabular ilium, on and ventral to the iliac crest (Figure 3.8/20). The insertion is via the fascial sheath enclosing the femorotibialis, thereby contributing to the formation of the patellar tendon to the tibiotarsus.

This muscular complex assist in the extension of the thigh and shank, with a lateral turning of the tibiotarsus. Furthermore it assists in the abduction of the leg.

3.3.2 *M. iliofibularis* (Figures 3.1/5 and 3.2/5)

The iliofibularis is comparable to the *M. biceps femoris* of mammals and many authors refer to this muscle as the biceps. It is a very large, fleshy, triangular-shaped muscle, occupying the lateral area medial to the lateral iliotibialis. The base of the triangle is attached to the entire length of the postacetabular ilium and the "point" of the triangular splits the caudal section of the gastrocnemius into an external and medial section. The muscle is slightly darker than the rest of the muscles of the hindlimb.

The iliofibularis originates by fleshy fibres on the postacetabular iliac crest, under (ventral to) the origin of the lateral iliotibialis (Figure 3.8/21). The belly tapers to a tendon which resembles a thick cord passing through the liga-

mentous loop to insert on the protuberance of the fibula (Figures 2.15/3 and 3.8/19).

The iliofibularis is a very strong flexor of the knee joint and an important muscle for the locomotion of the (flightless) ostrich. This muscle, together with the semitendinosus (3.3.3) and semimembranosus (3.3.5), resembles the "hamstring" group of mammals and only these muscles are responsible for the flexing of the knee joint.

3.3.3 *M. flexor cruris lateralis* (Figures 3.1/6, 3.2/6 and 3.3/8)

This is the homologue of the semitendinosus muscle of mammals and commonly referred to as such in birds. The head and a large part of the body is visible on the lateral surface of the thigh, protruding under the iliotibialis lateralis (3.3.1), with the tapering body passing medial to the iliofibularis (3.3.2). In this region the tendon meets the aponeurosis of the accessory semitendinosus (Figure 3.3/8') and also branches off to join the tendon of the semimembranosus. The semitendinosus and accessory muscle are represented by the symbols X and Y respectively in the muscle formulas (Table 3.1).

The semitendinosus originates from the caudal extremity of the ilium and ischium, as well as the transverse processes of two or three free coccygeal vertebrae (Figure 3.8/23). The insertion of this muscle is by a common tendon with the semimembranosus (3.3.5) on the protuberance of the fibula (Figure 3.8/19) as well as the origin of the accessory semitendinosus, which in turn is attached to the caudolateral surface of the femur (Figure 3.8/18), mainly on some part of the distal half.

This muscle, together with the biceps femoris (3.3.1) and the semimembranosus (3.3.5), acts as a flexor of the knee joint, and it also extends the hip joint (closing the angle between the postacetabular ilium and the femur).

3.3.4 *M. caudiliofemoralis* (Figure 3.3/6)

This muscle is commonly known as the piriformis in birds because it resembles this muscle of mammals. It is however normally of two distinct parts in birds. Although the piriformis of the ostrich also consists of two parts (A and B in the muscle formulas in Table 3.1), the *pars caudofemoralis* originates on the ilium and coccygeal vertebrae and inserts on the femur, but the *pars iliofemoralis* is only attached to the *pars caudofemoralis* and the femur, and not to the ilium. The piriformis of the ostrich is also very dark in colour and a thin, rectangular sheetlike muscle completely covered by the biceps femoris and the semitendinosus.

This muscle originates on the ventrolateral brim of the postacetabular iliac shaft (Figure 3.8/22) and the free coccygeal vertebrae with the insertion on the proximal third of the caudolateral surface of the femur (Figure 2.8).

The piriformis of the ostrich is most likely a "postular" muscle, without any significant action on extension of the thigh.

3.3.5 *M. flexor cruris medialis* (Figure 3.4/3)

This is the third member of the mammalian hamstring muscles, namely the semimembranosus. It is completely covered by the semitendinosus, and is an almost cylindrical muscle. Its round belly tapers to a long tendon, joining that of the semitendinosus.

The semimembranosus originates on the shaft of the ischium (Figure 3.8/24) as well as the membrane between the ischium and the ilium. It finds its insertion by a long common tendon with the semitendinosus (3.3.3) on the protuberance of the fibula.

The action of this muscle is both to flex the tibiotarsus and to resist extension of the tibiotarsus as other extensor muscles contract.

3.3.6 *M. pubischiofemoralis* (Figures 3.3/7 and 3.4/2)

The pubischiofemoralis muscle is also known as the adductor

femoris muscle. The muscle consists of two distinct parts, which also varies in colour. The dark outer (craniodorsal and caudoventral) section is considered by some (e.g. Getty, 1975) as the *pars superficialis* and the lighter central section as the *pars internus*. The two sections are so closely associated that they are considered essentially one muscle.

The origin of the adductor femoris is both on the lateral surface of the ischium and the pubis (Figure 3.8/25), while it inserts on the caudolateral surface of the femur (Figure 3.8/16).

The pubischiofemoralis is an adducter of the femur and also prevents the forward movement of the femur and hence a "postural" muscle.

3.3.7 *M. ischiofemoralis* (Figures 3.3/5 and 3.4/1)

This is a very short, thick cylindrical muscle extending from the ischium in a cranio-lateral direction towards the caudal aspect of the trochanter of the femur.

The ischiofemoralis muscle finds its origin on the lateral surface of the ischium, in the region of and caudal to the obturator foramen (Figure 3.8/26). The insertion on the lateral surface of the trochanter (Figure 3.8/13) is brought about by a very short, firmly attached tendon.

The action of this muscle is to rotate the thigh outwards.

3.3.8 *M. obturator internus* (Figures 3.1/7, 3.2/7, 3.3/9 and 3.4/4)

The internal obturator is a very big muscle in the ostrich covering the *incisura puboischiodica*. The body tapers to a tendon in the region of the obturator foramen, through which it passes (from medial to lateral) to reach the trochanter of the femur.

This muscle originates on the entire medial surface of the ischium and the lateral and medial surfaces of the distal two thirds of the pubis. The flat tendon inserts on the cauda=

lateral surface of the trochanter of the femur, caudoventral to the insertion of the ischiofemorialis (3.3.7) (Figure 3.8/14).

The internal obturator is responsible for the caudolateral rotation of the thigh.

3.3.9 *M. obturator externus* (not illustrated)

On the caudoventral brim of the acetabulum, a small fleshy mass, reaching to the caudolateral side of the trochanter, represents the external obturator muscle of the ostrich.

The origin of this muscle is on and in the caudolateral border of the acetabulum (Figure 3.8/27). The insertion is by a wide tendon on the caudolateral surface of the caudal aspect of the trochanter of the femur (Figure 3.8/12), caudal to and under that of the ischiofemorialis (3.3.7).

3.4 MUSCLES OF THE THIGH

The muscles of the upper leg or thigh have been discussed in the general section of this chapter (see 3.1). The action of the *Mm. femorotibialis* is to extend the knee joint. It remains to describe the structure, origin and insertion of each individual muscle.

3.4.1 *M. femorotibialis externus* (Figures 3.1/10, 3.2/4 and 3.5/1)

The external femorotibial muscle is the biggest of the four different parts, covering the lateral surface of the upper leg of the ostrich. This muscle originates by aponeurosis on the lateral surface of the femur, distally to the trochanter of the femur. The flat tendon joins the tendon of the iliotibialis lateralis (3.3.1) to insert on the patellar ligament.

3.4.2 *M. rectus femoris* (Figure 3.6/1)

This muscle covers the cranial surface of the femur. It

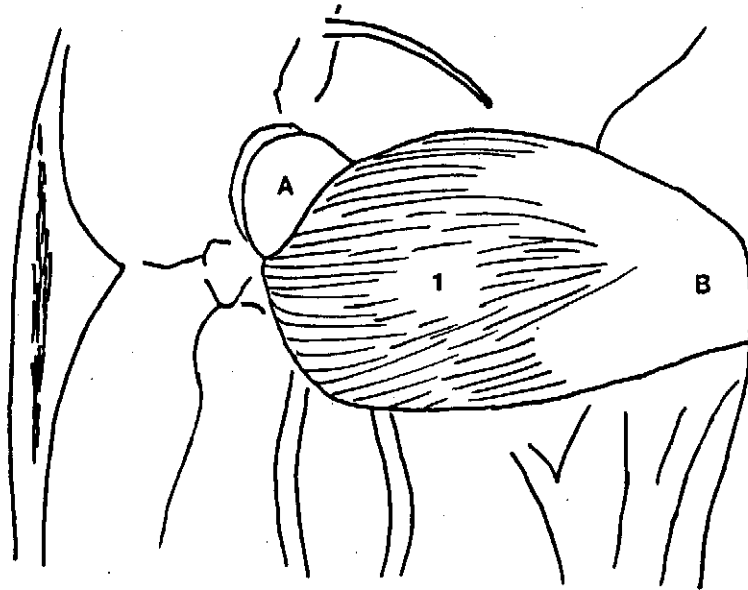


Figure 3.5 Lateral view of the superficial thigh muscles of the right leg of the ostrich

1 M. femorotibialis ext.; A trochanter major; B patellar ligament

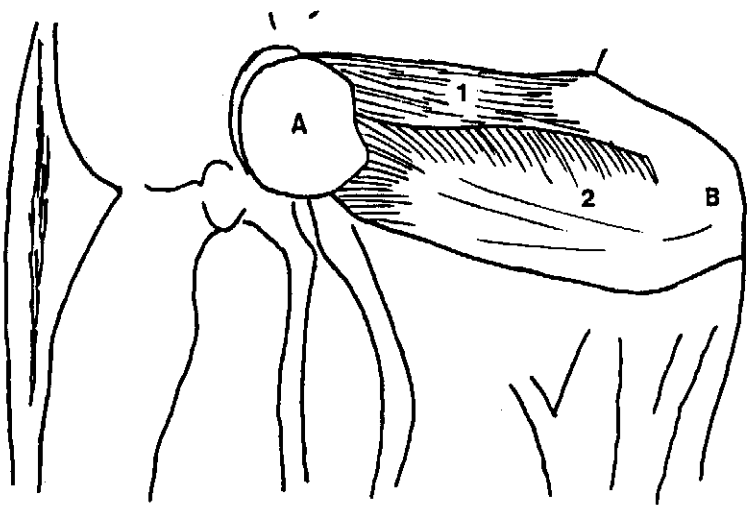


Figure 3.6 Lateral view of the second layer thigh muscles of the right leg of the ostrich

1 M. rectus femoris; 2 M. femorotibialis med.; A trochanter major; B patellar ligament

originates on the entire cranial and craniomedial surface of the femur, while its flat tendon joins that of the iliotibialis lateralis (3.3.1) and the lateral femorotibial muscle (3.4.1).

3.4.3 *M. femorotibialis medius* (Figure 3.6/2)

The medial femorotibial muscle is closely associated with the rectus femoris (3.4.2), but in the ostrich it is two different muscles. This muscle covers the full length of the femur distally to the trochanter. It finds its origin on the whole length of the lateral surface of the femur (Figure 3.8/17) and the flat tendon joins that of the rectus femoris (3.4.2) dorsally, and that of the iliotibialis lateralis (3.3.1) and lateral femorotibial muscle (3.4.1) medially.

3.4.4 *M. femorotibialis internus* (Figure 3.7/1)

This muscle originates on the medial and caudomedial length of the femur and its tendon joins the patellar ligament on the medial surface. It also inserts directly on the tibiotarsus.

3.5 MUSCLES OF THE LOWER LEG

In this section only two muscles are considered, namely the gastrocnemius and peroneus longus muscles. These two muscles are the biggest of the lower leg and since this study deals with the economical aspects of the ostrich carcass, the other muscles of the lower leg are omitted.

3.5.1 *M. gastrocnemius* (Figure 3.1/8)

The gastrocnemius muscle of the ostrich is the biggest and heaviest muscle of all. It almost covers the entire surface (lateral, caudal and medial aspects) of the lower leg.

The *pars externa* (Figure 3.1/8') originates on the lateral surface of the patellar ligament, while the body curves in a caudal direction to form a very thick tendon inserting with the other sections on the crux. The *pars media* (Figure 3.1/8")

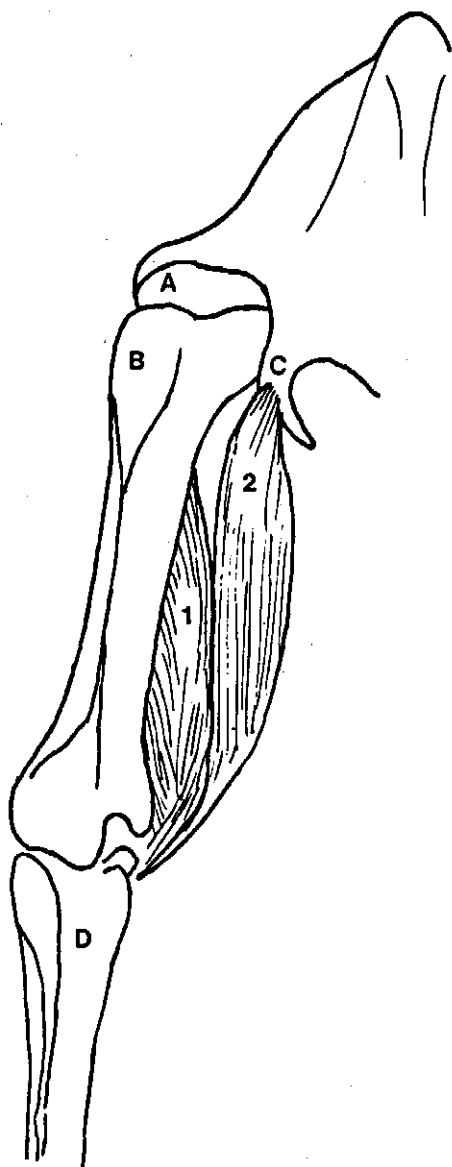


Figure 3.7 Cranial view of the medial layer thigh muscles of the right leg of the ostrich

1 M. femorotibialis int.; 2 M. gracilis A antitrochanter of the ilium; B trochanter major; C proc. pectinealis; D tibiotarsus

originates from the medial surface of the distal third of the femur and its tendon joins the external section. The *pars interna* originates on the craniomedial aspect of the patellar ligament and its tendon also joins that of the external and medial sections of the gastrocnemius.

The action of the gastrocnemius complex is to extend the tarsometatarsus.

3.5.2 *M. peroneus longus* (Figure 3.1/9)

The peroneus longus covers the cranial surface of the lower leg, not covered by the gastrocnemius.

The peroneus longus originates on the cranial aspect of the patellar ligament and patellar fascia, as well as the proximal end of the tibiotarsus, while it finds its insertion on the origin of one of the flexors of the digits in the metatarsus.

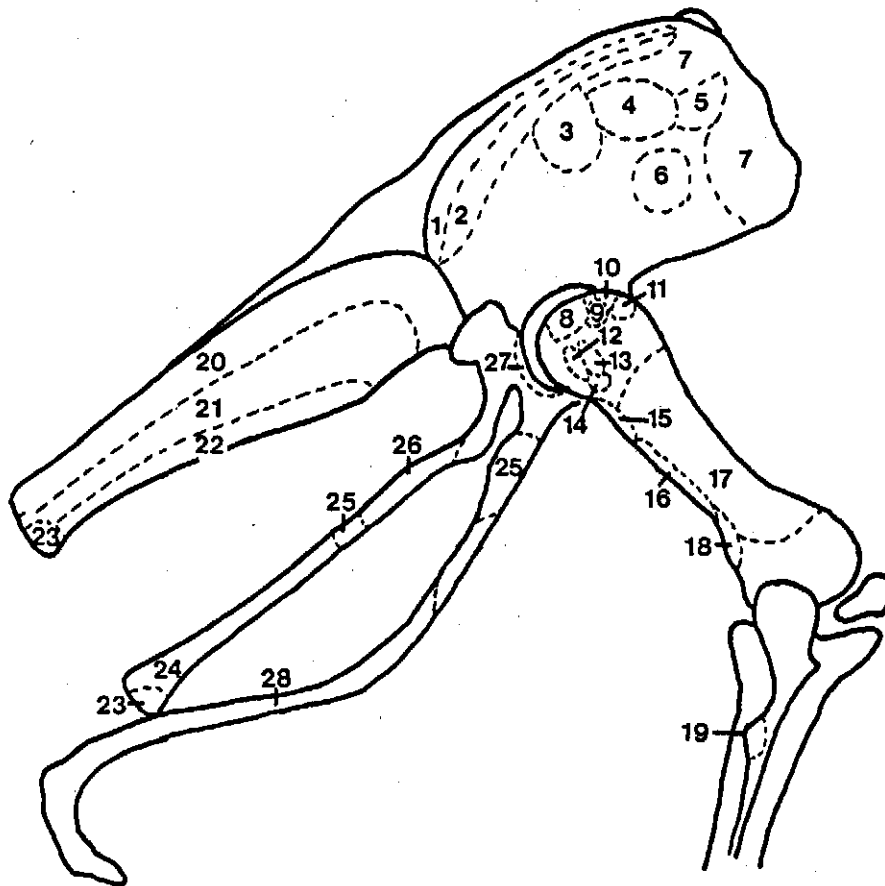


Figure 3.8 Origin (O) and insertion (I) points of some of the leg muscles of the ostrich

1 O: iliotrochantericus ext.; 2 O: iliotrochantericus int.; 3 O: iliotrochantericus caud.; 4 O: iliotrochantericus med.; 5 O: iliotrochantericus cran.; 6 O: ambiens; 7 O: iliobtibialis cran.; 8 I: iliotrochantericus ext. et int.; 9 I: iliotrochantericus caud.; 10 I: iliotrochantericus med.; 11 I: iliotrochantericus cran.; 12 I: obturator ext.; 13 I: ischiofemoralis; 14 I: obturator int.; 15 I: caudiliofemoralis; 16 I: pubischiofemoralis; 17 O: femorotibialis med.; 18 I: pars accessorius of the flexor cruris lat.; 19 I: iliofibularis and flexor cruris lat. et med.; 20 O: iliobtibialis lat.; 21 O: iliofibularis; 22 O: caudiliofemoralis; 23 O: flexor cruris lat.; 24 Lateral surface - O: flexor cruris med., Medial surface - O: obturator int.; 25 O: pubischiofemoralis; 26 O: ischiofemoralis; 27 O: obturator ext.; 28 O: obturator int.

4 COMMERCIAL CARCASS DIVISION AND MUSCLE MASS DISTRIBUTION

4.1 THE OSTRICH IN COMPARISON TO OTHER MEAT ANIMALS

The cuts with a high commercial value of beef, mutton and pork are the hind legs (rounds, legs or gammons) and loins, while the necks, shoulders, briskets and flanks take up a middle position, with the hind shanks (knuckles) and shins (hocks) the cheapest. In the case of cattle, the tail, commercially and in retail known as oxtail, is also considered an expensive cut. In poultry meat again the breast muscles, thighs and lower legs (drumsticks) are higher in commercial value than the necks and wings. The abovementioned price differentials are obviously related to seasonal demands, and also differs from every culture and country. X In this study all comparisons shall be made with the emphasis on the South African market, including raw cuts like steaks (tender, boneless meat which can be barbequed, grilled or fried), fillets (very tender boneless meat which can be barbequed, grilled or fried), cutlets (bone-in portions to be barbequed or grilled), as well as meat for biltong preparation (a dried, salted meat product produced from parallel fibred muscles, usually unsuitable for steaks or fillets), minced sausage meat or minced dried sausage meat (usually high collagen content) and factory meat (offcuts of all abovementioned cuts and mechanically deboned meat for the production of comminuted products).

X The percentage high value cuts of the ostrich is compared to similar cuts of pork, beef and lamb in Table 4.1. The fillet of the ostrich is not the homologue to that of other meat animals (*M. psoas major*). From the data in Table 4.1 it is clear that in the ostrich the high commercial value cuts vary between 80 to 90% of the carcass, whereas the other animals average about 45%. Furthermore, the two cuts from the ostrich leg sold as fillet comprise 10% of the carcass while beef fillet comprise 2% only of the carcass. The ostrich is indeed the "perfect" meat animal.

When the neck is added to the high commercial value cuts of the ostrich, and the tail to that of beef, these cuts comprise 93% of an ostrich carcass, and 52% of a beef carcass. The actual

masses of commercial cuts of an ostrich carcass are presented in Table 4.2, together with the cuts expressed as a percentage of the total carcass.

Table 4.1 The hind limbs, loins and fillets expressed as a percentage of total carcass mass of different meat animals ¹

<u>Animal</u>	<u>Carcass Mass, kg</u>	<u>Hindlimb, %</u>	<u>Loin, %</u>	<u>Fillet, %</u>
Pig ²	90	27	11	1,5
Cattle ²	300	29	17,5	2,0
Lamb ²	25	33	18	-
Ostrich (14 month)	37	75	4,5	9,0
Ostrich (Adult) ³	48	86	4	10,5

1 All masses as Bone-in

2 Weniger, Steinhauf and Pahl (1963)

3 Physiologically matured

Table 4.2 Mass and percentage of commercial cuts of the ostrich carcass

<u>Commercial cut</u>	<u>Mass, kg</u>	<u>Percentage</u>
Legs, bone-in (boneless)	40,9 (35,2)	86,0 (74,0)
Loin cutlets	1,8	3,8
Neck	1,6	3,4
Wings	1,5	3,2
Breast and Ribs	0,9	1,9
Tail	0,8	1,7
Total	47,5	100

*4.2 COMMERCIAL CARCASS DIVISION

Although almost all the useable meat (75%) is situated in the hindquarters, the rest (25%) of the carcass is very bulky and occupies a lot of expensive refrigeration space. For this reason the ostrich carcass is semi-hot deboned by cutting loose all the muscle attachments to the pelvic girdle and removing

the femur from the acetabulum (Figure 4.1/5 and /6). The internal obturator muscle is not deboned by cutting it loose from its attachment to the ischium and pubis, as well as its tendon inserting on the acetabulum. The legs and internal obturator muscles are removed at approximately two hours (h) *post mortem*. These are then immediately chilled at 0°C to reach an internal temperature of 7°C in 24 h. The described conditions should induce cold shortening, but this will be discussed in a later section.

4.2.1 LEG (Figure 4.1/5 and /6)

After the internal muscle temperature of 7°C has been reached, the deboning process is completed. The iliofibularis (3.3.2; Figure 3.2/5) and caudiliofemoralis (3.3.4; Figure 3.3 /6) muscles are removed and sold as fillet. The semimembranosus (3.3.5; Figure 3.4/3) is also a potential fillet muscle, as well as the semitendinosus (3.3.3; Figure 3.3/8).

Cuts used for steaks include the femorotibial muscles (3.4; Figure 3.2/1, 3.5/1, 3.6/1 and /2, 3.7/1 and /2), the external (3.2.2; Figure 3.1/2) and internal (3.2.3; Figure 3.2/2) trochanteric muscles, the internal obturator (3.3.8; Figure 3.4/4) as well as the semitendinosus (3.3.3; Figure 3.3/8).

Muscles suited for biltong production are the cranial and lateral iliotibial muscles (3.2.1 and 3.3.1; Figures 3.2/1 and 4), the ambiens (3.2.7; Figure 3.3/4), the pubischiofemoralis (3.3.6; Figure 3.4/2), the gracilis (3.2.8; Figure 3.7/1) and two muscles of the lower leg or drumstick, namely the gastrocnemius (3.5.2; Figure 3.1/8) and the peroneus longus (3.5.2; Figure 3.1/9).

All other leg muscles, that is the smaller trochanteric muscles (3.2.4, 3.2.5 and 3.2.6; Figure 3.3/1, 2 and 3) and the ischiofemoralis (3.3.7; Figure 3.4/1), together with the trimmings and offcuts of the abovementioned muscles are utilized as minced sausage or factory meat.

*From the ostrich carcass 11.5% fillet, 18,0% steak and 32,0% biltong meat can thus be obtained. With specific tenderizing treatments these portions may be shifted to more steak and less biltong meat.

4.2.2 LOIN (Figure 4.1/3)

The loin of the ostrich is treated much the same as that of lamb, that is sawn with a bandsaw into cutlets. The yield in cutlets is approximately 3,8% of the carcass.

4.2.3 NECK (Figure 4.1/1)

The neck of an ostrich resembles oxtail and is sold in one piece. The neck comprise 3,4% of the carcass.

4.2.4 WING (Figure 4.1/2)

This section of the ostrich also contains some meat and may be sold as fresh meat, mechanically deboned for manufacturing, or processed into a by-product such as carcass meal.

4.2.5 BREAST (Figure 4.1/4)

The breast and ribs contain very little meat and can, like the wing, be mechanically deboned or processed into a by-product such as carcass meal.

4.2.6 TAIL (Figure 4.1/7)

The tail of the ostrich is the only part with a lot of fat adhered to it and can be prepared similar to mutton tails (grilled or in soup). The tail comprise about 1,7% of the carcass.

4.2.7 BONES

The pelvic girdle, femur, tibia, fibula, ribs, pectoral girdle

and wing bones are all so-called clean bones and can be mechanically deboned, with the solids processed into bone meal.

4.3 INDIVIDUAL MUSCLE MASS DISTRIBUTION

The mass of each individual muscle of the leg of the adult ostrich is presented in Table 4.3. The fractions represent the mass of the same muscle at the 14 month stage divided by the adult mass of that muscle, in order to give some representation of the growth patterns of individual muscles. The closer the value to one, the earlier developing the specific muscle. All the muscles used for fillet are more developed at the 14 month stage than the average development of the muscles.

It is of interest to note that the muscles of the leg of the ostrich is also later developing than the rest of the carcass, since the carcass mass ratio of a 14 month old bird to an adult is 0,78, while the same ratio of the leg muscles is 0,64. This indicates that the muscles are still under developed in the 14 month old ostrich in comparison to the rest of the carcass.

4.4* PROTEIN AND FAT CONTENT OF OSTRICH MEAT

Ostrich meat is very lean with a high protein content of 20,45% in the fillet and 20,95% in the steak. The fat content of these muscles are 0,032 and 0,155% respectively. No single leg muscle contains more than 0,3% fat.

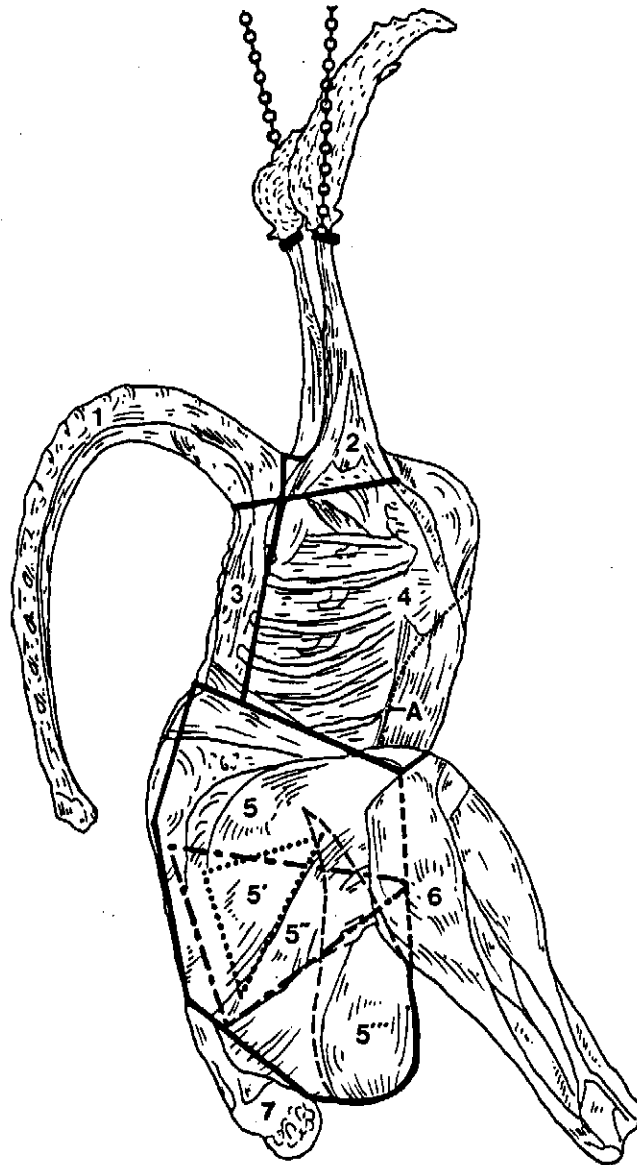


Figure 4.1 Commercial cuts of the ostrich carcass

1 neck; 2 wing; 3 back (cutlet); 4 breast and rib; 5 upper leg (steak) with 5' small fillet, 5'' fillet and 5''' small steak; 6 lower leg (shin); 7 tail; A cutting line for evisceration

5 POST MORTEM MUSCLE ACTIVITY

5.1 GENERAL OBSERVATIONS

The ostrich is stunned electrically, hoisted up by both legs and the main arteries cut in the throat, just under the head. After about 10 minutes bleeding time, the remaining feathers are plucked, the heads and feet removed and the hanging position changed to the illustration in Figure 4.1. This procedure takes place at ambient temperatures (maximum of 25°C) and can last 1,5 to 2h. In the latter hanging position the skin and viscera is removed and health inspection carried out.

In both hanging positions the contractile activity of the iliofibularis muscle is obvious. Shortly after the bleeding period this muscle contracts to pull the body in an upside down kneeling position. This muscle is very hard and extremely contracted at this stage. This muscle activity is still dominant over that of the extending muscles, even when the hanging position is changed, and no effect of the extending muscles (e.g. the femorotibial muscles) can be noted for the first two hours *post mortem*. After two hours, however, the energy reserves of the iliofibular muscle are exhausted and the muscle relaxes. This is at about the time of removing the leg from the rest of the carcass. At this stage in the *rigor mortis* process, hot deboning should not cause any negative side effects on meat quality under conditions of rapid cooling, such as cold shortening. The muscles responsible for extending the knee joint are not hot deboned when the leg is removed, since they find their origin on the femur and insertion on the patella and tibia. Here as well, no negative side effects are expected by rapid chilling at this stage.

5.2 DETECTION OF POST MORTEM MUSCLE CONTRACTION

Muscle biopsies, four centimeters long and five millimeters in diameter, were taken from the iliofibularis and external femotibialis muscles two hours *post mortem* and coupled to an apparatus (Figure 5.1) to detect *post mortem* muscle contraction. It

Table 4.3 Individual masses of specific leg muscles

Muscle No.	Muscle	Adult mass,kg	14 Month mass/ Adult mass	% of lower leg muscle	
				Adult	14 month
3.2.1	<i>M. iliotibialis cran.</i>	0,828	0,45	4,71	3,28
3.2.2	<i>M. iliotrochantericus ext.</i>	0,270	0,56	1,53	1,31
3.2.3	<i>M. iliotrochantericus int.</i>	0,306	0,72	1,74	1,93
3.2.4	<i>M. iliotrochantericus cran.</i>	0,086	0,64	0,49	0,48
3.2.5	<i>M. iliotrochantericus med.</i>	0,077	0,65	0,44	0,44
3.2.6	<i>M. iliotrochantericus caud.</i>	0,062	0,56	0,35	0,31
3.2.7	<i>M. ambiens</i>	0,303	0,69	1,72	1,84
3.2.8	<i>M. gracilis</i>	0,169	0,86	0,96	1,27
3.3.1	<i>M. iliotibialis lat.</i>	1,961	0,60	11,15	10,25
3.3.2	<i>M. iliofibularis</i>	1,807	0,70	10,27	11,12
3.3.3	<i>M. flexor cruris lat.</i>	0,599	0,77	3,40	4,03
3.3.4	<i>M. caudiliofemoralis</i>	0,700	0,71	3,98	4,38
3.3.5	<i>M. flexor cruris medi.</i>	0,207	0,87	1,18	1,58
3.3.6	<i>M. pubischiofemoralis</i>	0,210	1,00	1,19	1,84
3.3.7	<i>M. ischiofemoralis</i>	0,075	0,67	0,43	0,44
3.3.8	<i>M. obturator int.</i>	0,962	0,59	5,47	4,95
3.3.9	<i>M. obturator ext.</i>	0,015	0,67	0,09	0,09
3.4.1	<i>M. femorotibialis ext.</i>	0,954	0,64	5,42	5,34
3.4.2	<i>M. rectus femoris</i>	0,748	0,77	4,25	5,04
3.4.3	<i>M. femorotibialis med.</i>	0,271	0,79	1,54	1,88
3.4.4	<i>M. femorotibialis int.</i>	0,183	0,79	1,04	1,27
3.5.1	<i>M. gastrocnemius</i>	3,446	0,62	19,59	18,75
3.5.2	<i>M. peroneus longus</i>	0,816	0,71	4,64	7,15
	Rest of lower leg muscles	2,540	0,50	14,44	10,77
Total leg muscle mass		17,595	0,64		
Total 1/2 carcass mass		23,750	0,78		

must be stressed that the purpose was only to detect contraction against the gravity force on the very light needle and not to quantify this force. For this reason the labour required to move the needle was limited to the absolute minimum by the design of the moveable parts of the apparatus. The muscle biopsies were dissected parallel to the muscle fibres and coupled immediately in an isotonic Ringer solution. The apparatus with the muscle was placed in a cold room at 10°C, to simulate the conditions of the whole leg being chilled.

The iliofibular muscle showed no further activity in this period (2 h *post mortem* to 14 h *post mortem*), while the external femorotibial muscle started contracting after 30 minutes in cold storage (that is 2,5 h *post mortem*). This contraction reached a peak after six hours in cold storage (eight hours *post mortem*).

The abovementioned facts and observations described under 5.1 suggest that the *rigor mortis* processes take place at a faster rate in the iliofibular muscle (fillet) than in the femorotibial muscles (steaks).

These facts justifies the procedure of removal of the leg from the carcass at two hours *post mortem* without risking loss of tenderness due to cold shortening. The rate of temperature drop in the femorotibial muscles are slow enough to avoid this problem. Cold shortening may and does arise however in the cranial iliotibial muscle, having its origin cut loose in early *rigor mortis* and subjected to low temperatures shortly afterwards. This muscle is thus very tough and suitable for biltong production only.

5.3 *POST MORTEM* pH-PATTERN OF THE ILIOFIBULAR AND FEMOROTIBIAL MUSCLES

A graphic representation of the post mortem pH-decline of the iliofibular and femorotibial muscles are presented in Figure 5.2. It will be noted that the pattern is very typical and comparable to that of other animals, as for instance described by Lawrie (1974). Furthermore, the suspected faster rate of

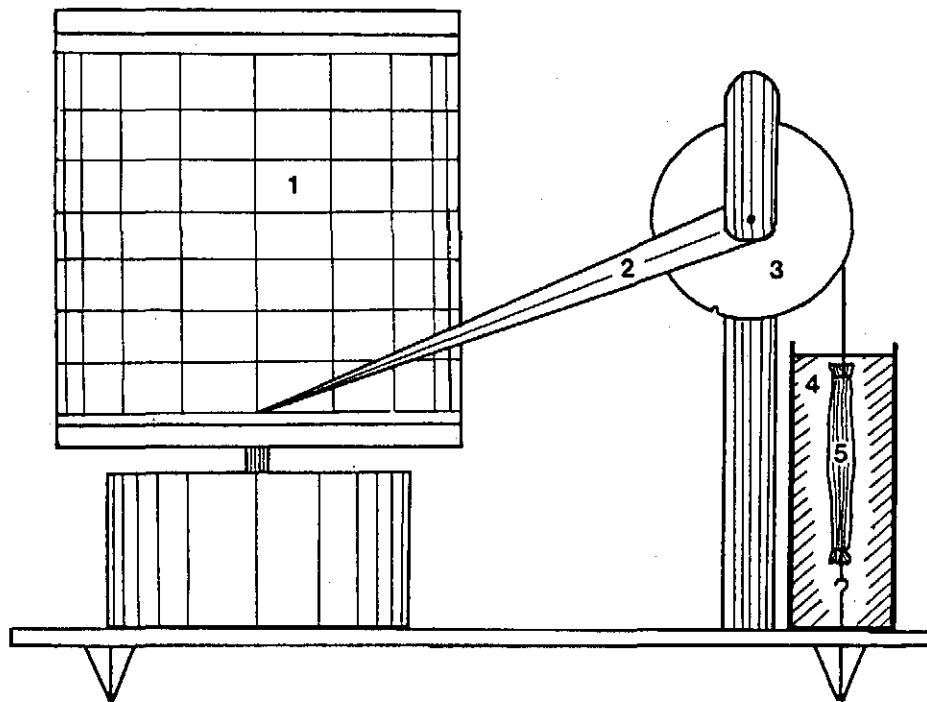


Figure 5.1 Apparatus for detection of muscle contraction

1 Rotating drum with graph paper; 2 Needle pen; 3 Low friction pulley; 4 Isotonic Ringer solution; 5 Section of muscle

post mortem metabolism is further stressed by the faster rate of pH-decline in the iliofibular muscle (fillet) compared to the femorotibial muscle (steak).

Although the iliofibular muscle is about the most active muscle in the live animal (related to the flexing of the knee joint and thus utilized in just about every move of the bird), given the fast rate of *post mortem* glycolysis and presumably other *rigor mortis* processes, it is understandable why this muscle is the most tender of all in the ostrich carcass. Although no ATP determinations were carried out in this study, it is reasonably safe to assume that the ATP reserves (contributing to toughness) must be close to exhausted after two hours *post mortem* in the iliofibular muscle.

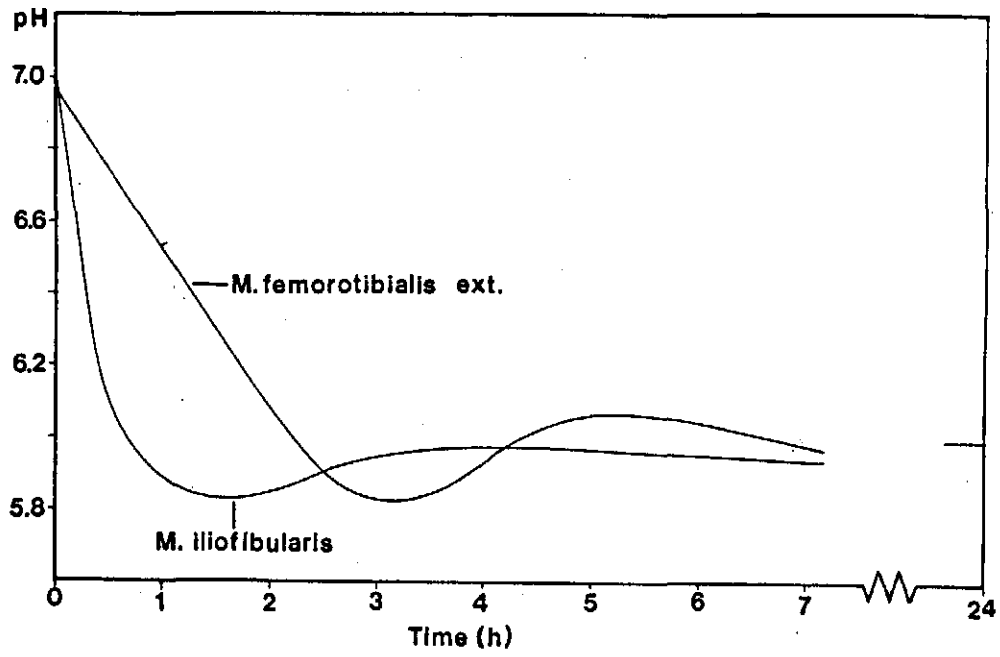


Figure 5.2 Post mortem pH-pattern of two different muscles of the ostrich

6 PALATABILITY

6.1 PILOT TRIALS

6.1.1 GENERAL REMARKS

*The mechanization of slaughter lines led to an increase in slaughterhouse capacity and reduced the time needed for the slaughtering process, evisceration and health inspection. The result was that carcasses are ready to and do enter chilling rooms shortly after the actual slaughtering. The side effects of the rapid chilling procedures, now enforced by hygienic laws and regulations, were drastic and opened a new field of scientific investigations to accelerate the onset of *rigor mortis* and catabolic processes in the muscles which, in turn, combats the negative side effects and adapts the carcass to these fast chilling practices.

These investigations included early *post mortem* electrical stimulation of the carcasses of meat animals, hot and cold deboning practices, vacuum ageing of meat, injection of proteolytic enzymes and tranquilizers shortly *ante mortem* and treatment of the meat with proteolytic and other enzymes.

6.1.2 METHOD AND PROCEDURES

Since the described fillet muscles are more tender than the steak muscles, some of the procedures, known for their tenderizing effect on meat, were carried out to determine their effects on ostrich meat.

The advantages of electrical stimulation are described in detail in the literature (e.g. Chrystall & Devine, 1978; Bendall 1980; Bouton, Ford, Harris & Shaw, 1980; Bouton, Westle & Shaw, 1980; Chrystall, Devine & Davey, 1980; George, Bendall & Jones, 1980; Riley, Savell, Smith & Shelton, 1980; Taylor & Marshall, 1980; Potthast, 1981). Some of these advantages are accelerated *post mortem* glycolysis, which in turn reduces the risk of cold shortening under rapid chilling conditions and thereby contributing to the tenderness of such treated

muscles. For this purpose four of the eight carcasses included in the pilot trials were electrically stimulated at 10 minutes *post mortem* with 45V DC, 10 Hz (duration: four minutes). Hot deboning and rapid chilling is normally associated with cold shortening and toughening of non-stimulated carcasses (Cuthbertson, 1980). Hot deboned meat is however suitable for processing (Gerrard, Mallion & Quin, 1977), since the pH is still relatively high, as well as the natural phosphate (ATP) content which results in a high water binding capacity. It is however very practical to remove the legs from the ostrich carcass before chilling, as mentioned under 4.2. To determine whether this practice has any negative effects on the tenderness of fillet muscles, the left legs of the eight ostriches were removed at one hour *post mortem* and immediately chilled, together with the intact right legs (still attached to the carcass), at 0°C to reach an internal muscle temperature of 5°C. After 24h right legs were also removed from the carcass and both legs and all the fillets and steaks divided into commercial cuts and flown from Oudtshoorn to Cape Town in thermal isolated containers. On arrival (30h *post mortem*) the average temperature was 6°C ± 1°C. The muscle pH-values of these fillets and steaks were determined and contact microbiological swabs (SS agar) taken.

The fillet and steak cuts were further divided into two, vacuum packed and stored at 4°C for a further 12h. At 42h *post mortem*, one pack of each muscle was fast frozen at -20°C, while the other pack remained at 4°C for a further seven days before being frozen. After fourteen and seven days respectively at -20°C the meat was slow thawed overnight, microbiological swabs taken and prepared for tenderness evaluation.

The meat was cut in 20 mm x 20 mm x 20 mm blocks and fried in shallow oil at 140°C for four minutes per side. The samples were organoleptically evaluated by eleven trained panelists on a scale of one to five: one being extremely tough; two represented tough; three, acceptable; four, tender; and five extremely tender. Shear force values were determined (25 mm diameter bore, parallel, Warner-Bratzler apparatus) on identically prepared samples in order to compare the obtained sensory and

mechanical values.

6.1.3 RESULTS

The pH-values are not presented since electrical stimulation nor deboning procedure had any significant effect on the pH 30h *post mortem*.

No microbiological deterioration could be detected either. The average count on arrival was 2,5 colonies/6 cm³; 3,4 colonies/6 cm³ on the immediate frozen group after 14 days and 2,8 colonies/6 cm³ on the aged group after 14 days. These colonies were lactose fermenting bacteria, but no *salmonellae* or *Shigella* species were isolated.

The results of the tenderness evaluation are presented in Table 6.1 (fillet) and Table 6.2 (steak). All results were compared to the standard method of treatment during and after slaughtering (that is: not electrically stimulated, semi-hot deboned, and not aged). The calculated statistical significance (P) of the observed differences from the standard method of treatment are presented in the same tables.

In order to determine which of the tenderizing treatments were preferred by the taste panel the average of each treatment mean was calculated. These results are presented in Table 6.3 for fillet and steak muscles.

The ranked averages obtained by means of the Warner-Bratzler apparatus was in agreement with that of the taste panel.

6.1.4 DISCUSSION

From the P-values in Tables 6.1 for fillets and 6.2 for steaks it is evident that the standard slaughtering procedure could hardly be improved on, except perhaps with electrical stimulation and hot deboning of the fillet followed by freezing without ageing, although the obtained differences were not significant by either method of evaluation.

The results with the steak muscles on the other hand indicated that the improvement in tenderness brought about by vacuum

Table 6.1 Taste panel (TP) and shear force (SF) values for tenderness of ostrich fillet muscles subjected to different treatments

Not electrically stimulated								
Bird number	Hot deboned ¹				Cold deboned ²			
	Not aged ³		Aged ⁴		Not aged		Aged	
	TP ⁵	SF ⁶	TP	SF	TP	SF	TP	SF
1	3,55	14,75	4,82	9,95	3,82	12,25	3,55	12,80
3	4,80	8,60	4,50	14,00	3,40	19,30	5,10	10,55
5	3,75	16,90	3,75	13,60	3,50	14,30	3,38	19,80
7	5,30	12,55	4,60	15,70	4,30	18,65	4,50	12,10
\bar{x}	4,35	13,20	4,42	13,31	3,76	16,13	4,13	13,81
P	-	-	>0,5	>0,5	0,22	0,44	0,42	>0,5

Electrically stimulated								
Bird number	Hot deboned				Cold deboned			
	Not aged		Aged		Not aged		Aged	
	TP	SF	TP	SF	TP	SF	TP	SF
2	3,55	13,35	3,82	13,25	3,36	19,90	4,64	14,35
4	3,90	10,80	4,00	13,65	4,10	18,35	3,70	17,45
6	4,50	10,45	5,00	11,95	3,38	16,60	3,50	18,40
8	5,10	7,70	4,80	9,50	4,40	11,20	5,90	5,90
\bar{x}	4,26	10,58	4,41	12,09	3,81	16,51	4,44	14,03
P	0,18	0,21	>0,5	>0,5	0,31	0,29	>0,5	>0,5

1 Hot deboned: Leg removed at 1h *post mortem*

2 Cold deboned: Leg removed at 24h *post mortem*

3 Not aged: Fast frozen at -20°C at 42h *post mortem*

4 Aged: Vacuum packed ageing at 4°C for 7 days, followed by fast freezing

5 TP scale : 1 = extremely tough
2 = tough
3 = acceptable
4 = tender
5 = extremely tender

6 SF: as by Warner-Bratzler on 25 mm diameter bore, parallel fibered samples

Table 6.2 Taste panel (TP) and shear force (SF) values for tenderness of ostrich steak muscles subjected to different treatments

Not electrically stimulated				
Bird number	Not aged ¹		Aged ²	
	TP ³	SF ⁴	TP	SF
1	4,46	10,15	4,73	10,28
3	4,20	8,68	5,10	7,28
5	4,25	11,35	4,26	10,53
7	5,30	11,05	5,80	8,58
\bar{x}	4,55	10,31	4,97	9,17
P	-	-	0,08	0,12

Electrically stimulated				
Bird number	Not aged		Aged	
	TP	SF	TP	SF
2	4,14	11,33	4,64	12,00
4	3,15	10,60	3,55	11,38
6	3,38	16,40	4,57	9,95
8	4,00	11,98	4,55	12,13
\bar{x}	3,67	12,58	4,33	11,37
P	0,045	0,001	>0,5	>0,5

1 Not aged: Fast frozen at -20°C at 42h *post mortem*

2 Aged: Vacuum packed ageing at 4°C for 7 days, followed by fast freezing

3 TP scale : 1 = extremely tough

2 = tough

3 = acceptable

4 = tender

5 = extremely tender

4 SF: as by Warner-Bratzler on 25 mm diameter bore, parallel fibered samples

packed ageing was more significant, as was the tenderizing effect of electrical stimulation followed by freezing without ageing. In both the cases of fillet and steak, the positive effect of electrical stimulation was counteracted by ageing of this meat. The reason for this is not clear and needs more investigation involving more animals.

The results presented in Table 6.3 showed that hot deboning and ageing of the fillet was preferred above electrical stimulation and cold deboning. In the case of steak muscles the non-stimulated and aged cuts were preferred above the electrically stimulated cuts.

Furthermore it was proved that the organoleptic evaluation of tenderness showed a close correlation with the mechanical evaluation (shear force) of tenderness. In the case of fillet the linear regression equation was $y = 5,28x + 35,86$ ($r = 0,74$) and in the case of steak $y = 2,65x + 22,44$ ($r = 0,98$) with x being the observed taste panel value and y the obtained Warner-Bratzler reading.

6.1.5 CONCLUSION

Since a taste panel did not prefer ostrich meat from electrically stimulated carcasses, and also because electrical stimulation of the carcass is only of real benefit in the steak muscles, where the effect is approximately equal to that of ageing of this muscles, the application of electrical stimulation was abandoned. Further trials were thus carried out only with ageing of steak muscles, while it is accepted that the fillet muscles are tender enough under the standard slaughtering procedures. The high correlation obtained between organoleptic and mechanical evaluation (shear force) of the tenderness of the ostrich steak muscles, suggested that the meat samples need only be evaluated mechanically. The microbiological results also indicated that this ageing procedure does not impair the microbiological standards of the ostrich meat.

Table 6.3 Ranked tenderness averages of treatment means for fillet and steak muscles as evaluated by a trained taste panel (TP) and shear force (SF)

Fillet				Steak			
Rank	Treatment	Score		Rank	Treatment	Score	
		TP	SF			TP	SF
1	HDB	4,36	12,30	1	NES	4,76	9,74
2	A	4,35	13,30	2	A	4,65	10,27
3	ES	4,23	13,30	3	NA	4,11	11,45
4	NES	4,17	14,11	4	ES	4,00	11,98
5	NA	4,05	14,11				
6	CDB	4,04	15,12				

ES	Electrically stimulated
NES	Not electrically stimulated
HDB	Hot deboned
CDB	Cold deboned
A	Aged
NA	Not aged

6.2 TENDERIZING OSTRICH STEAK CUTS BY VACUUM PACKED AGEING

The final trials consisted of 40 steak cuts obtained from the left and right legs of 20 ostrich carcasses. The birds were stunned electrically, bled out, cleaned and the legs removed and chilled at 0°C at two hours *post mortem*. After 24h chilling (internal temperature 7°C) the steak muscles were removed from the legs, marked individually and flown from Oudtshoorn to Cape Town to arrive at 5°C at 30h *post mortem*. All 40 muscles were divided into two parts, of which the one section of each muscle was vacuum packed and fast frozen immediately at -20°C. The other sections were also vacuum packed and aged at 4°C for 7 days before they were fast frozen at -20°C. After 14 and 7 days of frozen storage respectively, the samples were slow thawed overnight and prepared for mechanical tenderness evaluation (shear force) by frying in shallow oil at 140°C for four minutes per side. The results of this trial, with the

statistical significance (P) of the observed differences are presented in Table 6.4

Table 6.4 Average tenderness (shear force values) of steaks from the left and right legs of 20 ostrich carcasses subjected to different treatments

Treatment	Left legs	Right legs	P
Not aged ¹	12,590	13,145	n.s.
Aged ²	8,275	9,195	n.s.
P	0,001*	0,001*	

N.S. not significant

* highly significant

1 Not aged: Fast frozen at -20°C at 42h *post mortem*

2 Aged: Vacuum packed ageing at 4°C for 7 days, followed by fast freezing

3 TP scale : 1 = extremely tough
2 = tough
3 = acceptable
4 = tender
5 = extremely tender

4 SF: as by Warner-Bratzler on 25 mm diameter bore, parallel fibered samples

From this data it can be concluded that there is no difference in the tenderness of steaks from the left legs of ostriches compared to that from the right legs. It is also conclusive that vacuum ageing at 4°C for 7 days has a highly significant positive effect on the tenderness of ostrich steaks.

6.3 RECOMMENDATIONS TO IMPROVE TENDERNESS OF OSTRICH STEAK MUSCLES

Under the prevailing slaughtering and deboning procedures (that is: removal of the leg at 1h *post mortem*, 24h chilling before deboning) the fillet muscles are acceptable, without electrical stimulation of the carcass or further treatment to

increase tenderness. The most practical method of producing tender steak cuts is by incorporating a vacuum packed ageing procedure at 4°C for seven days for these cuts only in the standard slaughtering and deboning procedures, as described under 6.2. Certain other muscles which are at present being used as biltong meat e.g. gastrocnemius muscle, may also be used as steak provided that it is first made more tender by ageing these muscles at 4°C for 7 days.

7 TECHNOLOGICAL ASPECTS

√ 7.1 EMULSION PRODUCTS

The pH_f -value of ostrich meat is approximately 5,85 (Naudé, *et al.* 1979, reported values of > 6) and this is relatively high. Despite this fact, the water binding capacity is not very high under normal processing practise. Preparation of an emulsion under the addition of 3g/kg acid pyrophosphates rectified this problem however. * Ostrich meat can be used as the only source of protein in emulsion products such as Frankfurters, using 50% ostrich meat, 25% pork fat, 20% water, 0,3% acid pyrophosphate, 1,7% nitrited salt and 3% starches, spices, flavouring, colour enhancers and colour stabilizers.

√ 7.2 MINCED PRODUCTS

Minced ostrich meat, mixed with pork, pork fat and beef, produces excellent quality products such as raw sausages and patties. The addition of two to three percent rusk increases the quality of such products and eliminates the excudation of moisture.

√ 7.3 SEMI-DRIED, SMOKED PRODUCTS

The steak and fillet muscles are extremely suitable for the production of products similar to smoked beef. These muscles are dry salted with 25g/kg nitrited salt and cured for 10 days only, before being cold smoked to produce an excellent semi-dry product which can be sliced very thin.

√ 7.4 DRIED PRODUCTS

Minced ostrich meat, mixed with minced pork belly, salted (15g/kg) and spiced can be heat dried (30°C to 45°C) when filled in a 20 mm collagen casing, within 3 days to produce a typical and characteristic dried sausage.

The production of biltong is by means of dry salting (25g/kg) and normally acidification with 2% vinegar (5% acetic acid), spice addition and 3 days heat drying (35°C to 45°C) after a 24h wet dehydration period.

8 CONCLUSIONS

1. The ostrich is the only bird with a pubic symphysis.
2. The *M. gracilis* and *M. rectus femoris* is present only in the ostrich and no other birds.
3. The ostrich lacks the *M. iliacus*.
4. The legs, loin and neck comprise 92% of the carcass mass.
5. The fillet comprise 10% of the carcass mass.
6. Electrical stimulation has a positive effect on the eating quality of the meat of the ostrich.
7. Increased tenderness can be achieved in the steak cuts by vacuum ageing of the meat.
8. Ostrich meat contains less than 0,3% fat.
9. *Ostrich meat is suitable for all types of meat products.

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