THE INFLUENCE OF SKIN THICKNESS ON THE DETERMINATION OF THE PERCENTAGE OF BODY FAT (SKINFOLDS AND ULTRASOUND)

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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SUMMARY

There are several ways to assess the body composition of young men in a laboratory setting. However, due to the invasiveness, expense, time, specialised equipment, extensive instrumentation and level of skilled personnel required to perform these methods, they are generally not used in a clinical setting. New methods are being developed for clinical use, which may offer the potential for non-invasive, not too costly in terms of time and equipment, reliable and easy body composition estimate.

These methods involve the development of formulae which relate skinfold or circumference measurements, or a combination of both, to indirect estimates of body fat (Drinkwater, 1984:17). Since many of these methods involve the determination of the adipose tissue *in vivo*, most techniques rely on external body measurements through the skin.

The importance of the influence or contribution of the actual skin thickness on the determination of the caliper skinfold thickness has rarely been investigated. Ultrasound or sonar scans proved to be a fairly non-invasive and inexpensive, not too time consuming, yet accurate method to determine the skin and subcutaneous fat layer individually in human beings.

Various tests were performed on the subjects, such as hydrostatic weighing, lung functions, bio-electrical impedance analysis and a vast range of anthropometrical measurements including weight, stature, diameter, girth and skinfold (caliper), skin and fat (sonar) on fourteen body locations were recorded.

The body density values (skinfolds), according to Durnin & Rahaman (1967) and Jackson & Pollock (1978), were individually applied to the formulae of Brozek (1953) and Siri (1961) to calculate the percentage body fat. Correlations with hydrodensitometry were high, ranging from r=0,81499 (for Durnin & Rahaman and Brozek) to r=0,82338 (Jackson & Pollock and Siri) (see Figures 10 to 13).

The same procedure was followed with the sonar measurements and different combinations, such as fat, 1x skin + fat and 2x skin + fat, were used. Correlations with hydrodensitometry were remarkably high, seeing that these formulae were developed for the use of skinfold calipers, and ranged from r=0,77198 (Durnin & Rahaman and Brozek) to r=0,84545 (Jackson & Pollock and Siri) (see Figures 14a to 17c).

When applying the sonar (fat) measurements to the formula of Jackson & Pollock, it resulted in a relatively higher correlation (r=0,8455), as when compared to other combinations of sonar measurements, namely sonar (1x skin + fat) and sonar (2x skin + fat), which resulted r=0,83697 and r=0,81987 respectively. When substituting the supra iliac (anterior) and medial thigh body locations with the supra iliac (posterior) and anterior thigh values respectively, a good correlation (r=0,83575) was found.

Although all of these variations yielded good results, it can be seen that the formula of Jackson & Pollock was developed for the use of skinfolds (r=0,89224). When substituting the supra iliac (anterior) and anterior thigh body locations with the supra iliac (posterior) and medial thigh values respectively, a good correlation (r=0,86924) was found. This indicated that more attention should be given to these areas of fat deposits formerly not investigated, especially the medial thigh for females, and the posterior supra iliac for males.

Each of the 14 body locations was individually correlated with body density via three different methods, namely skinfold measurements (Harpenden caliper), fat measurements (sonar) and 2x Skin and fat (sonar). Skinfolds correlated the highest with body density, ranging from r=0,827 (abdomen) to r=0,615 (bicep). The second highest correlations were found to be that of fat thickness, varying from r=0,791 (tricep) to r=0,237 (chin). The sonar measurements (2x skin + fat) correlated third highest ranging from r=0,754 (chest) to r=0,239 (chin).

Subsequently no ultrasound formulae were available to compare this population group and a new regression equation, using seven sonar fat values, was developed to indirectly estimate the body density. These findings were compared to and correlated with hydrodensitometry (r=0,86784) (see Fig 29). A further regression equation was developed, using the sum of seven skinfolds as measured by caliper, in order to predict body density. This equation was also compared to hydrodensitometry and yielded a correlation of r=0,86936 (Fig 30).

Either method of measurement and accompanying formula yielded good results when compared to hydrodensitometry providing that the subject qualifies for the 18 to 30 year old endo-mesomorphic category. This study provides the health professional with alternatives where a choice between sonar and skinfold measurements can be made, depending on the preference of the patient and clinician or the time and apparatus available.

OPSOMMING

Daar bestaan verskeie maniere om die liggaamsamestelling van jong mans in 'n laboratorium milieu te bepaal. Weens die finansiële implikasies, gespesialiseerde toerusting, hoogs opgeleide personeel, ingrypende prosedure en tyd daaraan verbonde, word die meeste van hierdie metodes beperk tot navorsingsfasiliteite en derhalwe nie aangewend in 'n kliniese omgewing nie. Nuwe metodes word voortdurend ontwikkel ten einde 'n nie-ingrypende, bekostigbare, eenvoudige, dog akkurate alternatief daar te stel waarvolgens die mens se liggaamsamestelling bepaal kan word. Die meeste van hierdie metodes behels die ontwikkeling van vergelykings waar sekere antropometriese metings soos velvoumate, omtrekke en deursneemate van die ligaam en ledemate aangewend word om die liggaamsamestelling indirek te voorspel (Drinkwater, 1984:17). Aangesien die meeste van hierdie metodes die bepaling van liggaamsvet *in vivo* behels, word hierdie metings uitwendig deur die vel geneem.

Die belangrikheid van die invloed van die werklike veldikte se bydrae tot die velvoumeting, soos bepaal deur die velvouknyper, is nog weinig vantevore ondersoek. Ultraklank of sonar skanderings het getoon om 'n vinnige, relatief bekostigbare, nie ingrypende, dog akkurate bepalingsmetode van die dikte van die vel en onderhuidse vetlaag te wees.

Verskeie toetse en metings is op die proefpersone uitgevoer, wat onderwaterweging, bio-elektriese impedansie analise, longfunksies en breedvoerige antropometriese opmetings, met velvouknypers en sonar, op veertien verskillende liggaamsareas ingesluit het.

Die liggaamdigtheidwaardes (velvoue), soos bepaal met die formules van Durnin & Rahaman (1967) en Jackson & Pollock (1978), was elkeen ingestel in die formules van Brozek (1953) en Siri (1961) om die persentasie liggaamsvet te bereken. Korrellasies met onderwaterweging was hoog en het gewissel van r=0,81499 (Durnin & Rahaman en Brozek) tot r=0,82338 (Jackson & Pollock en Siri) (sien fig 10 tot 13). Dieselfde prosedure is gevolg vir die sonarmetings met verskillende kombinasies soos vet, 1x vel + vet en 2x vel + vet. Korrellasies met onderwaterweging was verbasend hoog, r=0,77198 en r=0,84545 vir Durnin & Rahaman en Brozek en Jackson & Pollock en Siri onderskeidelik. Aangesien bogenoemde formules ontwerp en ontwikkel is vir (vet) waardes wat ingestel word in die formule van Jackson & Pollock, lewer dit 'n hoër

korrrellasie (r=0,8455) as wanneer daar van die ander kombinasies soos sonar (1x vel + vet) (r=0,83697) of sonar (2x vel + vet) (r=0,81987) gebruikgemaak word. Wanneer die waardes van die supra iliaca (anterior) en anterior dy liggaamsareas vervang word met supra iliaca (posterior) en mediale dy waardes, word 'n goeie korrellasie van r=0,83575 verkry. Alhoewel al bogenoemde moontlikes goeie resultate en ooreenkomste getoon het, word daar duidelik getoon dat die formule van Jackson & Pollock ontwikkel was vir die aanwending van velvoumate (r=0,89224). Weer eens word gesien dat wanneer die waardes van die supra iliaca (anterior) en anterior dy liggaamsareas vervang word met supra iliaca (posterior) en mediale dy waardes vervang word, word 'n goeie korrellasie van r=0,869224 verkry. Dit dui daarop dat hierdie vetdeposito areas meer aandag kan geniet, veral die mediale dy vir dames en die posterior supra iliaca in die geval van mans.

Verder was elkeen van die veertien liggaamsareas op drie wyses, naamlik velvoumates (Harpenden knyper), vetwaardes (sonar) en 2x vel + vet (sonar) afsonderlik met liggaamsdigheid, soos bepaal deur middel van die onderwatermetode, vergelyk. Velvoue het die hoogste korrellasie met liggaamsdigtheid getoon en het gewissel van r=0,827 (abdomen) tot r=0,615 (bicep). Die tweede hoogste korrellasie was die van sonar vetwaardes, waar die tricep (r=0,791) die hoogste en ken (r=0,237) die laagste waardes getoon het. Laastens het die sonarwaardes (2x vel + vet), bors (r=0,754) tot ken (r=0,239), korrellasies getoon met die onderwaterweging.

Aangesien geen formules vir sonarmetings beskikbaar was om hierdie groep mee te vergelyk nie, is daar 'n nuwe regressievergelyking, met behulp van sewe sonar vetwaardes, ontwikkel om liggaamsdigtheid indirek te kon bepaal. Hierdie bevindings is vergelyk met onderwaterweging en 'n korrellasie van r=0,86784 is gevind (Fig 29). 'n Verdere regressievergelyking is ontwikkel waar die som van sewe velvoue, soos gemeet met die velvouknyper, aangewend word om liggaamsdigtheid te bepaal. Laasgenoemde vergelyking is ook met onderwaterweging vergelyk en toon 'n korrellasie van r=0,86936 (sien Figuur 30).

Enige van die bogenoemde metodes het goeie resultate getoon in vergelyking met die onderwaterweegmetode, met die voorbehoud dat die persoon kwalifiseer as 'n 18 tot 30 jarige endo-mesomorfiese man. Hierdie studie dui daarop dat diegene in die mediese milieu en gesondheidsberoepe, naas die velvoumetode, ook die sonarmetode vir die akkurate bepaling van die liggaamsdigtheid en persentasie liggaamsvet kan gebruik.

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A wise man has great power and a man of knowledge increases his strength.

Proverbs 24: 5

A body without motion deteriorates like still water.

Dr Ambrodick Nakovich

Russian Physician (1786)

To **my parents**, who set the perfect example

and create wonderful opportunities for me in life.

CONTENTS

CHAPTER THREE

CHAPTER FOUR

LIST OF TABLES

Table

LIST OF FIGURES

Figure

CHAPTER ONE

STATEMENT OF THE PROBLEM

INTRODUCTION

From the beginning people realised that the visible and tangible body composed of more than "blood and meat and bones and skin and the simple organs" (Keys & Brozek, 1953:245).

The great Hippocrates (450-400 BC), named the four constituents as "blood, yellow bile, black bile and phlegm", as the internal components (Drinkwater, 1984:1).

The ancient Greek athletes excelled in different Olympic events because they believed that every event required specific morphological characteristics (Blaauw 1978:1)

The Greek mathematician Archimedes realised that the volume of water that overflowed his bath when he entered, was equal to the volume of his submerged body. He also reasoned that an object floating or submerged in water is buoyed up by a counterforce that equals the weight of the water displaced. By taking into account that each substance has its own specific gravity, and therefore density, he could determine that King Hieron's crown consisted of different substances, both gold and silver (McArdle, Katch & Katch, 1986:609).

This phenomenon set anthropologists, physicians and other researchers on course to develop different methods for determining the densities of the different tissues of which the human body composes. Since many of these methods involve the determination of the adipose tissue *in vivo*, most techniques rely on external body measurements through the skin.

The importance of the influence or contribution of the actual skin thickness on the determination of the caliper skinfold thickness has rarely been investigated. The skin is a living organ that adapts in appearance, texture and form according to the role and physiological function it has to perform. To be able to understand this unique and essential part of the living human body, a brief look into the anatomy and composition has to be taken. The skin is the largest single organ of the body, performs a vast range of essential functions and since it is an external and visible organ, it is of remarkable physiological and clinical significance.

The skin, or integument, consists of two major layers attached to each other, namely the superficial epidermis and the underlying dermis. Their combined thickness range from 0,5 mm to over 5 mm depending on the different body locations (Meyer: 1983: 67.2). The skin serves a variety of functions and variations in the character of the dermis and epidermis occur according to functional demands (Reith & Ross, 1977:136). It plays an important role in protection, temperature control, dehydration, sensory functions (pressure, pain, itching, etc.) and many others.

The epidermis is of ectodermal origin and is fairly thin over the whole body, except for the soles of the feet and the palms of the hands. It consists of multiple layered stratified squamous epithelium of which the top layers of cells, stratum corneum, are strongly keratinised. Following this layer are the stratum lucidum, stratum granulosum, stratum spinosum and stratum germinativum. The term thin skin actually refers to thickness of the epidermis and does not include the dermis (Meyer:1983).

The dermis, also called cutis vera or real skin, originates from the mesoderm and is much thicker than the epidermis. It consists largely of dense irregular connective tissue and divides into the upper, thinner papillary layer and the deeper, thicker reticular layer (Reith & Ross, 1977:137).

A layer of connective tissue, the hypodermis or tela subcutanea, attaches the skin to the underlying structures (muscle and bone) and contains the largest depot of fat in the human body (Keys & Brozek, 1953:249).

THE PROBLEM

There are several ways to determine skin thickness, some more invasive such as the needle punch, punch or excision biopsy, while the other methods are less or non-invasive although very expensive, such as magnetic resonance imaging, computer axial tomography and ultrasound (sonar). The most common way to determine skinfold thickness is with a caliper. However, the use of such an apparatus for the determination of skin thickness is limited due to certain specific factors. These include the degree of compression exerted by the pincer arm at the point of contact, the double skin thickness measurements of the skinfold and most importantly the fact that the skin and subcutaneous fat layer cannot be differentiated or individually measured. These factors have lead to the investigation of the value and use of ultrasound scans to measure the actual skin thickness and therefore determine the influence and contribution thereof on the skinfold caliper readings.

PURPOSE OF THE INVESTIGATION

The purpose of this study was the following:

1. To investigate the influence of the skin thickness on the determination of the body density, as calculated by skinfold methods and formulae,

2. To correctly predict the body density from the data obtained from ultrasound measurements. To achieve that, the skin thickness had to be measured by the least invasive, yet accurate method, indirectly with a skinfold caliper and ultrasound apparatus (sonar).

3. To develop a formula to predict body density from ultrasound fat measurements.

The main objectives of this study can be formulated as follows:

1. To determine which parameter or measurement, Sonar (Fat) or [Skinfold (Caliper) - Sonar (2X Skin)], yields the best results when applied to the formula of Jackson & Pollock (1978) and compared to body density, as calculated by hydrodensitometry,
2. To determine which measurement, Skinfold (Sonar) or Skinfold (Caliper), yields the best results when applied to the formula of Jackson & Pollock (1978) and compared to body density as calculated by hydrodensitometry,
3. To develop a new regression equation for BD, using Skinfold (Caliper) measurements, in comparison to BD as calculated by hydrodensitometry.

The following hypothesis will be tested:

1. Skin thickness has a significant influence on the determination of body density via the skinfold method and can lead to an underestimation of percentage body fat.

2. Sonar fat measurement is a better predictor of the true percentage of body fat.

LIMITATIONS

Literature about this subject, apart from those found in journals of dermatological diseases and bacteriology, is sparse and the only other mentionable research in the past which may compare to normal, healthy human beings in a natural physical state, has been done by Bullen *et al* (1965) and Fanelli & Kuczmarski (1984) and Kuczmarski, Fanelli & Koch (1987). Only certain aspects, such as skin thickness (Kirsch, Hanson & Gibson:1984) and subcutaneous fat thickness (Hayes *et al*:1988), have individually been researched.

Due to the type of research done by the other investigators no parallel data and findings existed to compare with. In this study, where a vast range of parameters were investigated and compared to each other, the values obtained had to compare and correlate with body density, as recorded by hydrodensitometry, as a norm to verify the findings.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

There are several ways to assess the body composition of young men in a laboratory setting. However, due to the invasiveness, expense, time, specialised equipment, extensive instrumentation and level of skilled personnel required to perform these methods, they are generally not used in a clinical setting. New methods are being developed for clinical use, which may offer the potential for non-invasive, not too costly in terms of time and equipment, reliable and easy body composition estimate.

These methods involve the development of formulae which relate surface anthropometric measurements to indirect estimates of chemical or anatomical composition. Most notable of these formulae, are those which relate skinfold or circumference measurements or a combination of both to indirect estimates of body fat (Drinkwater, 1984:17).

DEFINITION OF TERMS

Introduction

Body composition literature contains a number of terms that are frequently used interchangeably, but which have widely differing meanings. Distinction is rarely made clear in the literature, the result being further confusion. Therefore the terms used in this thesis are adopted from Drinkwater (1984), except if stated otherwise, and are defined as follows:

Body composition

The combination of components, either chemical or structural, which compromises the whole of an organism. Therefore human body composition may be defined chemically in terms of water, lipid, protein and mineral or structurally in terms of tissues, organs and organ systems.

Fat

The mass that has been referred to as the anatomical entity, adipose tissue, or the chemical entity, lipid.

Adipose tissue

The tissue that consists of all the different types of lipids.

Lipid

The ether extractable lipid that consists of depot lipids such as triglycerides and free fatty acids from adipose tissue and essential lipids such as structural phospholipids of all cell membranes and nervous tissues, and lipids of bone marrow.

Lipid free mass

The mass of remaining body tissues after ether extraction of all lipid, this includes lipids of adipose tissue, bone, nervous tissue and structural lipids from membranes.

Adiposity

The total amount of adipose tissue present in the body, which includes subcutaneous tissues as well as adipose tissue surrounding organs, viscera and skeletal muscle.

Adipose-tissue-free mass

The mass of the remaining tissues of the body after the removal of dissectable adipose tissue i.e. adipose tissue that is separable by gross dissection. This term however is not equivalent to either lipid-free mass or lean body mass.

Lohman (1992:2) suggests that the adipose tissue or fat-free tissue should be 3% and 8% for males and females respectively.

Lean body mass

The remaining mass of the tissue in the body after the removal of all lipid except the essential lipids of cell membranes, nervous tissue and bone marrow. This term implies depot lipids such as the triglycerides of adipose tissue or muscle. Included in this term is an essential amount of lipid required for membrane maintenance and other physiological functions.

Keys and Brozek (1953: 269) reported that Behnke (1942) defined the lean body mass as "...the weight of the body less all except indispensable fat...". Behnke and Wilmore (1974:12) later estimated the quantity of essential lipid being from 3% to 7% of the body weight. Lohman (1992) cited that lean body mass for men and women should be 5% and 12% respectively. There may be sex dependant differences, females having a greater quantity of essential lipids than males, due to metabolically inactive adipose tissue.

Obesity

An excess of adipose tissue and its attendant depot lipids beyond that necessary for optimal function of the body or for survival under existing environmental conditions.

Keys & Brozek (1953:314) considered a man of normal weight and basal metabolic rate being obese when "adding obesity tissue means that perhaps a fourth of his weight gain is cellular mass".

Gray *et al* (1990:527) supported that by defining obesity as more than 25% and 30% body fat for men and women respectively.

Lohman (1992:80) also classified obesity as more than 25% and 32% for males and females respectively.

Density

The mass of the substance per unit volume and is usually expressed in grams per cubic centimetre.

Specific gravity

The ratio of the density of a substance to the density of water, at a specific temperature. The specific gravity is an abstract number independent of the units of measurement, but both the temperature of the substance and of the water must be specified (Keys and Brozek, 1953:267).

Somatotype

A somatotype is a description of present morphological conformation. It is expressed in a three-numeral rating, consisting of three sequential numerals, always recorded in the same order. Each numeral represents evaluation of one of the three primary components of physique which describes individual variations in human morphology and composition (Carter: 1982).

A particular category of body build, determined on the basis of certain physical characteristics, which can be subdivided into endomorphy, mesomorphy and ectomorphy (Dorland, 1960:1405).

Endomorphy

The endomorph is the pear shaped individual with a roundness of body parts, a large abdomen, round head, short neck, narrow shoulders, fatty breasts, short arms, wide hips, heavy buttocks and short, heavy legs (Carter:1982).

A type of body build in which tissues derived from the endoderm predominate. There is a relative preponderance of a soft roundness throughout the body, with a large digestive viscera and accumulations of fat. The body usually presents with a large trunk and thighs and tapering extremities (Dorland, 1960:489).

Mesomorphy

The mesomorph has a rugged musculature, large bones, prominent facial bones, a rather long but muscular neck, wide sloping shoulders, muscular arms and forearms, broad chest, heavily muscled abdomen, low waist, narrow hips, muscular buttocks and powerful legs (Carter:1982).

A type of body build in which tissues derived from the mesoderm predominate. There is a relative preponderance of muscle, bone and connective tissue, usually with a heavy, hard physique of rectangular outline (Dorland, 1960:904).

Ectomorphy

The ectomorph is characterised by small bones, has a large forehead, small facial bones, long skinny neck, narrow chest, round shoulders with winged scapulae, long slender arms, flat abdomen, inconspicuous buttocks and long, thin legs (Carter:1982).

A type of body build in which tissues derived from the ectoderm predominate. There is a relative preponderance of linearity and fragility, with a large surface area, thin muscles and subcutaneous tissue (Dorland, 1960:466).

HISTORICAL BACKGROUND

According to Drinkwater (1984) and Keys & Brozek (1953) the direct analysis of the gross body composition is a complex and laborious procedure which has rarely been done on man. Data on human body composition from direct cadaver analysis are sparse. German anatomists however, had taken the lead more than a century ago and for fifty years dominated the work done on the determination of human body composition.

The initial cadaver research, albeit on a very limited basis, was done by Moleschott in 1859 (Widdowson, McCance & Spray, 1951:113). The other principle investigators of that era were Bischoff (1863), Volkmann (1873) and Vierordt (1888) (Keys & Brozek, 1953:247).

The Oriental researchers, Lee & Ng (1965), were the first to concentrate on the actual skin and skinfold thickness of cadavers. They investigated 71 Chinese subjects (43 males and 28 females), in a post-mortem study, with ages ranging from 1 month to 71 years.

Lee (1957) had already shown that the thickness of the skin proper varies according to age, sex and in different regions of the body. Of the nine areas, from four regions of the body investigated, the "subscapular skin is remarkably thicker than the skin of the other areas" and it averages about 1,7 times thicker than the next thickest skin (Lee & Ng, 1965:100).

They concluded their study with the findings that, firstly there is a difference in skin thickness between sexes over the age of 11 years (males having thicker skin than females), secondly that the subscapular skin is the thickest and the biceps skin the thinnest and lastly, that the subcutaneous fat layer tends to be higher in females than in males (Lee & Ng, 1965:102).

The only project in recent years on human body composition done postmortemly to predict body fat by skinfold measurements and supported by cadaver evidence, was investigated by the Brussels Cadaver Analysis Study in Belgium (October 1979 to June 1980). Twenty-five elderly cadavers (12 males and 13 females with ages ranging from 55 to 94 years) were dissected (Martin, Ross, Drinkwater & Clarys, 1985:31). The influence of skin thickness was also investigated and they reported that the effect of skin would be most marked at those sites and in those subjects with little adipose tissue.

Although the contribution of the double skin thickness to the total skinfold thickness is generally not large, it may lead to significant errors, especially in lean subjects (Martin *et al*, 1985:35). Their findings support those of Lee & Ng (1965) and conclude that "the effect of skin thickness was most marked subscapular where skin thickness accounted for 28,1%" of the skinfold caliper reading (34,9% for males and 23,9% for females) (Martin *et al*, 1985:35).

Since the time of Archimedes researchers have worked on developing acceptable formulae and equations for the determination of human body composition by using the technique of underwater weighing.

Behnke was the first researcher to experiment with underwater weighing as a viable method of determining body density. He already started working as early as 1930 when doing research on United States Navy Divers. Behnke, Feen & Welham (1942) were the first researchers to successfully use the method of underwater weighing for determining body density and therefore Dr Albert R. Behnke can be called the father of the densitometric method.

Another method, utilising helium gas dilution, is based on the technique, in which volume differences between the volume in a special chamber and subject volume is analysed. One of the biggest contributors toward improvement of this method was the physicist William Siri in 1965 (Behnke & Wilmore, 1974:26).

Ultrasound has been proposed as another alternative non-invasive technique to measure subcutaneous fat thickness. Temple (1956) have been one of the earliest researchers experimenting with ultrasonic depth measurements as an alternative for determining fat in vivo in animal body composition studies.

One of the most non-invasive, yet still not as accurate, methods in recent years to be used in especially health and training facilities, is bio-electrical impedance analysis (Nash:1985). The theory of bio-electrical impedance analysis is based on the total body impedance or resistance of an electrical flow that is induced directly into the body via electrodes.

The first researcher to propose a comprehensive method for the anthropometic estimation of several components of body composition was the Czechoslovakian anthropologist Matiegka in 1921 (Drinkwater, 1984:19). He developed a series of equations for the prediction of the mass of skin and subcutaneous tissue, skeletal muscle, bone and the remaining organs plus viscera.

The most common and popular method for clinical estimation of body fat however, is by measuring skinfolds with a caliper. The use of skinfold, circumferences and diameter measurements individually, or in combination, have been used to estimate body density and therefore also the determination of percentage body fat (Pollock & Jackson, 1984:606).

There is an almost uncountable number of different combinations of variables for the use of these anthropometrical measurements and research has led to the development of well over 100 prediction equations over the last 30 years (Lohman, 1981:182). Wilmore (1983:22), Lohman (1982) and Jackson & Pollock (1978) stated that the regression equations developed for the determination of body density with skinfolds tend to be population specific.

Henceforth each method of determining body composition, including the advantages and disadvantages, will be discussed individually in detail.

DETERMINATION OF BODY COMPOSITION

LABORATORY METHODS

IN VITRO ANALYSIS

Chemical analysis

The direct analysis of the gross body composition is a complex, expensive and laborious procedure that has rarely been done on man. German anatomists however, as already mentioned, had taken the lead more than a century ago and for fifty years dominated the work done on the determination of human body composition. The principle investigators of that era were Moleschott (1859), Bischoff (1863), Volkmann (1873) and Vierordt (1888) (Keys & Brozek, 1953:247)

These data unfortunately are considered to be of limited value since they were not well documented and did not include associated anthropometric data. Drinkwater (1984: 12) reported further that chemical body composition analysis for this century had been documented for foetuses (Zeigler, O'Donnell, Nelson & Fomon, 1976), neonates (Yssing & Friis-Hansen, 1965) and infants (Fomon, 1967), but very little information about the chemical composition is available.

Apart from this, the only other research until the middle of this century, were done on 4 cadavers (2 males, 1 female and 1 baby boy) by Widdowson, McCance & Spray (1951) for the years between infancy and adulthood (Malina, 1980).

Forbes, Casper & Mitchell (1953:360) studied 8 cadavers (6 males and 2 females) which were kept at a constant temperature of -18 °C. They tried to limit dehydration to the minimum by wrapping each body in plastic covers.

Womersley (1974) had cited the main problem with cadaver studies seemed to be internal hydration (oedema) which effects the determination of protein (12,9%-23,8%) and mineral (4,9%-7,6%) contents. Another problem is that the cause and time of death are not always well recorded, as well as the effects of certain illnesses and diseases. The densitometric method might only be applied to fresh cadavers (Keys & Brozek:1953), which makes correlation with this method of determining body composition very difficult.

The Brussels Cadaver Study in the early years of the previous decade investigated, among other subjects, the phenomenon of the prediction of body fat by skinfold, supported by cadaver evidence (Martin *et al*, 1985).

Although skinfold calipers can only estimate subcutaneous adiposity and hence, in order to estimate total body fat, certain assumptions regarding the relationship between internal and subcutaneous fat must be made. Ross *et al* (1985:37) suggest that, for both males and females, the deposition of each kilogram of subcutaneous adipose tissue is associated with the accumulation of 200g of internal adipose tissue.

IN VIVO ANALYSIS

DETERMINATION OF BODY DENSITY

Hydrostatic weighing

Most of the *in vivo* methods for determining body composition have been directed towards the estimation of body fat content. The methods rely on the two component model, which considers the body to be divisible into a lipid and a lipid-free component (Drinkwater, 1984:13). The hydrostatic method of underwater weighing is based on the Archimedes principle, which states that the reduction of the body weight underwater is equal to the weight of the water replaced (Keys & Brozek, 1953:266).

This method of estimating body composition has become the "gold standard" against which all other indirect methods are typically validated (Wilmore, 1983:21). This method, also called hydrodensitometry, relies on the assumption that the densities of different body tissues vary and it was commonly accepted that the density for the lipid and lipid-free components of the body are constant at 0,900 g/ml and 1,100 g/ml, respectively (Siri, 1957).

Keys & Brozek (1953: 271) measured the density of human fat of 20 adult male and female subjects to range from 0,8982 to 0,9009 g/ml with the mean of 0,9000 g/ml at 37 °C, with no significant differences to body location of the fat or sex. They continued to cite that, since there was a mean change in the density of human body fat of 0,00074 g/ml per 1 °C, the average temperature of human body fat in a normal living human being close to 36 °C, the mean density of human fat at this temperature would be O,90074 g/ml.

Thus, the bigger the contribution of fat to the total body weight, the lower the total underwater weight would be. The total body density (D) is the total body mass (M), determined in air, divided by the total body volume (V):

$$D = \frac{M}{V} \qquad (1)$$

The estimation of body density by underwater weighing (UWW) is considered to be the most accurate method for body composition assessment (Jackson and Pollock, 1982:194).

However, there is no single method of underwater weighing that is considered to be the only accepted standard. Different tanks are used requiring the subject to crouch (Barnes, 1987:42), sit (Jackson & Pollock 1985:78), kneel (Akers & Buskirk, 1969:649) or lie down (Williams, Anderson & Currier, 1984:660).

Additional variations are introduced in the determination of the subject's residual volume by helium dilution (Timson & Coffman, 1984:412), oxygen dilution (Marks & Katch, 1986:486), nitrogen dilution (Brozek, Henchel, Keys & Carson, 1949:241) or prediction equation (Grimby & Soderholm, 1963:199), either at the time of underwater weighing (Akers & Buskirk, 1969:650), or at a different time (Timson & Coffman, 1984:412).

As already stated, is the total body volume equal to the reduction of weight occurred according to the density of the water at the specific temperature of the water (Behnke & Wilmore, 1972: 22; Weast, .1969: F5).

The total body volume can be determined via the following equations (Williams *et al*, 1984:660):

$$V = \frac{WA - WW}{DW} \qquad (2)$$

where

V = Volume

WA = Weight in air

WW = Weight in water

DW = Density of water at a specific temperature.

Equation 2 can be further developed to the following:

$$D = \frac{WA}{\frac{WA - WW}{DW}} \qquad (3)$$

Biologically, the fat-free body mass varies in composition among different groups of which water, skeletal content and muscle mass are the major variables (Lohman 1982:47).

The densities of the different tissues vary as well and are affected by age, sex, race, physical training, recent fluctuations in body weight and fluid balances (Williams *et al*, 1984:662). Generally, the densities of tissues are greater in the young (Flint *et al*, 1977:559 and Jackson & Pollock, 1978:504), greater in men than in women (Wilmore, 1983:22 and Katch & McArdle, 1973:445) and greater in blacks than in whites (Schutte, Townsend, Hugg, Shoup, Malina & Blomquist, 1984:1647 and Seale 1959:37).

Determination of the body volume takes place during submersion, after a maximal expiratory effort. However, the measurement is influenced by two extraneous volumes i.e. air trapped in the lungs or residual volume (RV) and the volume of air trapped in the gastro-intestinal tract (GIV). These two air volumes need to be subtracted from the volume of the body underwater. Behnke & Wilmore (1974) and Buskirk (1961) devised this basic formula for determining the density of the body considering these factors:

$$D = \frac{WA}{\frac{(WA - WW)}{DW} - (RV + GIV)} \qquad (4)$$

Buskirk (1961) found the average GIV to be a negligible volume of 100 ml. Although many factors may have an influence on the determination of body density, residual volume is the most important. Residual volume has been the lung volume used most widely during hydrostatic weighing because it is the volume least affected by hydrostatic pressure (Timson & Coffman, 1984:411) and is probably the most consistent lung volume to measure both in and out of the water.

Residual volume is affected by variables such as age, sex, endurance training, posture, smoking habits and the presence of pulmonary disorders (Williams, *et al*, 1984:663). Generally women have a smaller physique and therefore a lower residual volume than men and it tends to increase in both sexes with increasing age and with deconditioning (Buskirk, 1961:91 and Brozek 1960:155). Smokers generally have a larger residual volume than non-smokers (Williams *et al*, 1984: 663).

Underestimation of the residual volume results in underestimation of the buoyancy force and consequently results in overestimation of the percentage of body fat and vice versa. Persons who are uncomfortable in water and especially underwater, may require extensive instruction and practise to attain true residual volume values underwater. A definitive change in lung volumes occur during submersion with a decrease in total lung capacity (Bondi, Young, Benett & Bradley, 1976:736; Girandola, Wisewell, Mohler, Romero & Barnes, 1977:276; Robertson, Engle & Bradley, 1978:679 and Timson & Coffman, 1984:413).

Residual volume was shown to decrease (Agostini, Gurtner, Torri & Rahn, 1966: 251; Bondi *et al*, 1976:736; Ostrove & Vaccaro, 1982:220; Pence, Henchel, Keys & Carson, 1949:45 and Robertson, Engle & Bradley, 1978:679), remain constant (Craig & Ware, 1967:423; Prefaut, Lupi-H & Anthonisen, 1976:320 and Sloan & Bredell, 1973:23) and increase (Brandom, Baileau & Lohman 1981:22) with submersion. Mayhew & Piper (1982:16) have shown in a comparison of the methods of determination of residual volumes, that the average percentage fat difference ranged from 1,1% to 3,1%.

Barnes (1987:41) indicated that an error in residual volume is critical, since every 100 ml difference of the residual volume in a calculation, results in an error of 0,7% body fat. This fact is supported by a variance of ± 200 ml in residual volume which corresponds to a percentage body fat variability of ± 1,5% to 1,8% fat, according to Marks & Katch (1986:488).

An accurate determination of the residual volume is therefore crucially necessary during hydrostatic weighing. Although a maximal expiratory effort is requested, the subject is not always able to exhale maximally, due to psychological factors, and therefore the amount of air not expired must be monitored accurately.

The amount of expiratory reserve volume which is not exhaled, must be incorporated and then formula (4) changes to the following:

$$D = \frac{WA}{\frac{WA - WW}{DW} - (RV + GIV + ERV)} \quad (5)$$

Underwater weighing is performed, while the subject remains submerged, seated in a chair that is suspended from a scale, with only residual volume and the remaining pre-recorded ERV in the lungs.

The underwater weight is determined as the mean weight of the final of three trials (Katch 1969:212).

A trend effect, due to learning and fatigue, develops in situations where repeated trials are performed (Marks & Katch, 1986:436). They base their guidelines representing the higher significance of underwater weight on the following criteria:

1. the highest value which is recorded more than twice,
2. the second highest value recorded if (1) does not apply,
3. the third highest value recorded if (1) and (2) do not apply.

The methods described above require the subject to exhale maximally before submersion during hydrostatic weighing. The residual volume is determined on land before the subject moves into the water.

Blaauw (1988:13) found this method to be inaccurate due to the following reasons:

1. there is no control over the expiratory effort of the subject or whether a maximal exhalation had taken place,

2. in the case where a maximal exhalation had occurred, the time which the subject is submerged is not sufficient enough to take an accurate reading of the scale due to fluctuations taking place,

3. even, if a maximal exhalation had taken place, the tester would not know the amount of air remaining in the lungs.

Unfortunately, once a method achieves "gold standard" status, its limitations are quickly forgotten and it is ascribed a degree of infallibility (Wilmore, 1983:21). However, the main disadvantages of the hydrostatic weighing method for determining body density, according to Pollock & Jackson (1984) and Katch & McArdle (1983), are:

1. it is among the most invasive of methods,

2. it is expensive in terms of both time and money,

3. it is limited to facilities with the needed infrastructure,

4. it requires highly trained personnel,

5. it requires a high degree of co-operation from the subject,

6. it is limited to fairly healthy people and cannot be used for children and the elderly due to health and safety hazards.

Water displacement

This method is based on the same technique as underwater weighing with the difference that the subject's actual water displacement is measured and not the underwater weight. This is done by accurately measuring the increase in the water level of the tank from a calibrated burette that is connected to the side of the tank. The determination of the residual volume is also necessary when using this method and calculations for the volume of gastro-intestinal air must also be made (Consolazio *et al,* 1963:298; Behnke & Wilmore, 1974:25 and Keys & Brozek, 1953:273).

According to Keys & Brozek (1953:273) studies performed by Kirk (1947) revealed volumes emissed from the gastro-intestinal tract to be 25 to 50 ml and rarely as much as 100 ml. Buskirk (1961), however found the average volume of gastro-intestinal air to be 100 ml. This value of 100 ml of the GIV is supported by Lohman (1992:11)

Equation 4 can then be applied to the following as devised by Behnke & Wilmore (1974:25):

$$BD = \frac{WA}{\frac{V}{DW} - (RV + 100\ ml)} \qquad (6)$$

where

BD = Body density

WA = Weight in air

V = Body volume

DW = Density of water at a specific temperature

Although this method is not as accurate as the hydrostatic weighing or helium dilution methods, there are certain advantages such as the isolated measurement of a body segment or limb. Some of the most common disadvantages of this method are the difficulties experienced by the investigator to read the difference of the water levels accurately and also for the subject to remain still and calm while submerged at a state of apnoea.

Helium dilution

The helium gas dilution method is based on the technique, in which volume differences between volume in a special chamber and subject volume is analysed. One of the biggest contributors toward improvement of this method was the physicist Wlliam Siri in 1965 (Behnke & Wilmore, 1974:26). This method requires a person to be placed in a special closed, sealed room with a known volume, while a known volume of helium in a second room then circulates the air of the first room. The helium gas moves freely and enters the subject's respiratory tracts and lungs, but not his other body tissues.

The concentration of helium is determined at the point of equilibrium and applied to the known body volume. The real volume determined is that being of the difference between the volume of the room and that of the subject.

The accuracy of this method however depends on the following factors such as the volume of the room must be known, as well as the size of the room which must be able to accommodate the largest of subjects, yet compact enough to determine the body volume accurately.

This method has several advantages over hydrodensitometry, firstly since ones does not need to determine the residual volume (the respiratory tracts form part of the body volume) and secondly, because of its non-invasiveness it can be widely utilised for children, geriatrics and different sizes and shapes of bodies.

Although the principles of the helium dilution method are more complex than hydrostatic weighing and initial expenses may be high, Behnke & Wilmore (1974:27) stated that the running costs are low and requires no highly skilled personnel to operate the system.

Ultrasound (Sonar)

Ultrasound has been proposed as another alternative non-invasive technique to measure subcutaneous fat thickness. This method for determining body composition is based on the sound conducting properties of the body's tissues. Pulses of sound are emitted by the machine and the returning echoes are used to determine the depth of the different tissues. Temple (1956) has been one of the earliest researchers in body composition experimenting in animal studies with ultrasonic depth measurements as an alternative for determining fat in vivo.

Since skinfold measurements are also based on subcutaneous fat thickness, these two methods have been compared (Bullen *et al*, 1965; Kuczmarski *et al*, 1987; Hayes *et al*, 1988 and Fanelli & Kuczmarski, 1984). Ultrasonic measurements were also demonstrated to be strongly correlated with direct measures of subcutaneous fat by electrical conductivity (r=0,98), needle puncture (r=0,98) and soft tissue radiographs (r=0,88) (Fanelli & Kuczmarski, 1984:704).

In an ultrasound device, electrical energy is converted in an ultrasonic probe to high frequency ultrasonic energy, which is then transmitted into the body in the form of short pulses (Bullen *et al*, 1965:376). These sound waves impinge perpendicularly upon the interfaces between the tissues that differ in their acoustical properties, thus creating different images.

There are two basic methods of presenting the image. Firstly, the signals may be displayed on an oscilloscope as a series of peaks which vary in height with the magnitude of the returned echoes and the time gaps between successive echoes can be related to distances within the structure. This type of image is called an amplitude modulated display or A-scan and is generally preferred for accurate distance measurements.

Secondly, a rapid series of A-scans can be acquired in one plane by employing a linear array of transducers, which generate a two-dimensional television image. Strong and weak echoes are shown as bright and dim dots respectively and it is called a brightness modulated display or B-scan (Kirsch, Hanson & Gibson, 1984:280).

B-scans have obvious advantages of a picture that facilitates diagnostic or pathological properties, although accuracy is sacrificed in the process. In order to convert distance, in the case of the A-scan, into actual depth, the sound velocity in human fat tissue at a specific temperature must be known. There seems to be uncertainty about this because Hayes *et al* (1988:304) reported 1450 m/s, Bullen *et al* (1965:377) 1467 m/s at 35 °C, Tan *et al* (1981:127) 1518 m/s and Kirsch *et al* (1984:282) 1540 m/s, respectively.

Different types of fluids can be used for the suitable transmission of sound waves between the probe and the skin surface. Mineral oil (Bullen *et al*, 1965:377 and Katch, 1984:790) and water soluble transmission gel (Fanelli & Kuczmarski, 1984:704) and Kuczmarski *et al* (1987:718) both have yielded good results, although the latter is more expensive.

The degree of compression involved with skinfold measurements varies with the location (Kuczmarski *et al*, 1987:718) and age (Brozek & Kinley, 1960:45) and has been attributed to factors such as subcutaneous fat thickness, state of hydration, distribution of fibrous tissue and blood vessels (Fanelli & Kuczmarski, 1984:703) and differences in sex (Hayes *et al,* 1988:308 and Kuczmarski *et al*, 1987:723).

Brozek and Mori (1958:322) have studied the effect of caliper compression on the skinfolds by comparing half the thickness of double folds to the corresponding non-compressed ultrasound values:

$$U = \frac{C}{2} \qquad (7)$$

Percentage compression was calculated by Fanelli & Kuczmarski (1984) with the following equation:

$$\% \text{ compression} = \frac{U - 0{,}5C}{U} \times \frac{100}{1} \qquad (8)$$

where

U = Ultrasound (mean fat thickness)

C = Caliper (mean skinfold thickness)

This equation was later used and changed by Kuczmarski *et al*, (1987) to read as follows:

$$\% \text{ compression} = \frac{1 - 0{,}5C}{U} \times \frac{100}{1} \qquad (9)$$

Bullen *et al* (1965:380) found the median skinfold caliper values to be 66% and 61% of the uncompressed ultrasound measurements for the abdominal and triceps sites respectively, which are similar to the findings of Gram (1956:178) of 65%. Ultrasonic values were translated by Bullen *et al* (1965:381) to comparable double skinfold equivalents by multiplying the ultrasound values by the appropriate constant factors (1,2 for the triceps and 1,3 for the abdominal and subscapular sites respectively) and obtained correlations between these measurements of r=O,80 and r=0,90 for the triceps and abdominal sites respectively for men.

Kuczmarski *et al* (1984:708) found a good correlation (r=0,807) between ultrasound and caliper measurements for the triceps site, which was higher than Haymes *et al* (1976) (r=0,64), but similar to that reported by Bullen *et al* (1965) (r=0,80).

For the comparison of the caliper and ultrasound techniques with body density, as determined by hydrodensitometry, Kuczmarski *et al* (1984:706) cited the single best predictors of body fat were the triceps site (r=0,749) and the waist (r=0,736) respectively.

Although there are many other variables such as adipose tissue hydration, local tension, sex, age and body location which may influence ultrasound measurements, this is found to be a superior method for predicting body density and body fatness especially for obese people for whom compression is the greatest (Kuczmarski *et al,* 1987:723) and for lean subjects, for whom the influence of skin thickness can be as high as 34% and 23,9% for males and females respectively (Martin *et al*, 1985:35)

Biochemical methods

Potassium 40 (^{40}K)

Total body potassium is a substance which is thought to be constant in the human body and is used to determine lean body weight. This used to be considered as a standard method for body composition analysis, but research showed it to have a higher degree of variability than body density and total body water methods (Lohman, 1984:596).

Since the isotope ^{40}K occurs naturally in the lean tissue of the body, making up approximately 0,012% of the body potassium, the gamma rays that it emits can be measured using a whole body counter (Smith, Hesp & McKenzie, 1979:171). This method assumes that there is no potassium contained in the lipid component and that the lipid-free component contains 68,1 mEq potassium per kilogram (Drinkwater, 1984:15). Although this method has advantages such as rapidness (less than 4 minutes), non-invasiveness, requiring only the subject to lie down in a chamber, there are certain disadvantages too.

These include the level of skilled personnel is high, it is very expensive and the procedure is confined to advanced research facilities.

Potassium 42 (^{42}K)

This method, which uses the ^{42}K radio-isotope, relies on the assumption that 95% of potassium in the body is found intracellular. It is more accurate than the ^{40}K method, for it determines the cell mass, but is reckoned to be invasive since the procedure takes as long as 40 hours (Forbes: 1962). Furthermore does it also require advanced research facilities, skilled personnel and it is costly.

Determination of Body Water

The basic living cell of an organism contains protoplasm, which has a basic composition of water, salts and proteins, plus skeletal structures and variable amounts of fat. Hence if it were possible to estimate the total water contents of the body, the fat-free body mass could be calculated. Therefore, by subtracting the fat-free mass from the gross body weight, the total amount of body fat can be calculated (Keys & Brozek, 1953:281).

This method is based on the concept that certain isotopes or substances will distribute evenly within a specific compartment of water and that, this dilution of a known amount of isotope into the unknown volume of body water, allows the calculation of the amount of body water (Behnke & Wilmore: 1974). The use of total body water to estimate body fat and fat-free body content is overlooked by many researchers and laboratories as a criterion method because of its methodological problems (Lohman, 1992:14).

Brozek & Keys (1953:283) stipulated certain requirements for a test substance:

1) it should rapidly penetrate and dissolve in all the water of the body,

2) It should not be absorbed on, be combined with or be destroyed by other constituents of the body,

3) it should be eliminated from the body at a precisely measurable rate,

4) it should not be toxic in the limited test amounts needed and,

5) be readily and accurately measurable in the blood serum.

Estimation of total body water by isotope dilution, normally using the non-radioactive deuterium oxide (^2H_2O - heavy water), or tritium oxide (^3H_2O - radioactive water) is one of several ways to determine body composition. The non-radioactive deuterium can be measured by infrared absorbtiometry or mass spectroscopy. In the first case of infrared sampling, respiratory water sampling is the most practical and best choice of physiological fluid, because it is quick (10 minutes collection period), non-invasive, most practical and less expensive. In the case of mass spectometry the procedure takes longer, it is more expensive, but it is the most precise method of the two (Lohman, 1992:14).

One of the most convenient and best solutes used for total body water estimates in the early years was antipyrine (1,5-dimethyl-2-phenyl-3-pyrazolone) and proved to produce satisfactory results in estimation of body fat when compared to densitometry in nine individuals (Messenger & Steele: 1949).

Lohman continues to cite that there are certain critical methodological concerns with the isotope dilution technique, namely:

1. the accuracy and precision of estimates when different physiological fluids are sampled,
2. the magnitude of the protein-hydrogen exchangeability,
3. constancy of the hydration of the fat-free body mass and variation in a specific population (menstruation, disease, exercise dehydration, etc.),

4. mean hydration of the fat-free body as a function of population (infants, the elderly, children, etc.).

In order to estimate the body fat, as a proportion of the total body weight, a standard equation must be implemented:

$$F = 1 - kA \tag{10}$$

where

F = Fat

A = Total body water (Antipyrine)

k = Constant (Assumed % of water of a body less fat))

Therefore it can be clearly seen that the calculation of body fat is very much dependent on the choice of the value of the constant. Osserman, Pitts, Welham & Behnke (1950) assumed that water is constantly 71,8% of the body weight less fat, k=1,393 (1,000/0.718), where McCance & Widdowson (1951) preferred to select 71,0% (k=1,4). Keys & Brozek (1953:289-292) proceeded to elaborate on the equation above and developed it further until no less than 19 formulae later they conclude with "these are the uncertainties before any allowance for analytical errors or variability in the application of the methods for estimating total body water or extracellular fluid" can be made.

This method of assessing total body water, and percentage body fat, has even been referred to in the literature as the "silver standard" (McBride, 1986:14). This procedure is not very often used since it is highly invasive, administered orally or even by means of intravenous injection, requires highly trained staff and is limited to ideal laboratory and research facility settings.

Bio-electrical impedance analysis (BIA)

The theory of bio-electrical impedance analysis is based on the total body impedance or resistance of an electrical flow that is induced directly into the body via electrodes. In the human body, the fat-free body mass, specifically the total body water, act as the conductor of an electrical current. Thus the more fat tissue, the more the relevant resistance would there be (Lukaski:1987). This method is used widely, especially in health facilities, since the latest equipment is easy to use, rapid results are obtained, it is safe, non-invasive and requires little co-operation from the subject. Bio-electrical impedance analysis yields a measure of body resistivity, which is the inverse of conductivity. It makes use of the fact that impedance to electrical flow of an injected current is related to the volume of a conductor, the human body, and the square of the conductor's length and the subject's height (Segal *et al*, 1985:1565).

Total body resistance is measured by use of a four terminal impedance analyser, also called a tetrapolar bio-electrical impedance analyser (Lukaski, Bolonchuk, Siders & Hall, 1990:434). Current injector electrodes are placed distally on the dorsal surfaces of the right hand and right foot at the distal metacarpals and metatarsals respectively, and proximally between the distal prominences of the radius and the ulna of the right hand's wrist and between the medial and lateral maleoli of the ankle of the right foot.

An excitation current of 800 μA at 50 kHz is introduced into the subject's hand and the resistance is read on a zero to 1000 Ohms scale. Measurements of the resistance and the reactance are made, using the electrodes placed on the ipsi-lateral and contra-lateral sides respectively (Lukaski *et al*, 1985:912).

Empirically derived formulae are used to calculate the estimated body density, from which the percentage fat and lean body mass can be derived. All measurements are taken with the subject fully clothed, except for shoes and socks, while lying in a supine position.

The bio-electrical impedance analysis method appears to be promising, although the equations normally provided with the instrument can give unsatisfactory results overestimating the lean body mass of obese subjects (Segal *et al*, 1985:1569). Kushner, Schaeller & Bowman (1984) have also demonstrated that the existing formulae for use with the instrument yielded poor results for predicting total body water in comparison with measured values.

Segal *et al* (1985:1565) have found that lean body mass predicted from bio-electrical impedance analysis by use of prediction equations correlated highly (r=0,912) with biochemical methods (total body water) of determining lean body mass. The use of equations on athletes overestimate fatness and in obese subjects underestimate fat and therefore does BIA not yield good predictions for very lean and very fat subjects. Other factors such as age, gender, ethnic group, physical activity and patient populations also effect the validity of this method (Lohman, 1992:55).

Although there may be some advantages of bio-electrical impedance analysis, such as convenience, non-invasiveness, cost effectiveness, rapidness and safety, this method still seems to be "only as good as the software in the little box" (Nash, 1985:129).

Total body electrical conductivity (TOBEC)

One of the most promising methods which is virtually non-invasive, is the measurement of TOBEC. This method is based on the same electrolyte principle that demonstrates the differing bio-electrical properties of lean tissue and fat as electrical impedance analysis, but the principle is reversed.

Where bio-electrical impedance analysis measures the body's resistance of a directly induced current, TOBEC measures the body's conductance of currents induced by a magnetic field around it (Presta, Segal, Gutin, Harrison and Van Italie, 1983:524). A person placed in the midst of an electromagnetic field disturbs the field in such a way that is dependent on the amount and distribution of his electrolyte content (Horswill, Geeseman, Boileau, Williams & Layman, 1989: 593). The electrical conductivity of lean tissue is far greater than that of fat, owing that to the much higher electrolyte content of lean tissue (Pethig, 1979).

The subject lies supine on a platform that is conveyed through a copper coil. While the subject passes through the coil, an electro-magnetic field is generated for approximately 30 seconds. The solonoidal coil is driven by a 5 MHz oscillating radio frequency current. The change in the coil impedance between the condition when the subject is inside the coil and when the coil is empty, is measured and the change is proportional to the total electrical conductivity of the body. This change is in turn proportional to the lean body mass (Presta *et al*, 1983:736).

Total body electrical conductivity appears to be a valid method for non-invasive estimates of the muscle mass compartment of lean body mass. The measurement is specifically influenced by the amount of tissue that facilitates the conduction of electricity, namely tissues with a high water and electrolyte constituent.

Components of fat-free weight that are poor conductors of electricity such as bone, can have a significant influence on body composition analysis obtained from hydrostatic weighing (Pethig, 1979). Most of the research on TOBEC has also included hydrostatic weighing data and a development of prediction equations for TOBEC. Horswill *et al* (1989:595) states that "persons with dense bone or skeletal frames may be underestimated for lean mass and overestimated for percentage body fat because of the contribution of bone weight to the total body mass, but not to the TOBEC values". This implies that a better prediction of fat-free weight can be made when bone density can be evaluated.

To assess muscle mass, Horswill *et al* (1989) found a correlation coefficient of r=0,98 between TOBEC measurements and independent measurements of muscle mass, therefore suggesting that TOBEC provides a reliable method of assessing muscle mass. Although there are factors such as age and sex (Presta *et al*, 1983:525) dehydration and osmolality of the lean body mass, Horswill *et al* (1989:597) concludes that "TOBEC measurements of lean body mass are highly correlated with muscle mass as estimated from 3- methyl-hystidine excretion and fat-free weight from hydrostatic weighing".

Segal *et al* (1985:1565) reported in a sample of 75 male and female subjects, ranging from 4,9% to 54,9% body fat, a high correlation (r=0,962) between densitometrically determined lean body mass and the TOBEC method by the use of a developed regression equation. This confirmed the validity of the TOBEC method. The correlation increased even further (to r=0,973) when the variable of sex was added to the prediction equation. Although total body electrical conductivity measurements are still fairly expensive and confined to research and laboratory facilities, it is a potentially reliable non-invasive method for estimating muscle mass within the fat-free compartment, the fat- free weight and lean body mass.

Dual Energy Radiography

There are many ways to determine bone mineral content, including single photon absorptiometry (SPA), dual photon absorptiometry (DPA), dual X-ray absorptiometry (DEXA), etc. These bone densitometers measure bone mineral content (g/cm) and bone mineral density (g/cm^2), but are not able to determine bone density. In addition to bone mineral estimations, Mazess (Lohman, 1992:25) found that with the dual energy approach the fat and lean contents of the soft tissue of the body can also be estimated.

With the development of dual energy radiography (DER), total bone mineral content of the body as a function of age (children, adults and geriatrics), gender, and activity level can be determined. The assumption that, a 17,6% proportion of all minerals in the body is found in the nonosseous compartment and the remaining 82,4% in bone (Brozek:1963), must be made in order to determine body composition with this technique.

Studies on 13 subjects comparing fat percentage from body density with the percentage fat from dual photon absorbtiometry correlated highly (r=0,92) with a standard error of estimate (SEE) of 3,2% (Heymsfield, Wang, Kehayias and Pierson: 1989). Wang *et al* (1989) extended their sample to 99 subjects and found a correlation for males of r=0,87, with a SEE of 3,4 %.

Dual energy radiography provides the opportunity to determine the mineral content of the body as a function of age, gender and activity level, with the advantages of non-invasiveness, low radiation exposure and high precision. Its estimates of bone mineral may lead to improved estimates of the fat-free body density in different populations ranging from children to the elderly.

Furthermore, high estimates of fat content and regional composition, which may even lead to indirect estimates of abdominal fat, can be made and more research into and development of this method can lead to new understanding of biological variation in body composition (Lohman, 1992:36).

Biopsies

The direct way to determine actual skin thickness in vivo is with this method and can be performed via two techniques, namely excision or punch biopsies. In the first case tissue is removed by a longitudinal, elliptical scalpel cut through the skin into the subcutaneous tissue, whereas a round bladed punch is pressed and turned through the skin and its underlying layers in the latter mentioned way.

This method is frequently used in laboratory and hospital environments to determine the different layers of skin and subcutaneous tissue. It works well when the different types of cells must be coloured and identified for pathological and hystological purposes, but there are certain key issues at hand when the influence of skin thickness on body composition is investigated. The main problem regarding *in vivo* biopsies is that of expansion and overhydration of the excised tissue after it has been removed. The measurements change immediately when the skin and subcutaneous tissues are not under tension and stretch as it would be in a state of intactness.

Another serious implication includes the medico-legal matter of informed consent which the patients or subjects have to sign. Furthermore, is the fact that the researcher is bound by prescheduled operative and surgical procedures, which may not include the anatomical regions of the body being investigated. It is also time consuming, expensive and population specific (race, gender, age, etc.)

Another pitfall is that of the health status of the patient. Normally patients undergoing operations have underlying illnesses or predispositions, which may effect their normal metabolism, especially fat, as well as tissue hydration. Most of the non-invasive studies strive to predict the body composition of normal, healthy individuals and therefore data obtained from hospitalised people is not comparable to and representative of normal society.

Therefore to enable research into the skin thickness and/or the influence thereof, the skin has to be in the natural intact state, without scar tissue, uniformly hydrated and subjected to the normal skin tension that occurs *in vivo.*

FIELD METHODS

Anthropometry

One of the first researchers, working since 1921 on the determining of the chief components of body mass, to document his investigations systematically, was the Czechoslovakian anthropologist Matiegka (Brozek, 1963:3). He developed a series of equations to predict the weights of skin and subcutaneous tissue, skeletal muscle, bone and the remaining organs and viscera. Matiegka's approach, deriving his data from the cadaver studies done by Vierordt in 1890 and 1906, was to use groups of anthropometric measurements which closely related to specific tissues and thus developing a series of coefficients (Drinkwater, 1984:19).

Skinfolds

Skinfold thickness measurements have been used frequently to estimate body fatness in epidemiological and metabolic studies (Gray, 1990:571). The most common method for clinical estimation of body fat is by measuring skinfolds with a caliper. There is an almost uncountable number of different combinations of variables for the use of anthropometrical measurements, skinfolds, circumference and girth measurements individually or in combination, and research has led to the development of over 100 prediction equations (Jackson, 1984:616).

One of the major fat deposits in the human body is located subcutaneously. Since total subcutaneous fat is associated with total body fat, it is believed that the sum of several skinfold sites can be used to estimate total body fat. However, several other fat deposits exist in the body such as inter- and intramuscular fat, fat surrounding the internal organs and digestive tract, and other fat including essential lipids in bone marrow and the nervous system (Lohman, 1981:184). Further, the distribution of fat in the body has shown to vary considerably between individuals and whether how much fat is located viscerally or subcutaneously.

The rationale for fatfold (skinfold) measurements is based on the fact that a relation exists between the fat located in the depots directly beneath the skin and internal fat and body density (McArdle *et al*, 1988:496). As already mentioned, Ross *et al* (1985:37) suggested that, for both males and females, the deposition of each kilogram of subcutaneous adipose tissue is associated with the accumulation of 200g of internal adipose tissue.

Since 1930 a special pincer-type caliper was used to measure subcutaneous fat at selected body sites relatively accurately. There is a number of different calipers in general use today, such as the Harpenden, Lange, Holtain, etc. - all with one characteristic in common, namely the constant tension or pressure of 10 g/mm^2 being exerted by the pincer arms at the point of contact. The caliper works on the same principle as a micrometer used to measure distance between two points. The procedure for measuring skinfolds thickness is to grasp a fold of skin and subcutaneous fat with the thumb and forefinger pulling it away from the underlying muscular tissues following the natural contour of the fatfold. The thickness of the double layer of skin and subcutaneous fat tissue are directly read from the caliper dial and recorded in millimetres (McArdle *et al*, 1988:496).

These skinfold or fatfold measurements are then put into mathematical regression equations designed to predict body density or percentage body fat. These equations however are population specific (Jackson & Pollock:1978 and Sloan:1967) and predict fatness fairly accurately in samples where subjects are similar in age, sex, training state and fatness to those from which the equations were derived (McArdle, 1988:498).

The skinfold caliper has a number of known limitations and some are accentuated in obese subjects. Kuczmarski *et al* (1987:717) list them as the following:

1. The amount of tissue picked up to form the skinfolds may vary between observations,
2. The fat-muscle interface cannot always be palpated,
3. Skinfold thickness impossible to measure at those sites where it exceeds the maximum opening of the caliper,
4. The caliper tips may slide on larger skinfolds,
5. Subsequent measurements for obese people may be lower than previous readings, due to oedema and compression of the fat,
6. Difference in the elastic properties of fat and skin tissues vary with age from one individual to another,
7. The degree of compression varies on different body locations,
8. Variation in the depth at which the caliper is placed has a more marked effect on the readings of obese people than lean subjects,
9. Inter-observer differences in measurements may lead to differences in time of which the caliper is held (shorter time leads to higher readings),
10. People who are ticklish or experience pain may influence the accuracy of the readings due to tension or movement.

In conclusion, some opinions also have it that skinfolds can also be somewhat invasive, since most of the anatomical sites for the measurements are normally covered with clothes and pinching of the skin is required. Inconsistencies also arise depending on the equation selected (Sinning *et al,* 1985), as well as the presence or loss of obesity tissue (Scherf *et al*, 1986).

Body Mass Index

A fact well known by now is that body weight is made up by different tissues such as muscle, organs, skeleton and fat. The Body Mass Index (BMI) is the easiest anthropometric index to take, involving only the weight (W) and stature or height (H). Several variations of ratios or indices can be used including the weight-height ratio (W/H), Quetelet's index (W/H^2), Ponderal index ($H/W^{0,333}$), Khosla-Lowe or Rohrer index (W/H^3) and Benn index (W/H^p), (where exponent p is derived from a specific population) (Lee *et al*, 1981:233).

The indice chosen as the best predictor of adiposity, with the highest correlation with body fat and the lowest with height (r=0,748), is the Quetelet's index (W/H^2) (Dembert, Jekel & Loren, 1984:392):

$$\% BF = -16,498 + 1,360 (W/H^2) \qquad (11)$$

where

BF = Body Fat

W = Weight

H = Height

An individual with a large ratio of musculo-skeletal system to stature, can have a BMI in the obese range and yet not be overfat. Similarly a small skeletal or musculo-skeletal frame in relation to height will lead to an underestimation of per cent body fat.

Slaughter & Lohman (1980:170) found in body mass impedance, compared to underwater weighing, a standard error of estimate (SEE) in predicting fat-free body mass of 9,8% in males and 8,1% in females.

Jackson & Pollock (1985) cited an overestimation of 2,3 % and 2,2% fat in males and females respectively when they compared BMI with skinfolds.

Micozzi *et al* (1986) found significant correlations with per cent fat from hydrostatic weighing, body mass index and subscapular skinfolds, while Cronk & Roche (1982:349) preferred the triceps skinfold, especially in woman. Although measuring stature and weight is the easiest way to predict body density and therefore percentage of body fat, it is potentially biased and hence not uniformly applicable (Lee *et al*, 1981:238).

All these methods discussed in this chapter have shed some light on the topic modern man's quest to determine body composition accurately. Not all of these methods and procedures can be performed readily in a clinical environment, since they require specialised and expensive equipment as well as skilled technicians, are time consuming, more or to the lesser extent invasive and expensive. To be able to determine body composition accurately, easily, non invasively and not too costly appears to present a situation which researchers and health professional alike faces every day. For this research it had been decided that anthropometrical measurements, taken with a skinfold caliper and ultrasound apparatus would be used. The methods and procedures followed for this research are explained in detail in the next chapter.

CHAPTER THREE

METHODS AND PROCEDURES

INTRODUCTION

THE SAMPLE

RESEARCH METHODS

Determination of the Body Volume

Determination of the Anthropometrical Measurements

Determination of the Ultrasound (Sonar) Measurements

Determination of the Lung Volumes

Determination of Bio-electrical Impedance

Determination of Punch Biopsies

CALCULATIONS

Calculation of Body Density

Calculation of Percentage Body Fat

Calculation of Somatotypes

Calculation of Skin Thickness

Calculation of Fat Thickness

Calculation of Lung Volumes

Calculation of Percentage Caliper Compression

INTRODUCTION

All the testings and measurements were taken at the Biokinetics Laboratory of the Department of Human Movement Studies of the University of Stellenbosch. Most of the people involved in the study were undergraduate students in Human Movement Studies. They were all sportsmen, classified according to the Heath-Carter Somatotype (Carter:1982), as mesomorphs or endo-mesomorphs, and participated mainly in endurance events such as bi-and triathlons or cycling.

THE SAMPLE

Forty five male students of the University of Stellenbosch participated in the study. Their ages ranged from 18 to 30 years, with an average of 21,9 years.

RESEARCH METHODS

All the apparatus were tested beforehand and calibrated according to the manufacturers' instructions. The Autospiro A500 Spirometer, used for the determination of the lung functions, was checked for accuracy and calibrated daily. The Avery beam balance scale, used for the determination of the body mass on land and Salter 236T Thermoscale for the hydrostatic weight, were calibrated daily before the start of each daily testing session. The Harpenden skinfold caliper was checked daily and adjusted to zero if needed be.

The sonar apparatus, ALOKA Echo Camera SSD 500 with 5 MHz probe, was calibrated by the agent, X-Ray Imaging Services. The bio- electrical impedance analyser needed not to be calibrated daily. All the tests on a subject were performed on the same day except in the case of the 12 subjects, whom had biopsies taken which were taken within eight weeks after the first visit without having changed their nutritional and health status or activity levels.

DETERMINATION OF THE BODY VOLUME (UNDERWATER WEIGHT)

The hydrostatic method of underwater weighing is based on the Archimedes principle, which states that the reduction of the body weight underwater is equal to the weight of the water displaced by the body. The total body volume will be equal to the person's weight as corrected by the density of the water at the specific temperature of the water.

Further corrections should be made for the residual volume and the expiratory reserve volume remaining in the lungs and respiratory tracts after a maximal exhalation effort. The tank used for underwater weighing was a round custom made fibre glass tank with a diameter of 0,85 m and a depth of 1,60 m. A building scaffolding was erected and placed over and around the tank and wooden struts were used as platforms. A suspension scale, Salter 236T Thermoscale, which was used for the underwater weight measurements, was connected to the platform on which the subject was placed and was suspended from a horizontal beam above the tank. The Autospiro was placed close nearby so that the lung volume measurements could easily be taken.

The testing procedure was carefully and extensively explained individually to each subject before the testing session commenced. The examiner also confirmed with the subject that he understood everything thoroughly.

The water temperature was maintained as closely as possible at 29 °C (SD ± 2,52). Each subject, trying not to agitate the water, slowly descended down the side into the tank from a rope that was suspended from a horizontal beam. The subjects were requested to urinate and defecate, if needed, before entering the tank. Although the subjects entered the tank with a small bathing costume, it was dismissed of and all measurements inside the tank were taken without any clothes.

The subject, standing with his feet on the bottom of the tank, was instructed to submerge underwater and then step onto the platform while the rest of the structure was put over his head and into place. This was done to get the subject's head and hair completely wet, to familiarise himself with the new environment and become used to the confinement of the tank and water temperature. He then stood with both feet on the platform, which was connected to the suspension scale by a non-stretchable rope, with only his head emerging from the water. This was done to minimise unfamiliarity and discomfort as not to influence the reliability of the results.

The testing procedure was again explained comprehensively after which a practice or trial run took place to ascertain that the subject understood the instructions completely. In the case of any uncertainty the whole procedure was explained again and demonstrated on land. For each underwater weighing, the mouthpiece of the spirometer was placed in the mouth of the subject in such a fashion that the lips were sealed completely around it.

A noseclip was secured over the subject's nose to ensure that no respiration could take place through the nasal airways. Therefore all the air respired by the subject could be closely monitored and accurately recorded. While the subject remained in this half squatting position, the whole protocol was briefly explained again. The spirometer was switched on and the subject breathed normally into the apparatus while the tidal volume was recorded. A deep exhalation, followed by a maximal inhalation and then followed by a maximal exhalation, was requested and recorded. At the very end of the maximal expiratory effort the subject let go of the mouthpiece and submerged into the water from a standing position into a squatting position on the platform, without any further respiration taking place.

The subject then sat motionless underwater on the platform, without making contact with the sides of the tank, for as long as possible to allow damping of the needle oscillations on the weight scale and to ensure accurate readings.

The investigator held a hand on the bottom of the scale to steady it at first and then let go to record independent readings to the nearest 20 grams. Each subject was weighed ten times in order to ensure accurate readings and to comply with the guidelines of Marks & Katch (1986:436). The reason for measuring the expiratory effort was to determine the exact amount of the expiratory reserve volume which was not exhaled during the testing. The extraneous weights of the platform and the suspension apparatus were subtracted from the measured underwater weight. The water temperature was tested and recorded immediately after each subject had been weighed underwater.

DETERMINATION OF THE ANTHROPOMETRICAL MEASUREMENTS

All the anthropometrical measurements were taken by a trained anthropometrist and were done according to the Brussels Protocol (Kinanthropometric Congress in Brussels, Belgium:1978). The anatomical orientation sites were identified and marked with a demographic pen before the skinfold, circumference, diameter and sonar measurements were taken. The measurements were repeated to ensure they were within the specific tolerance limit (*tl*) for each parameter (Ross *et al*, 1980).

Stature (*tl* =3 mm)

The subject stood, without shoes, with the back against the stadiometer so that the heels, buttocks, upper back and the back of the head made contact with the vertical beam. The chin was tucked in slightly so that the head was held in the Frankfurt horizontal plane. The subject was requested to stretch to the full height, without lifting the heels, and after a normal inspiration, the measurement was taken from the vertex to the platform. Stature was recorded in centimetre to the nearest millimetre.

Body Mass ($t\ell$ =0,2 kg)

The subject stood, without any shoes and clothed only in a small bathing costume, on the Salter beam balance scale for the determining of the body mass on land. The mass was determined in kilograms to the nearest 100 grams.

CIRCUMFERENCES

All girth measurements were taken with a thin flexible, inelastic (non-stretchable) metal tape perpendicular to the longitudinal axis of the said body part. The tape was gently in contact with the skin and was moved up and down until the highest values could be determined. All measurements were taken on the dominant side.

Chest ($t\ell$ =2 mm)

While the subject's arms were slightly raised laterally (abduction), the tape was placed horizontally at the level of the fourth sternebrum. The subject, with arms relaxed to their natural position at the sides of the trunk, was then requested to exhale normally while the measurement was taken.

Waist ($t\ell$ =3 mm)

The subject faced the anthropometrist and the tape was placed at the level of the natural waist, which is the narrowest part of the torso.

Abdomen ($t\ell$ =3mm)

The maximum girth was taken at the level of the greatest anterior extension of the abdomen in a horizontal plane, normally albeit not always at the level of the umbilicus.

Biceps (relaxed) ($t\ell$ =2mm)

The subject stood erect, with arms hanging freely at the sides of the trunk and palms facing the thighs. The measurement was taken at the midpoint, between the acromion process and the olecranon process, of the upper arm.

Biceps (tensed) ($t\ell$ =2 mm)

While the right arm was held horizontally at shoulder level, with the hand in supination, the subject was requested to clench a fist and flex the elbow fully. The measurement was taken with the tape held at a right angle to the longitudinal axis of the upper arm at the point of maximum girth.

Calf ($t\ell$ =1 mm)

The subject was requested to stand upright with the feet about 20 cm apart as to distribute the body mass equally. The maximum girth measurement was taken by moving the tape up and down the long axis of the lower leg until the highest value was determined.

Ankle ($t\ell$ =2 mm)

The minimum girth measurement of the calf was taken just proximal of the maleoli of the ankle joint.

DIAMETER MEASUREMENTS

The Harpenden sliding calipers were held steady between the thumb and forefinger and pressed firmly against the bony mass when the diameter values were determined.

Bi-epicondylar (humerus) ($t\ell$ =1 mm)

The subject's right arm was flexed at a right angle and held horizontally with the ground. The width between the medial and lateral epicondyles were determined in such a fashion that the sliding caliper halved the angle that was made by the flexed elbow.

Bi-condylar (femur) ($t\ell$ =1 mm)

The subject's right foot was placed flat while the knee joint was flexed at a 90° angle. The width between the medial and lateral condyles was determined and firm pressure was applied to the contact areas of the caliper as to rule out the effect of the underlying tissues on the reading.

DETERMINATION OF SKINFOLD MEASUREMENTS

All skinfold measurements were taken with a Harpenden skinfold caliper which exerts a constant pressure of 10 g/mm^2 at all widths. The skinfold was grasped firmly by the thumb and index finger of the left hand so that the skin and subcutaneous adipose tissue were pulled away from the underlying muscle and tissues. The caliper, which was held in the right hand, was then placed perpendicular over the skinfold approximately one centimetre below the thumb and finger of the left hand. The caliper grip was released so that full tension was exerted on the skinfold with the pressure pads parallel to each other. The underlying muscle mass was fully released in order to facilitate the grasping of the skinfold. All the skinfolds, except the abdominal, were taken on the dominant side of the body while the subjects stood upright and relaxed.

The thigh and calf measurements however, were taken while the heel was placed on a chair to ensure a relaxed thigh and the foot was placed on a chair with the knee at a 90° angle to ensure a relaxed calf, respectively. The pressure was applied to the caliper by releasing the right hand's grip to ensure full tension on the skinfold. The dial was read approximately 2-3 seconds after the grip on the caliper was released. In the case where a value could not be obtained within 3 seconds, another skinfold measurement was done where the skinfold was grasped more firmly between the fingers.

Subscapula (SS)

An infero-lateral fold was taken on a diagonal line coming from the inferior corner of the scapula at a 45° angle, running obliquely downward and outward.

Triceps (TRI)

A vertical fold taken on the posterior midline of the upper arm over the triceps muscle, midway between the acromion process of the scapula and the olecranon process of the ulna, with the elbow extended and relaxed at the sides of the subject.

Biceps (BI)

A vertical fold taken on the anterior midline of the arm over the biceps muscle, midway between the anterior axillary fold and the antecubital fossa.

Chest (CH)

A diagonal fold taken midway along the oblique line running, from the most superior margin of the axilla, to the nipple of the lateral border of the pectoral muscle.

Axilla (AX)

A horizontal fold on the mid-axillary line at the level of the xiphoid process of the sternum.

Anterior Supra-iliac [S(A)]

A diagonal fold above the crest of the ilium, just anterior of where an imaginary vertical line would come down from the mid-axillary line.

Posterior Supra-iliac [S(P)]

A diagonal fold on the posterior above the crest of the ilium, just lateral of where an imaginary vertical line would come down from the subscapular location and horizontally in line with the anterior supra-iliac location.

Abdominal (ABD)

A vertical fold taken laterally adjacent to the umbilicus but not including the umbilical tissue.

Anterior Thigh (AT)

A vertical fold on the anterior surface of the thigh midway between the inguinal fold and the patella.

Medial Thigh (MT)

A vertical fold taken in exactly the same fashion as that of the anterior thigh except on the medial line of the thigh.

Patella (PAT)

A horizontal fold on the anterior surface of the thigh taken one centimetre above the mid-superior border of the patella.

Medial Calf (MK)

A vertical fold on the medial surface of the calf over the widest part of the gastrocnemius muscle.

Chin (K)

A vertical fold midway between the superior edge of the os hyoides and the temporalis of the mandible.

Cheek (W)

A horizontal fold taken at a 90° ankle, one centimetre superior of the imaginary line between the submandibular indentation and the condylar process.

DETERMINATION OF ULTRASOUND MEASUREMENTS

All ultrasound, also called sonar, measurements were taken with a field portable B-mode ultrasound device, attached to a 5,0 MHz transducer (ALOKA SSD 500 Echo Camera, X-Ray Imaging Services Pty.Ltd.). These measurements were taken at the exact sites, as premarked by demographic pen, of all the skinfold caliper measurements.

The ultrasound transducer, with its stand-off adapter, was coated with an acoustic water soluble transmission gel. It was held manually approximately 5 mm perpendicular above the marked site, hence contact was provided without compression of the dermal surface and subcutaneous tissues. The skin and subcutaneous fat layer of each site were measured individually by electronic calipers to the nearest third of a millimetre and tabulated in Table 4 and Table 5.

After each site was measured, the subject's skin was cleaned with a paper towel to remove the remaining transmission gel.

DETERMINATION OF LUNG VOLUMES

The following regression equation for the determination of the residual volume (RV), as devised by Grimby & Soderholm (1963:203), was used:

$$RV = [\, 0{,}022(A) + 1{,}98(H) - 0{,}015(W) - 1{,}54 \,] \qquad (12)$$

where

A = Age in years

H = Height in meter

W = Weight in kilogram

The expiratory reserve volume (ERV) was accurately determined and tabulated in order to give a precise volume and the amount of air not expired during the determination of the underwater weight.

The vital capacity (VC), inspiratory capacity (IC), inspiratory reserve volume (IRV) and tidal volume (TV) were also accurately measured and recorded.

DETERMINATION OF BIO-ELECTRICAL IMPEDANCE

The subject was requested not to eat for 12 hours prior to the testing session and to urinate before the testing procedures commenced. Four spot electrodes, two distally and two proximally, placed on the wrist and ankle surfaces, were secured by Velcro bands. To ensure good contact, a transmission gel was applied before the electrodes were fitted.

A painless signal of 800 μA at 50 kHz was introduced to the deep body tissues and the highest of three values was recorded. The recorded values, as well as the subjects' age, height, sex and body build were sent away to the agents who computed the values and converted all the data to body density and percentage body fat.

DETERMINATION OF PUNCH BIOPSIES

Twelve of the forty-six male subjects participated in the punch biopsies study. This part of the study, due to its invasiveness and specialised procedures, was approved by the Ethical Committee of the Faculty of Medicine of the University of Stellenbosch at Tygerberg. This study was conducted at the Tygerberg Hospital and was also approved by the Superintendent: Research Projects of the said institution. All the subjects gave their informed written consent of the Medical School as well as the Department of Dermatology at Tygerberg Hospital.

Four 6 mm Stiefel punch biopsies were taken from each subject by a specialist in the operating room of the Department of Dermatology at the said hospital. The four sites identified were the biceps, medial thigh, subscapular and posterior supra-iliac and were on the exact locations where the sonar and skinfold measurements were taken.

The subjects were injected with a local anaesthetic and the tissues removed were individually placed in pre-marked test tubes, which were sealed and immediately taken to the laboratory of the Department of Anatomical Pathology of the said hospital where processing, colouring, fixing, etc. were done.

The microscopic measurements and relevant interpretations were done by the head of the Department of Anatomical Pathology.

This study proved to be of little significant research value concerning the global project due to unforeseen problems such as tissue hydration, expansion, etc. Nevertheless a huge academic lesson was learned as to how research is done in a hospital surrounding of such an extent, involving many people from different departments co-operating to achieve one goal.

CALCULATIONS

Programs for the statistical analysis were provided by Mr Chris Els of C&R Computer Services of Stellenbosch.

CALCULATION OF BODY DENSITY (HYDRODENSITOMETRY)

The body density, according to the underwater weighing method (hydrodensitrometry), was calculated according to the following formulae:

$$BD = \frac{WA}{\frac{(WA - WW)}{DW} - [RV + ERV(x)]} \qquad (13)$$

Where

WA = Weight of body in air in kilogram

WW = Weight of body underwater in kilogram

DW = Density of water at a specific temp in g/ml

RV = Residual volume in litres

ERV(x) = Part of the ERV not expired in litres

CALCULATION OF BODY DENSITY (INDIRECT METHODS)

The most common non-invasive method of determine body density and therefore also percentage of body fat, is by applying certain skinfold measurements to formulae or regression equations. The body density, according to the indirect methods of the researchers, Jackson & Pollock (1978) and Durnin & Rahaman (1967), was calculated with the following formulae:

JACKSON & POLLOCK (1978)

Sum of Skinfolds:

$$x = (SS + TRI + CH + AX + ABD + S(A) + AT)$$

$$BD = 1{,}16439 - 0{,}05477 (\log x) \quad (14)$$

where

SS = Subscapula

TRI = Triceps

CH = Chest

AX = Axilla

ABD = Abdomen

S(A) = Supra-iliac (anterior)

AT = Anterior thigh

DURNIN & RAHAMAN (1967)

Sum of Skinfolds:

$$x = (SS + S(A) + TR + BI)$$

$$BD = 1{,}1610 - 0{,}0632 (\log x) \qquad (15)$$

where

SS = Subscapula

S(A) = Supra-iliac (anterior)

TRI = Triceps

BI = Biceps

CALCULATION OF PERCENTAGE BODY FAT

In order to obtain the percentage body fat, each body density value, as determined by the methods of hydrodensitometry, Jackson & Pollock (1978) and Durnin & Rahaman (1967), was then individually put into the following percentage body fat formulae:

Brozek (1963) : $$\% \text{ Fat} = \left(\frac{4{,}570}{BD} - 4{,}142 \right) \times \frac{100}{1} \qquad (16)$$

Keys & Brozek (1953) : $$\% \text{ Fat} = \left(\frac{4{,}201}{BD} - 3{,}813 \right) \times \frac{100}{1} \qquad (17)$$

Rathburn & Pace (1945) : $$\% \text{ Fat} = \left(\frac{5{,}548}{BD} - 5{,}044 \right) \times \frac{100}{1} \qquad (18)$$

Siri (1961) : $$\% \text{ Fat} = \left(\frac{4{,}950}{BD} - 4{,}500 \right) \times \frac{100}{1} \qquad (19)$$

where

BD = Body Density

CALCULATION OF SOMATOTYPES

The calculation of the three different components of the somatotype of the subjects were calculated with the following Heath-Carter formula (Carter:1982):

Endomorph

Sum of Skinfolds:

$$x = (TR + S(A) + SS)$$

$$ENDO = -0{,}7182 + 0{,}1451(x) - 0{,}00068\,(x^2) + 0{,}0000014(x^3) \qquad (20)$$

where

TR = Triceps

S(A) = Supra-iliac (anterior)

SS = Subscapula

Mesomorph

$$MESO = [(0{,}858 \times H) + (0{,}601 \times F) + (0{,}188 \times AC) + 0{,}161 \times CC)] - (0{,}13 \times S) + 4{,}50 \qquad (21)$$

where

H = Humerus Diameter (Bi-epicondylar)

F = Femur Diameter (Bi-condylar)

AC = Arm Girth Corrected (Biceps Girth - Triceps Skinfold/10)

CC = Calf Girth Corrected (Calf Girth - Medial Calf Skinfold/10)

S = Stature

Ectomorph

$$ECTO = [(Stature/\sqrt[3]{BodyMass}) \times 0{,}732] - 28{,}38 \qquad (22)$$

CALCULATION OF SKIN THICKNESS

The thickness of the skin was determined with the ultrasound apparatus. The electronic calipers were locked on the external border of the epidermis and then moved to the area where the cutis vera and the tela subcutanea met. This distance was measured to the nearest third of a millimetre and tabulated.

CALCULATION OF LUNG VOLUMES

Residual volume (RV)

The residual volume was calculated by using the regression equations devised by Grimby & Soderholm (1963):

$$RV = [\,0{,}022(A) + 1{,}98(H) - 0{,}015(W) - 1{,}54\,] \qquad (23)$$

where

RV = Residual volume in litres

A = Age in years

H = Height in metres

W = Weight in kilograms

Expiratory Reserve Volume (ERV)

The expiratory reserve volume was determined by requesting the subject to breathe normally and then exhale maximally after a deep inspiration.

Vital Capacity (VC)

The vital capacity was determined by requesting the subject to exhale maximally after a maximal inspiratory effort. Before underwater weighing took place, the subject breathed normally so that a tidal volume could be recorded. While remaining seated, the subject was then instructed to exhale completely and then inhale completely after which a near maximal exhalation took place and then the subject submerged underwater without any further respiration taking place. The ERV on the last effort before the subject went underwater was thus closely monitored and recorded. The remaining air in respiratory tracts of the subject could then be easily accurately determined.

CALCULATION OF PERCENTAGE CALIPER COMPRESSION

The percentage caliper compression was calculated with the following formula devised by Fanelli & Kuczmarski (1984):

$$\% \text{ Compression} = \frac{U - 0{,}5C}{U} \times \frac{100}{1} \qquad (24)$$

where

U = Ultrasound (mean fat thickness)

C = Caliper (mean skinfold thickness)

STATISTICAL PROCESSING

The statistical processing was done by Mr Chris Els of C & R Computer Services of Stellenbosch. The statistical program of Quattro Pro 1.0 of Windows 5.0 version was used to compute the different statistical parameters. The Pearson Product Moment correlations between relevant variables were calculated and the significance thereof was determined. The level of significance for all statistical tests was $p<0{,}05$.

The calculations and computations of the data of the different parameters investigated were tabulated and graphically displayed. In the next chapter the results will be individually discussed in detail in relation to the findings of other researchers and the hypotheses of the first chapter.

CHAPTER FOUR

RESULTS AND DISCUSSION

INTRODUCTION

This study investigated the influence of skin thickness on the determination of the percentage body fat according to skinfold and ultrasound methods. Therefore various parameters were investigated, namely skinfold thickness, measured by the Harpenden skinfold caliper, fat and skin thickness individually, as well as in combination with each other, as measured by an ultrasound (sonar) apparatus.

Initially all these measurements were subjected to various body density formulae and applied to percentage body fat formulae. These findings were all compared to and correlated with hydrodensitometry, which were taken as the norm. A systematical method of statistical elimination was applied to identify the body locations that individually correlated the highest with body density via the underwater weighing method.

All measurements and formulae used in this investigation were correlated with body density, as determined by hydrodensitometry or underwater weighing, due to the absence of other studies in this field of research.

A series of new regression equations was developed for skinfold caliper measurements as well as for sonar fat measurements.

RESULTS

ANTHROPOMETRICAL CHARACTERISTICS

A complete analysis of the anthropometrical characteristics of the subjects who participated in this study is given in Table 1 and can be summarised as follows.

Age

The ages varied from 18 to 30, with an average of 21,93 years (SD±2,535)

Stature

The subjects' stature varied from 168,9 cm to 196,2 cm, with an average of 179,35 cm (SD±6,031), while their body mass varied from 60,5 kg to 103,8 kg, averaging 76,96 kg (SD±9,726).

Body density

The body density, as determined by hydrodensitometry, varied from 1.0437 g/cm^2 to 1,0933 g/cm^2, with an average of 1,0794 g/cm^2 (SD±0,0118).

Girths and Diameters

The girth and diameter measurements were taken to be able to calculate the different components of the somatotypes. The bicep values were recorded with the arms flexed and tensed, as well as extended and relaxed.

Somatotypes

The somatotypes were calculated according to the Heath-Carter (1982) formula and the results were 3,61; 4,95; 2,56 for endomorphy, mesomorphy and ectomorphy respectively (see Figure 1). The somatotypical profile of the subjects of this study can be classified as endo-mesomorph.

Table 1. ANTHROPOMETRICAL CHARACTERISTICS

Parameter	Total	Average	Range			S D
Age (years)	987	21.93	18.00	-	30.00	2.535
Stature (cm)	8071	179.35	168.90	-	196.20	6.031
Mass (kg)	3463	76.96	60.50	-	103.80	9.726
Body density (g/cm^3) hydrodensitometry	49	1.0794	1.0437	-	1.0933	0.0118
Girth (cm)						
Bicep	1515	33.66	29.00	-	40.00	2.240
Chest	4471	99.35	88.70	-	117.20	5.980
Abdominal	3712	82.48	72.40	-	98.50	6.343
Calf	1700	37.78	32.80	-	45.60	2.626
Ankle	1010	22.45	19.80	-	25.80	1.379
Diameter (cm)						
Humerus	309	6.87	6.20	-	7.80	0.373
Femur	430	9.55	8.60	-	10.50	0.464
Somatotype						
Endomorphy	163	3.61	2.50	-	5.67	0.831
Mesomorphy	223	4.95	2.19	-	7.67	1.086
Ectomorphy	115	2.56	0.57	-	5.61	1.094

N = 45

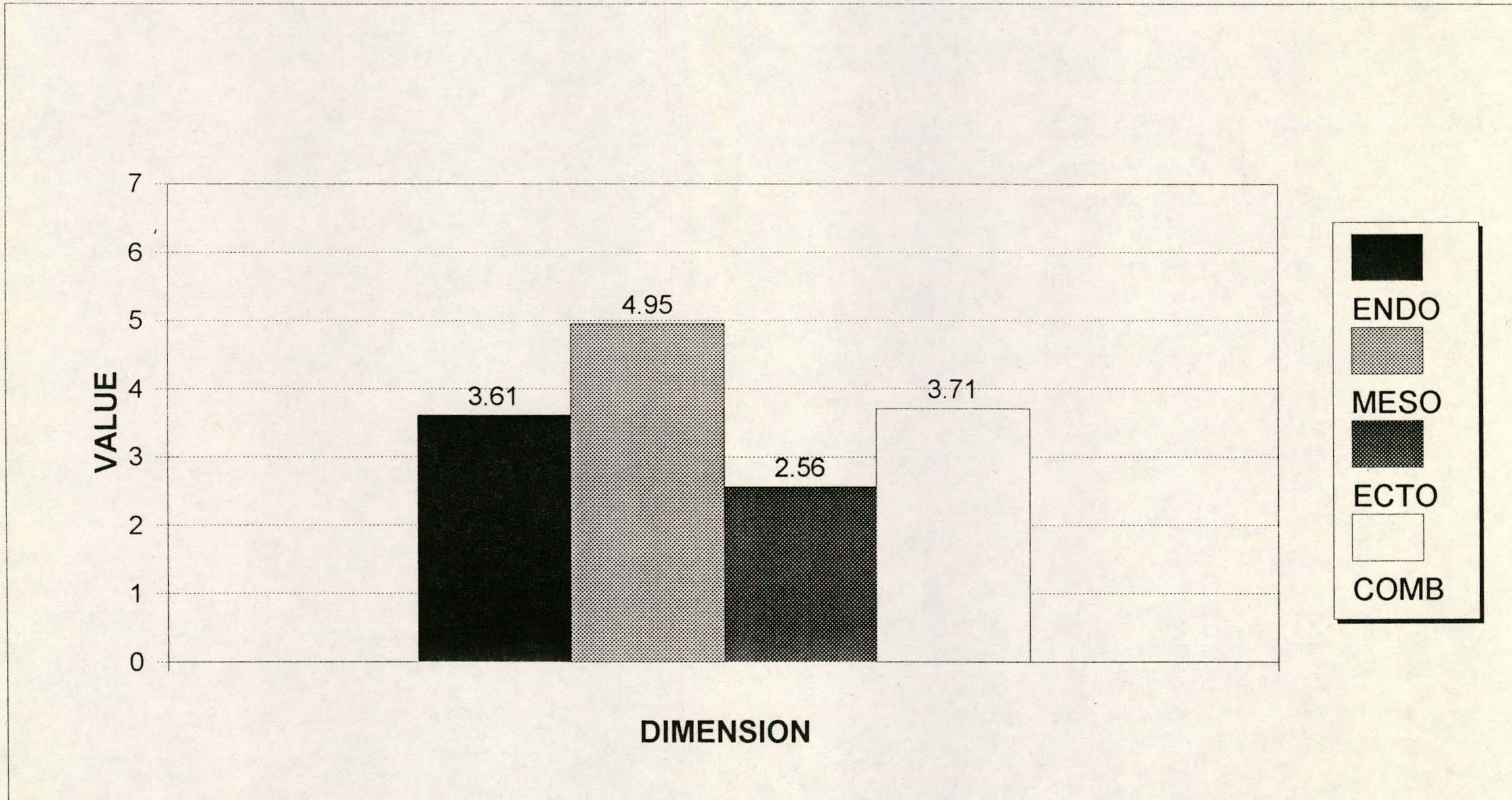

Figure 1. SOMATOTYPES

Skinfold Thickness (Harpenden Caliper)

Average skinfold thickness (caliper) was compared for the 14 body locations (see Table 2 and Figure 2). Supra iliac posterior (18,28 mm) yielded the highest value and the bicep site (3.42 mm) the lowest. The reason why the supra iliac (posterior) values for the skinfold caliper are the highest, although no similar high sonar fat values were recorded, may be attributed to a probable incompressibility of the fat at that specific body location.

Although this particular body location has not been researched before, this may agree with the findings that the skinfold values of the trunk of the body yield higher results than those of the extremities (Scherf *et al*:1986 and Shimokata *et al*:1989)

Skin Thickness (Sonar)

Average skin thickness (sonar) was also compared for the 14 body locations (see Table 3 and Figure 3). The subscapula site had the highest (3,55 mm) and the bicep site the lowest (1,37 mm) values respectively. Although they conducted their studies on cadavers, these findings agree with the research of Lee & Ng (1965:102) who also cited that there is a variation in skin thickness, depending on the body location. The contribution of the skin thickness to the total skinfold thickness may lead to significant errors, especially in the subscapular site. The contribution of the skin thickness value of this specific body site was 37,9% in this study. This value is supported by that of Martin *et al* (1985:35), who reported a value of 34,9%.

These findings confirm the first hypothesis that the skin thickness can influence the determination of percentage body fat according to skinfold methods.

Fat thickness (Sonar)

When the average fat thickness (sonar) was compared from site to site, the abdomen value (7,56 mm) yielded the highest and the bicep (1,97 mm) the lowest readings (see Table 4 and Figure 4). This is in accordance with Bullen *et al* (1965), who cited similar findings for the abdominal area.

Table 2. SKINFOLD THICKNESS MEASUREMENTS (mm): HARPENDEN CALIPER

Parameter	Total	Average	Range	S D
Sub Scapula	422	9.38	5.2 - 21.4	3.041
Tricep	383	8.50	4.4 - 15.2	3.061
Bicep	154	3.42	2.2 - 7.4	1.066
Chest	232	5.16	2.8 - 11.8	2.220
Axilla	316	7.01	3.8 - 15.0	2.780
Supra lilac (Anterior)	256	5.69	3.2 - 14.6	2.493
Supra lilac (Posterior)	823	18.28	8.2 - 34.8	7.605
Abdominal	457	10.16	4.8 - 27.2	5.564
Thigh (Anterior)	542	12.05	4.2 - 34.0	5.176
Thigh (Medial)	474	10.53	3.8 - 18.8	4.917
Patella	426	9.46	4.8 - 22.0	3.486
Calf (Medial)	322	7.16	3.4 - 19.8	3.101
Chin	229	5.10	3.0 - 9.8	1.546
Cheek	258	5.72	3.6 - 13.4	1.693

N = 45

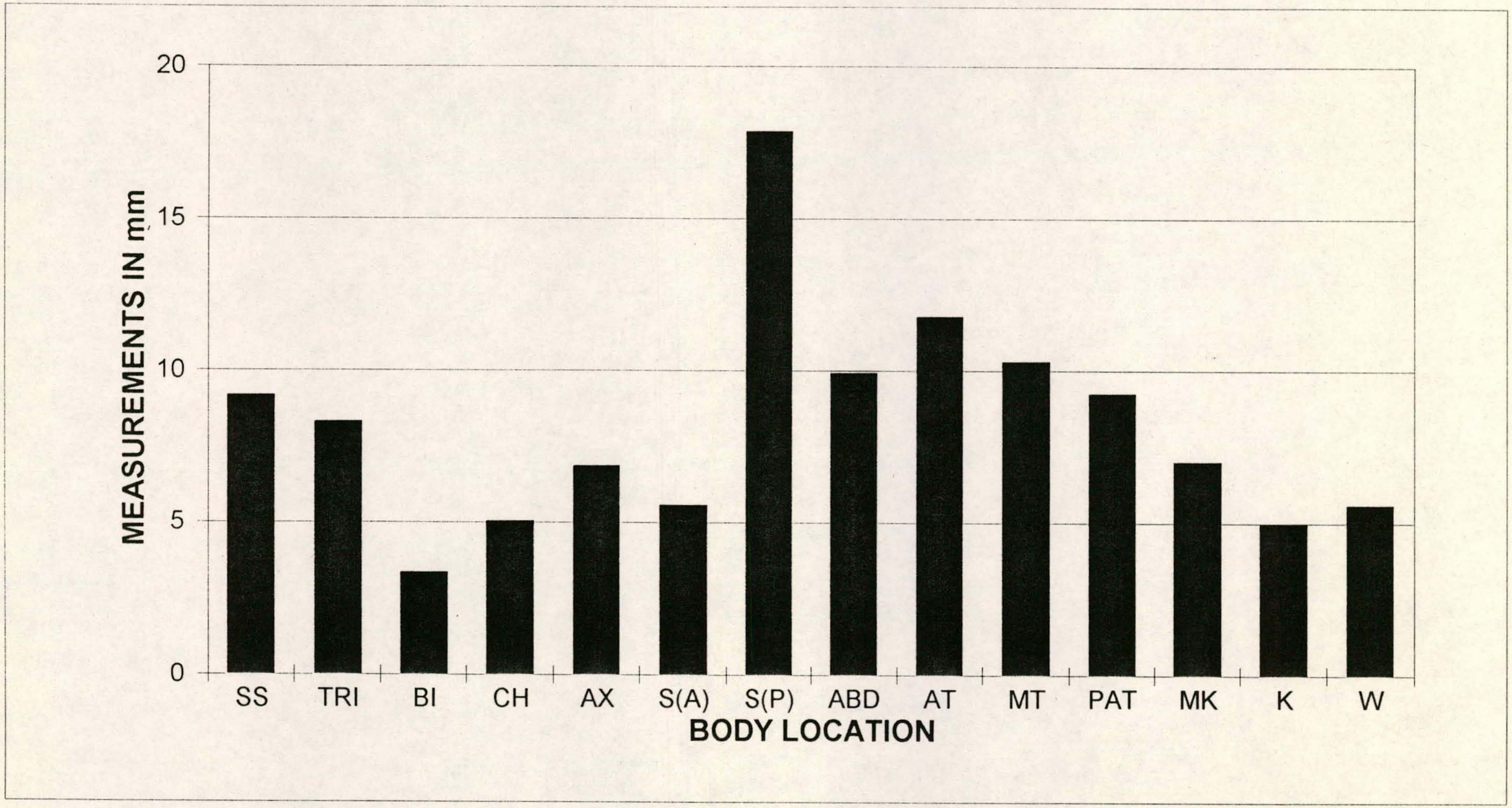

Figure 2. **AVERAGE SKINFOLD THICKNESS: HARPENDEN CALIPER**

Table 3. SKIN THICKNESS MEASUREMENTS (mm): SONAR

Parameter	Total	Average	Range	S D
Sub Scapula	160	3.55	2.67 - 5.00	0.503
Tricep	91	2.03	1.33 - 3.00	0.413
Bicep	62	1.37	1.00 - 2.00	0.278
Chest	85	1.90	1.33 - 2.67	0.331
Axilla	88	1.95	1.00 - 3.00	0.396
Supra lilac (Anterior)	84	1.87	1.33 - 2.67	0.336
Supra lilac (Posterior)	122	2.71	1.67 - 4.00	0.524
Abdominal	97	2.16	1.33 - 3.00	0.418
Thigh (Anterior)	96	2.14	1.67 - 3.00	0.344
Thigh (Medial)	96	2.14	1.67 - 2.67	0.306
Patella	93	2.07	1.33 - 3.67	0.487
Calf (Medial)	84	1.87	1.33 - 2.67	0.287
Chin	90	1.99	1.33 - 3.00	0.358
Cheek	85	1.90	1.33 - 2.67	0.316

N = 45

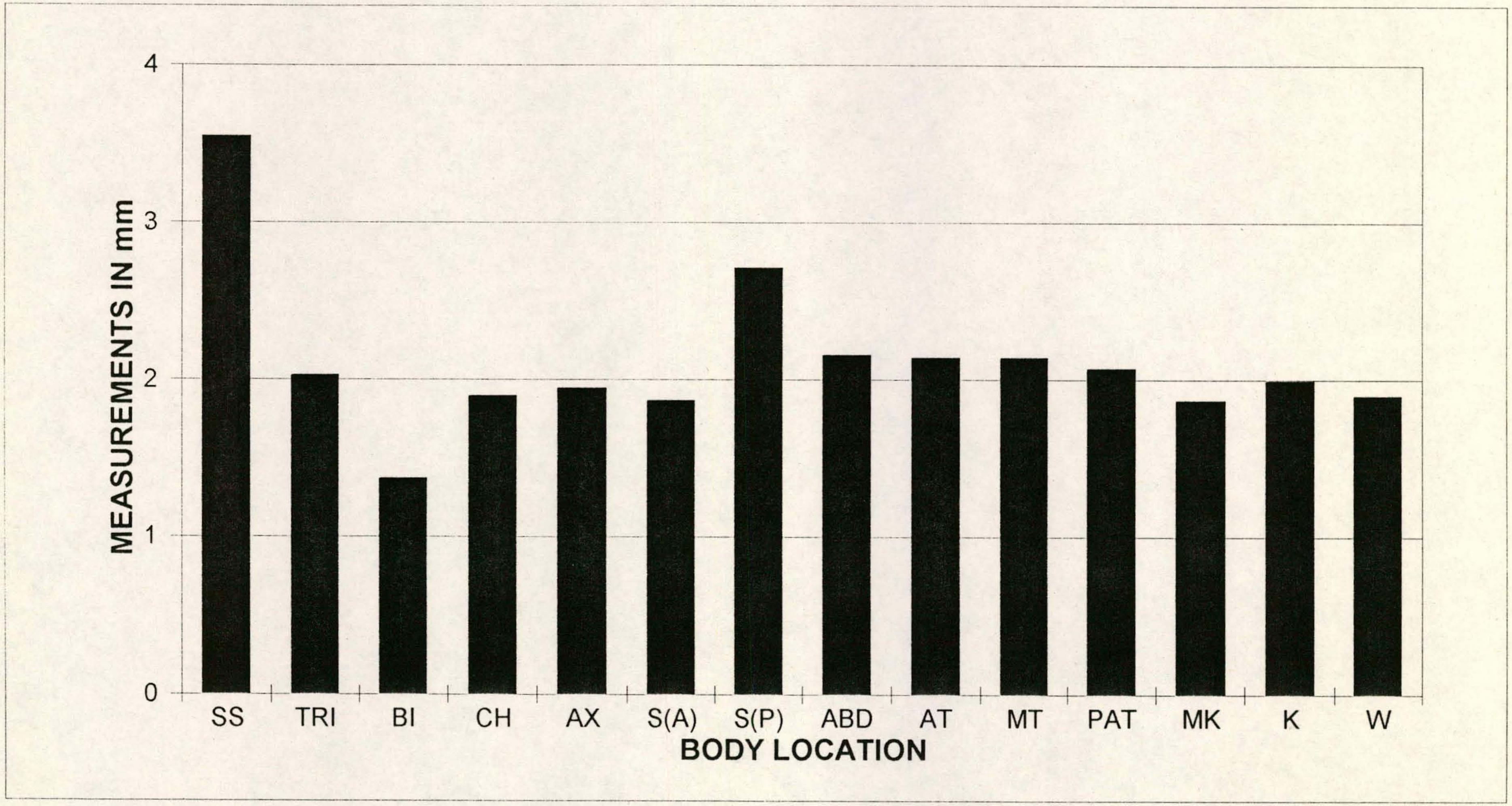

Figure 3. **AVERAGE SKIN THICKNESS: SONAR**

Table 4. FAT THICKNESS MEASUREMENTS (mm): SONAR

Parameter	Total	Average	Range	S D
Sub Scapula	190	4.21	2.00 - 11.00	1.736
Tricep	159	3.53	1.33 - 8.00	1.436
Bicep	89	1.97	1.00 - 3.67	0.631
Chest	139	3.08	1.00 - 7.67	1.487
Axilla	146	3.24	1.00 - 8.00	1.563
Supra lilac (Anterior)	126	2.79	1.33 - 8.00	1.381
Supra lilac (Posterior)	215	4.79	2.00 - 9.00	1.994
Abdominal	340	7.56	1.33 - 29.00	6.101
Thigh (Anterior)	196	4.35	1.67 - 11.67	1.961
Thigh (Medial)	242	5.37	2.00 - 11.00	2.393
Patella	149	3.31	1.67 - 7.67	1.377
Calf (Medial)	131	2.91	1.67 - 6.67	1.183
Chin	120	2.67	1.33 - 6.00	0.822
Cheek	113	2.51	1.00 - 4.67	0.703

N = 45

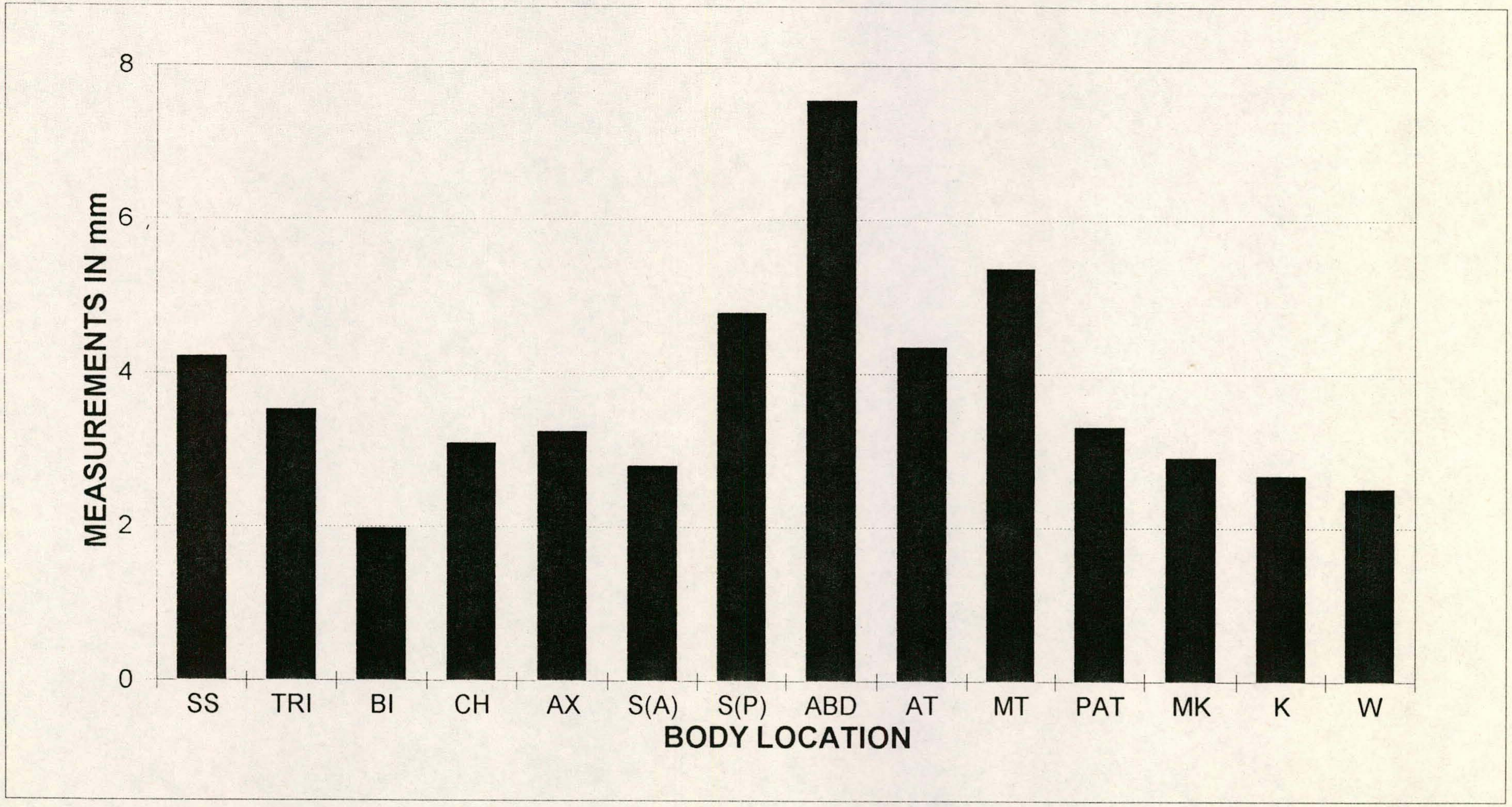

Figure 4. **AVERAGE FAT THICKNESS: SONAR**

Skinfold (Caliper) vs Sonar (Fat)

The relation of the skinfold caliper measurements (compressed) to the sonar (fat) values (uncompressed) can be seen in Figure 5a. The supra iliac (posterior) site reveals the biggest difference, while the biceps site the smallest. In all the cases the caliper readings are bigger than the sonar readings. The sonar fat values varied from 26,17% (posterior supra iliac) to 74,36% (abdomen) of the skinfold measurements.

Skinfold (Caliper) vs Sonar (1x Skin + Fat)

The relation of the skinfold caliper measurements (compressed) to the sonar (1x skin + fat) values (uncompressed) can be seen in Figure 5b. Again the supra iliac (posterior) site reveals the biggest difference, while the biceps site the smallest. Again the caliper readings are the bigger of the two, but the increment has changed markedly, especially in the bicep, chest, abdomen, chin and cheek locations.

The sonar (1 x skin + fat) values ranged from 41,0% (posterior supra iliac) to 97,76% (bicep), which agrees with Martin *et al* (1985) that the influence of the skin thickness would be most marked at those sites and subjects with little adipose tissue.

Skinfold (Caliper) vs Sonar (2x Skin + Fat)

The relation of the skinfold caliper measurements (compressed) to the sonar (2x skin + fat) values (uncompressed) can be seen in Figure 5c. The supra iliac (posterior) site reveals the biggest difference, but a significant change in profile has taken place, where the sonar values are the biggest in 8 of the 14 cases. The influence of the caliper compression on the measurements reflects in the values of the subscapula, bicep, chest, axilla, supra iliac (anterior), abdomen, chin and cheek. In this case the values ranged from 55,82%, supra iliac (posterior), to 137,83% (bicep). Again the last value agrees with Martin *et al* (1985). The notable difference between the caliper and sonar reading of the supra iliac (posterior) can assume to be the incompressibility of the subcutaneous layer of adipose tissue. This area definitely needs more research done into and may reveal to be of significance to the distribution and prediction of percentage body fat , particularly in men.

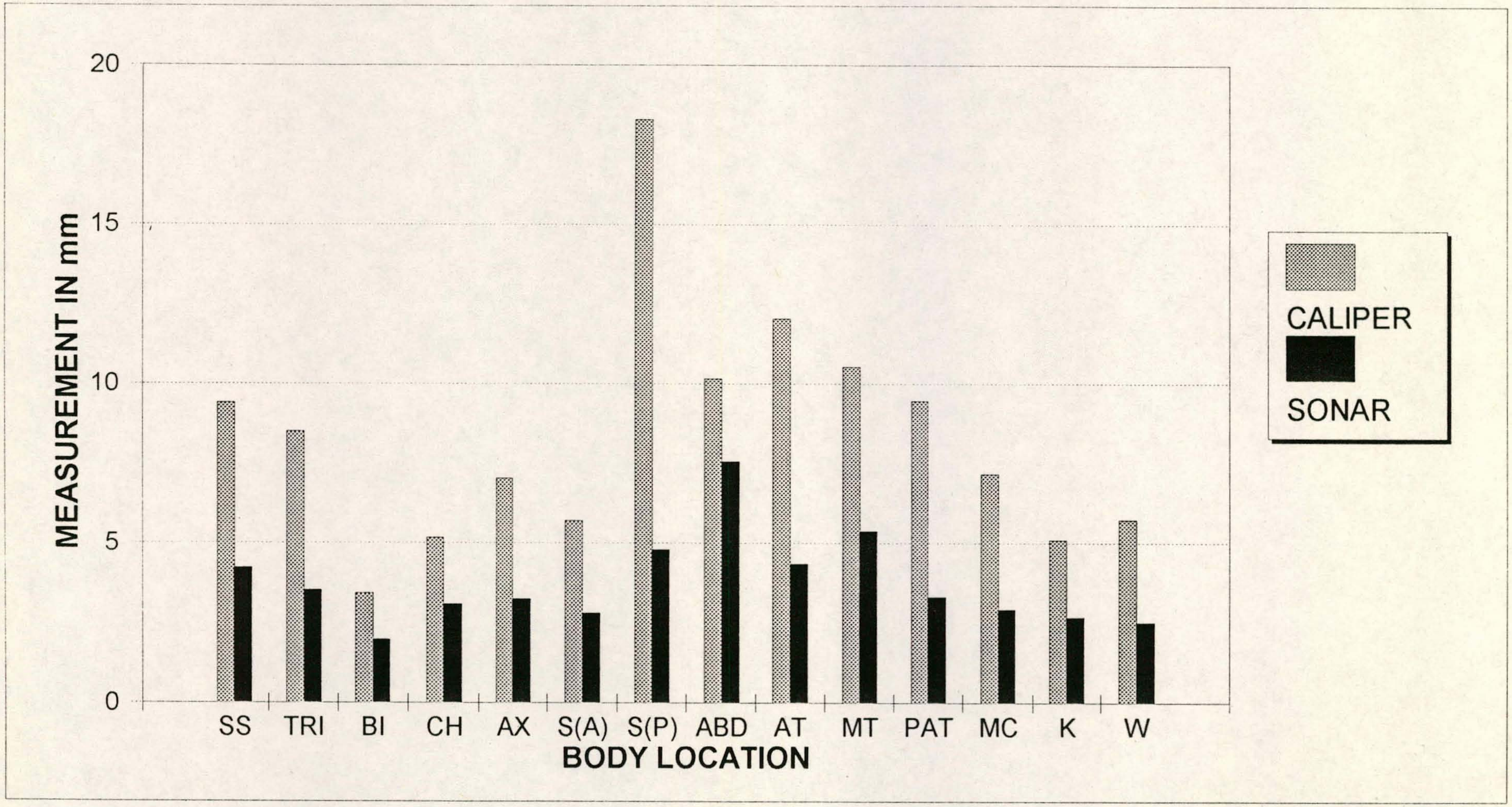

Figure 5a. **SKINFOLD (HARPENDEN CALIPER) VS SONAR (FAT)**

Table 5. SKINFOLD THICKNESS MEASUREMENTS (mm): (FAT + 1 x SKIN): SONAR

Parameter	Total	Average	Range	S D
Sub Scapula	360.70	8.02	5.33 - 15.00	1.92
Tricep	254.71	5.66	2.66 - 10.00	1.70
Bicep	154.02	3.42	2.00 - 5.67	0.84
Chest	230.09	5.11	2.67 - 9.67	1.63
Axilla	238.33	5.30	2.33 - 9.67	1.79
Supra lilac (Anterior)	216.74	4.82	3.00 - 10.00	1.52
Supra lilac (Posterior)	337.97	7.51	4.33 - 12.34	2.02
Abdominal	434.65	9.66	2.66 - 32.00	6.24
Thigh (Anterior)	297.38	6.61	3.67 - 13.67	2.04
Thigh (Medial)	342.02	7.60	4.00 - 13.00	2.35
Patella	247.34	5.50	3.34 - 10.00	1.58
Calf (Medial)	221.73	4.93	3.00 - 8.67	1.43
Chin	211.37	4.70	3.33 - 8.00	0.88
Cheek	200.70	4.46	3.00 6.67	0.82

N = 45

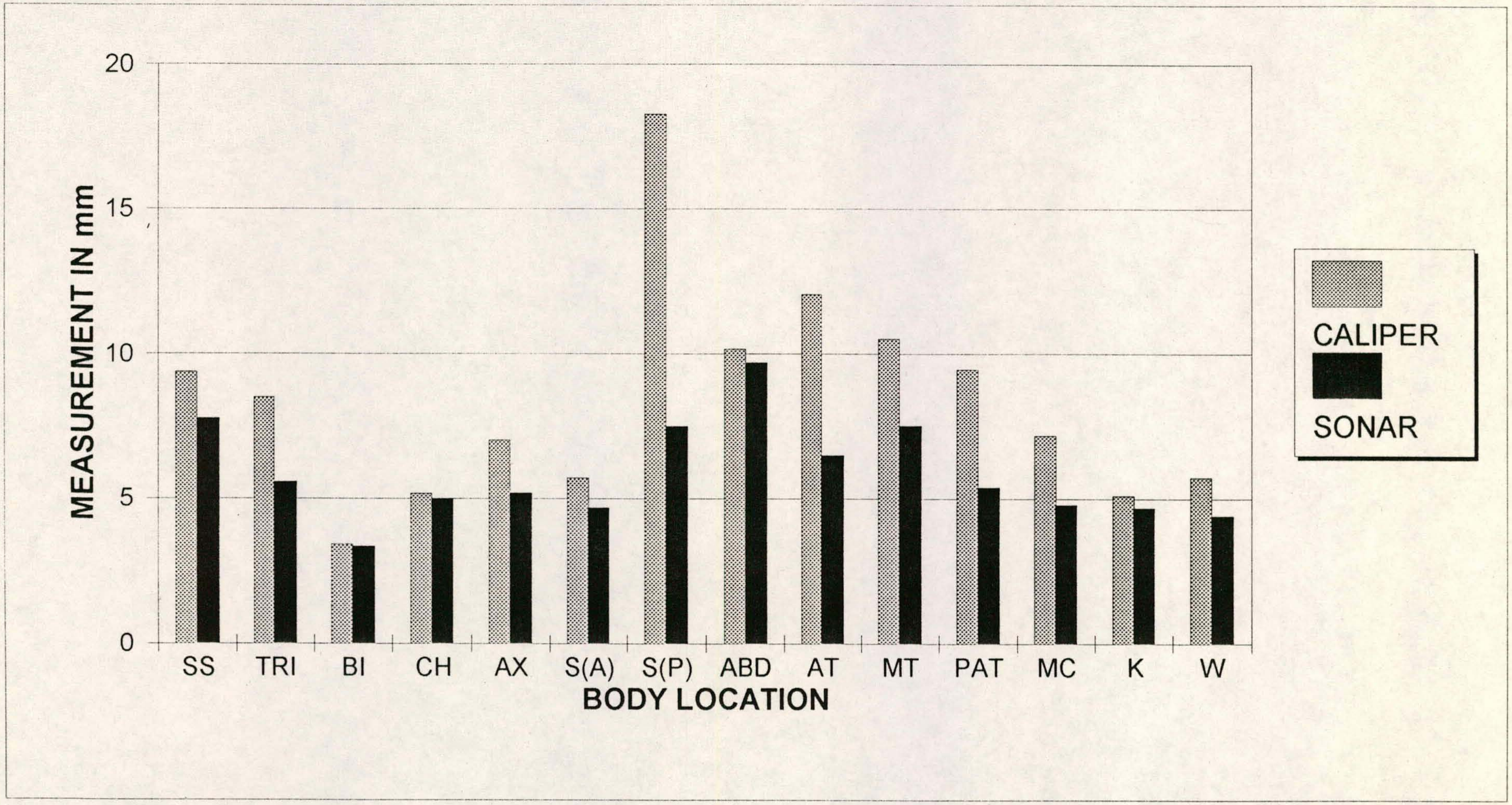

Figure 5b. **SKINFOLD (HARPENDEN CALIPER) VS SONAR (1 x SKIN + FAT)**

Table 6. SKINFOLD THICKNESS MEASUREMENTS (mm): (FAT + 2 x SKIN): SONAR

Parameter	Total	Average	Range	S D
Sub Scapula	509.0700	11.3127	7.67 - 19.00	2.2580
Tricep	341.3900	7.5864	3.99 - 12.00	1.9635
Bicep	211.9900	4.7109	3.00 - 7.67	1.0864
Chest	309.4900	6.8776	4.33 - 11.67	1.7909
Axilla	321.3200	7.1404	3.66 - 12.01	2.0452
Supra Iilac (Anterior)	293.7700	6.5282	4.33 - 12.00	1.7027
Supra Iilac (Posterior)	459.2800	10.2062	6.33 - 16.01	2.4003
Abdominal	533.9800	11.8662	3.99 - 35.00	6.4627
Thigh (Anterior)	388.4100	8.6313	5.67 - 15.67	2.1334
Thigh (Medial)	434.3700	9.6527	5.67 - 15.00	2.4305
Patella	335.7000	7.4600	4.99 - 12.66	1.8501
Calf (Medial)	299.1300	6.6473	4.33 - 10.67	1.4736
Chin	299.7300	6.6607	4.99 - 10.01	1.0865
Cheek	283.7300	6.3051	4.33 - 9.01	1.0347

N = 45

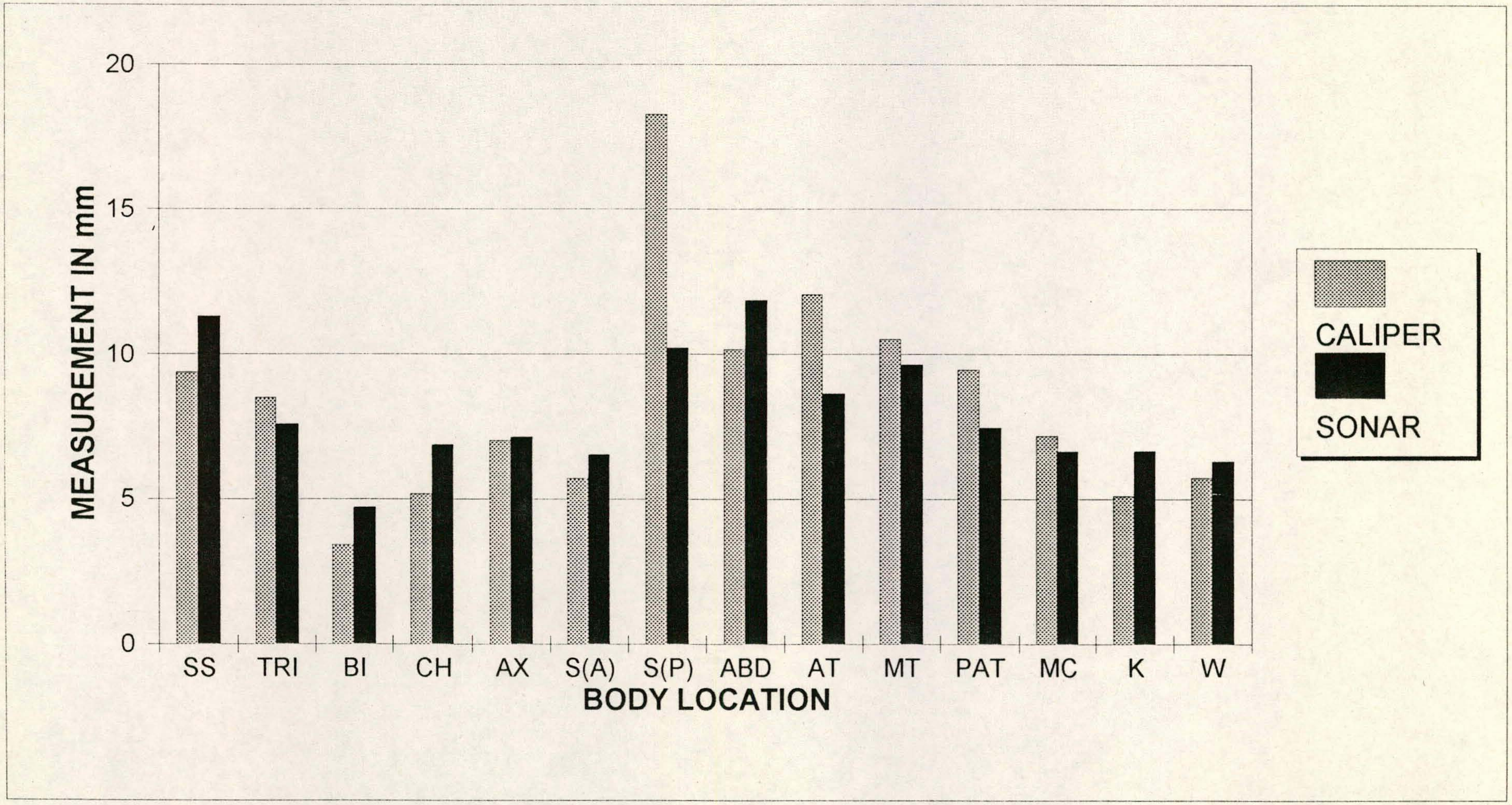

Figure 5c. **SKINFOLD (HARPENDEN CALIPER) VS SONAR (2 x SKIN + FAT)**

Percentage Caliper Compression

Skinfold caliper compression (see Table 7), was calculated with the formula of Fanelli & Kuczmarski (1984) and correlates with the findings of Bullen *et al* (1965:380) for the triceps and abdomen sites of r=0,721 and r=0,867 respectively. Different reasons may contribute why measurements with the skinfold caliper are lower than those taken with the sonar and includes factors such as a higher skin tension, the pressure of 10g/mm^2 exerted between the pincer plates at the point of contact, causing the subcutaneous fat spread out and the subject's body position when the caliper fold is taken.

Lean Body Mass and Fat

The lean body mass of the subjects, as calculated according to the formula of Siri (1961), varied from 58,05 kg to 86,09 kg, averaging 70,06 kg. When this formula was applied to convert body density to percentage body fat, [Fat mass = (% Body fat/100) x Body mass], corresponding fat values varied from 1,73 kg to 23,21 kg, with an average of 6,89 kg (see Figure 6a-c).

Lung Volumes and Capacities

The lung volumes and capacities can be seen in Table 8. The subjects' vital capacity on dry land ranged from 3,64 ℓ to 7,49 ℓ, with an average of 5,321 ℓ, while it was reduced in the water to between 3,34 ℓ and 6,46 ℓ, averaging 4,808 ℓ. Residual volumes, when submerged during the underwater weighing, varied from 1,085 ℓ to 1,548 ℓ averaging 1,316 ℓ, while corresponding expiratory reserve volumes (ERV) ranged from 0,100 ℓ to 1,210 ℓ, with an average of 0,513 ℓ. A definite change in lung volumes occurred during submersion and that confers with the findings of other researchers (Bondi *et al*:1976; Girandola *et al*:1977 and Timson & Coffman:1984).

The special importance of recording the ERV during the hydrostatic weighing session is accentuated and agrees with the findings of Brandom *et al* (1981:22) and Timson & Coffman (1984:411).

Table 7. % COMPRESSION: CALIPER VS ULTRASOUND

Location	Caliper	Ultrasound	% Comp.
Sub Scapula	9.3822	11.3127	58.53
Tricep	8.5000	7.5864	43.98
Bicep	3.4178	4.7109	63.72
Chest	5.1600	6.8776	62.49
Axilla	7.0133	7.1404	50.89
Supra lilac (Anterior)	5.6933	6.5282	56.39
Supra lilac (Posterior)	18.2844	10.2062	10.43
Abdominal	10.1600	11.8662	57.19
Thigh (Anterior)	12.0533	8.6313	30.18
Thigh (Medial)	10.5289	9.6527	45.46
Patella	9.4622	7.4600	36.58
Calf (Medial)	7.1644	6.6473	46.11
Chin	5.0978	6.6607	61.73
Cheek	5.7244	6.3051	54.60
Ave % compression			48.45

N = 45

Table 8. LUNG VOLUMES AND CAPACITIES

Parameter	Total	Average	Range	S D
Vital Capacity (Land)(liters)	239	5.321	3.640 - 7.490	0.84214
Vital Capacity (Water)(liters)	216	4.808	3.340 - 6.460	0.69481
ERV (liters)	23	0.513	0.100 - 1.210	0.27832
Residual Volume (liters)	59	1.316	1.085 - 1.548	0.10147
Water density (g / cm^3)	45	0.996	0.994 - 0.998	0.00074

N = 45

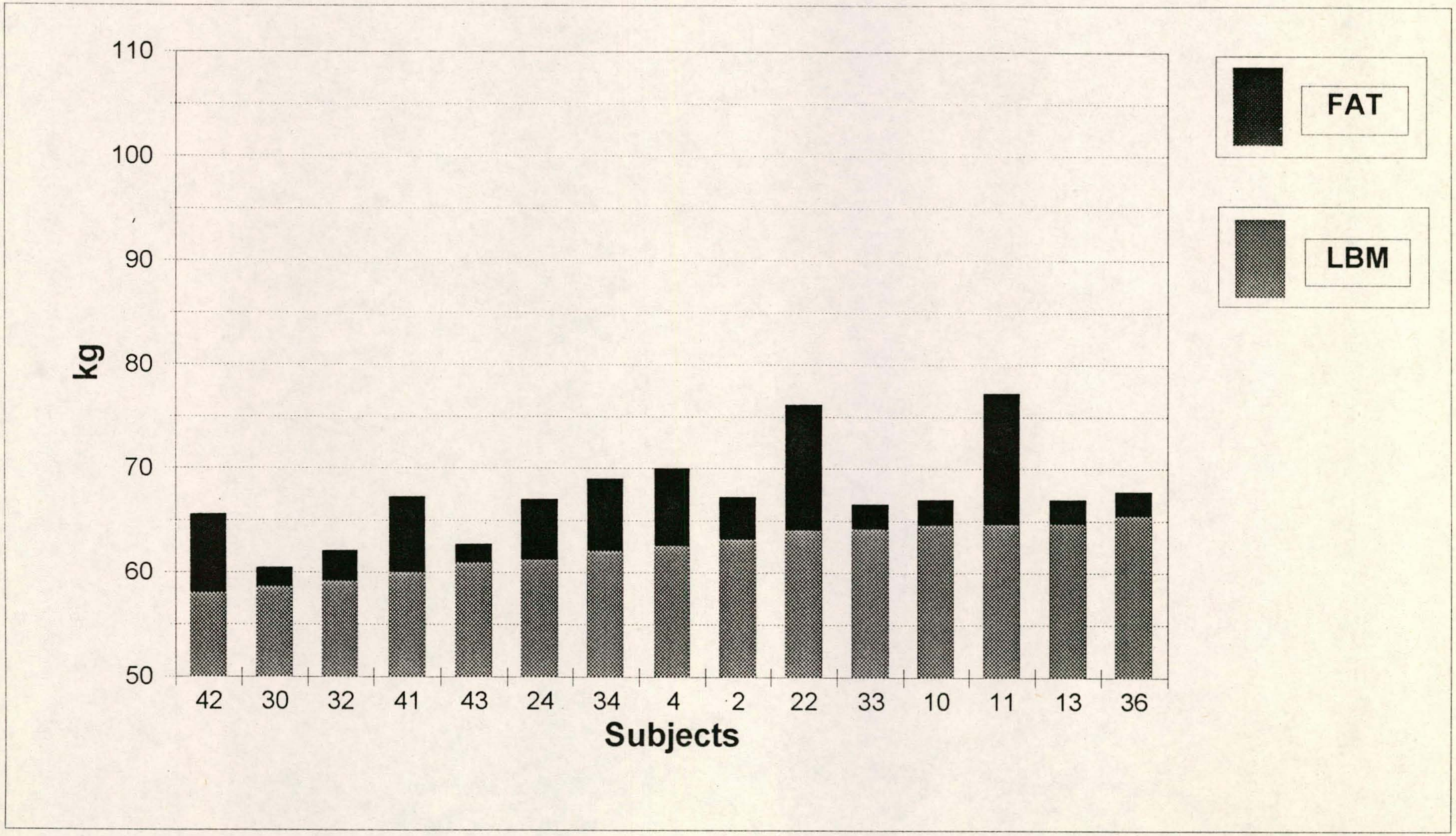

Figure 6a. **LEAN BODY MASS AND FAT**

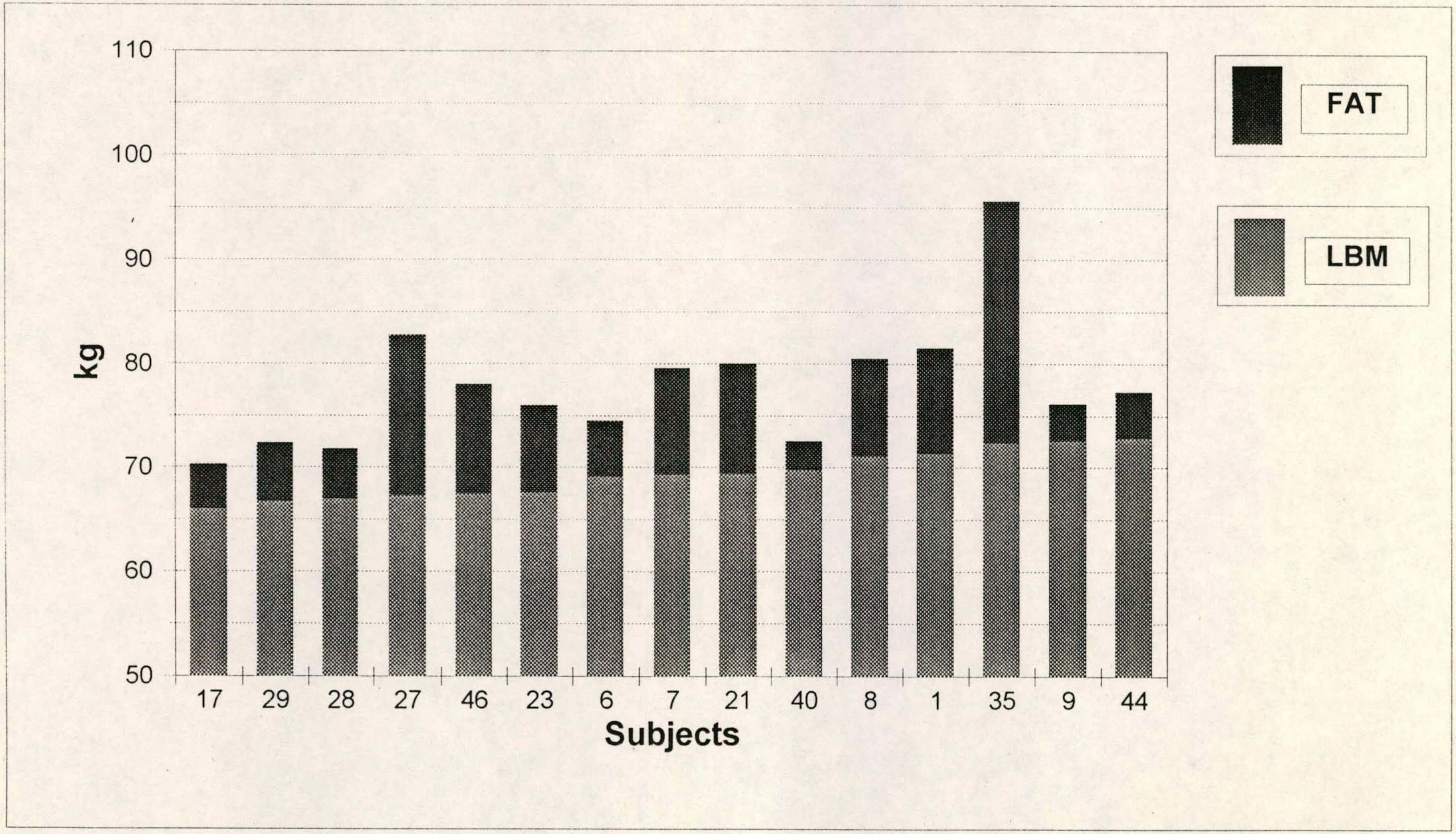

Figure 6b. **LEAN BODY MASS AND FAT**

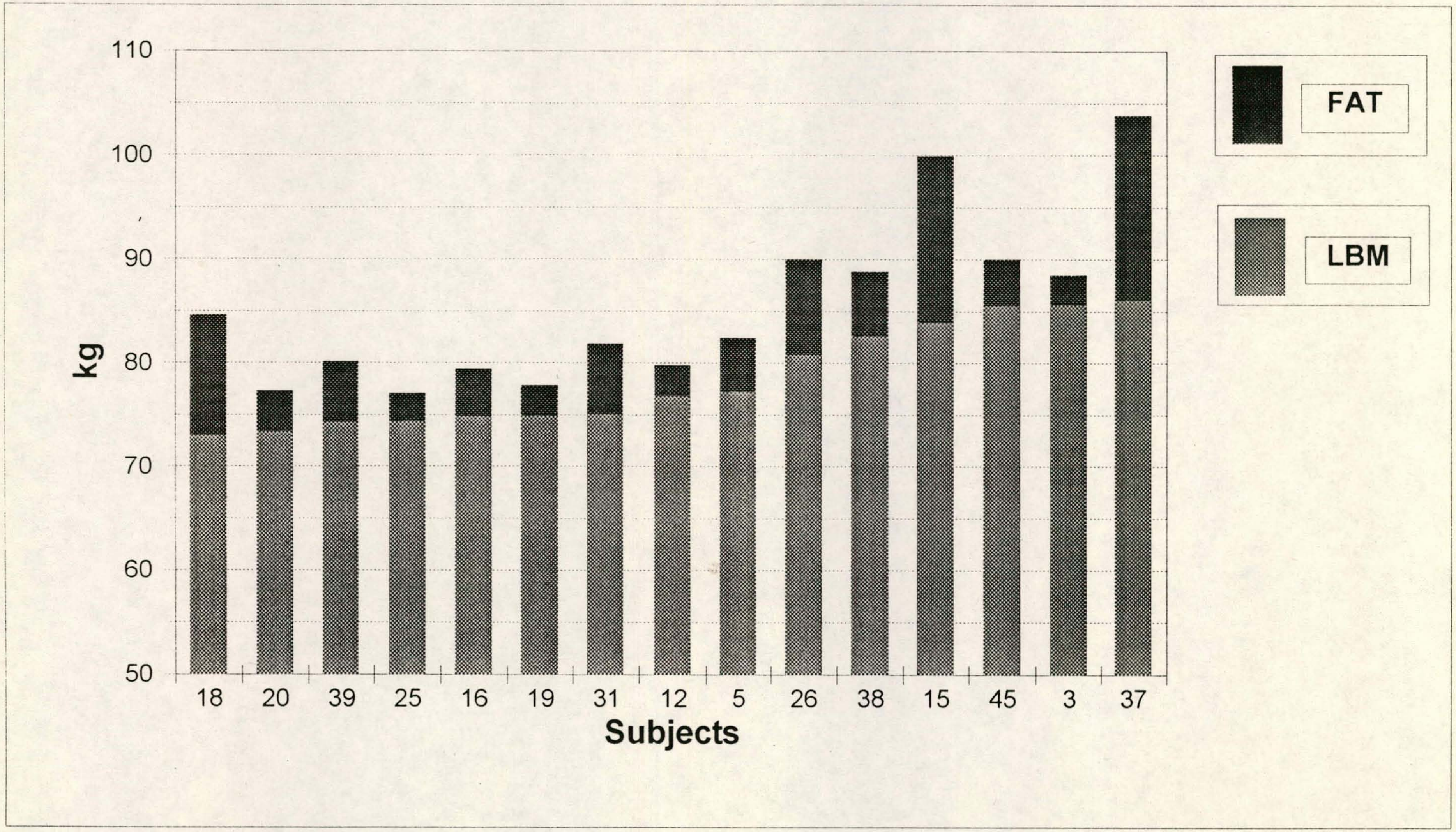

Figure 6c. **LEAN BODY MASS AND FAT**

Bio-electrical Impedance Analysis (BIA)

When comparing percentage body fat of the BIA study, as calculated by the formula of Siri (1961), the BIA correlated relatively low (r=0,603) with hydrodensitometry (see Figure 7). It can be assumed that BIA overestimates the body density, which in turn results in an underestimation of percentage body fat. Furthermore, the program processing the raw scores, only calculated body density to the second decimal that may also have contributed to the inaccurate results of the percentage body fat. In conclusion, this research agrees with Nash (1985:129) that this method still seems to be "only as good as the software in the box".

PROCESSING OF ANTHROPOMETRICAL DATA

Body Density Formulae

Initially the subjects' data were used to calculate body density via three methods and formulae, namely hydrodensitometry, Durnin & Rahaman (1967) (D & R) and Jackson & Pollock (1978) (J & P) (see Figure 8).

Percentage Body Fat

These densities were then applied to the following four formulae of Brozek (1963), Siri (1961), Keys & Brozek (1953) and Rathburn & Pace (1945) to calculate the percentage body fat (see Figure 9).

Two of the percentage body fat formulae, Keys & Brozek (1953) and Rathburn & Pace (1945), were statistically eliminated due to a significant underestimation and overestimation respectively of percentage body fat.

Skinfolds

Durnin & Rahaman (1967) and Jackson & Pollock (1978) were used to calculate body density, using the parameters of skinfolds. The body density values, according to Durnin & Rahaman and Jackson & Pollock, were individually applied to the formulae of Brozek (1953) and Siri (1961) to calculate the percentage body fat. Correlations with hydrodensitometry were high, ranging from r=0,81499 (for Durnin & Rahaman and Brozek) to r=0,82338 (Jackson & Pollock and Siri) (see Figures 10 to 13).

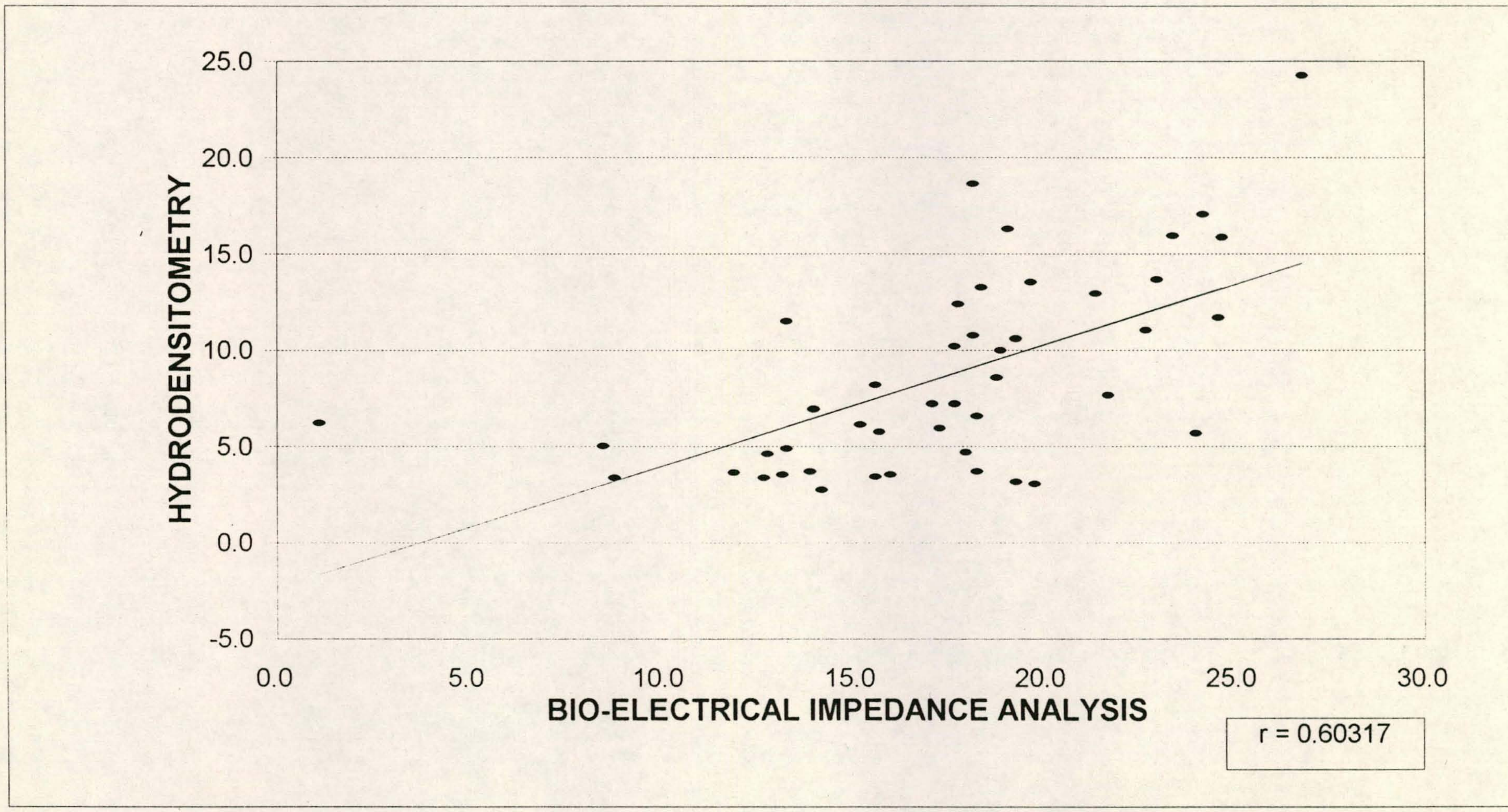

Figure 7. **% FAT: SIRI (1961)**

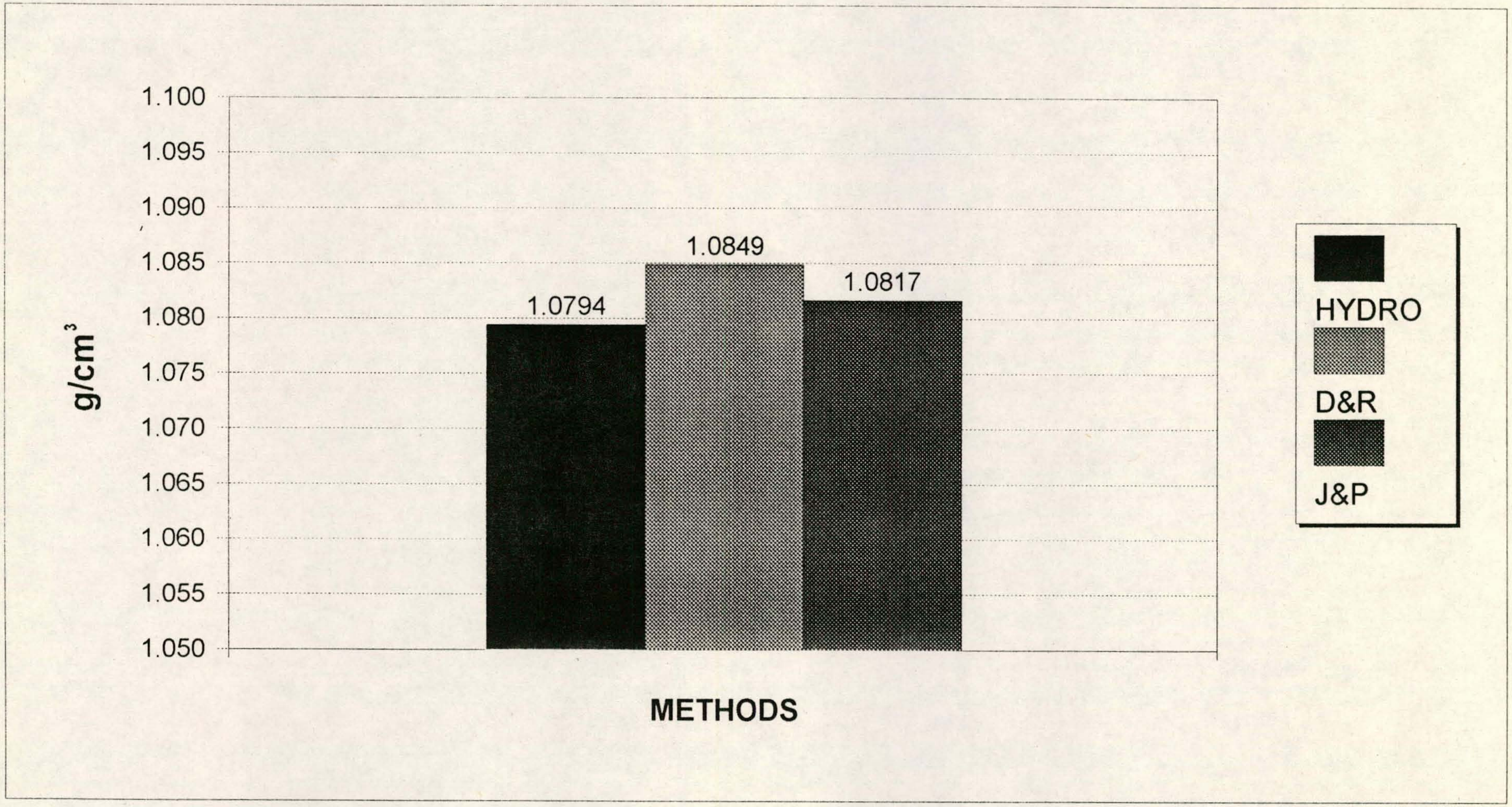

Figure 8. **BODY DENSITY IN g/cm^3: COMPARISON OF 3 METHODS**

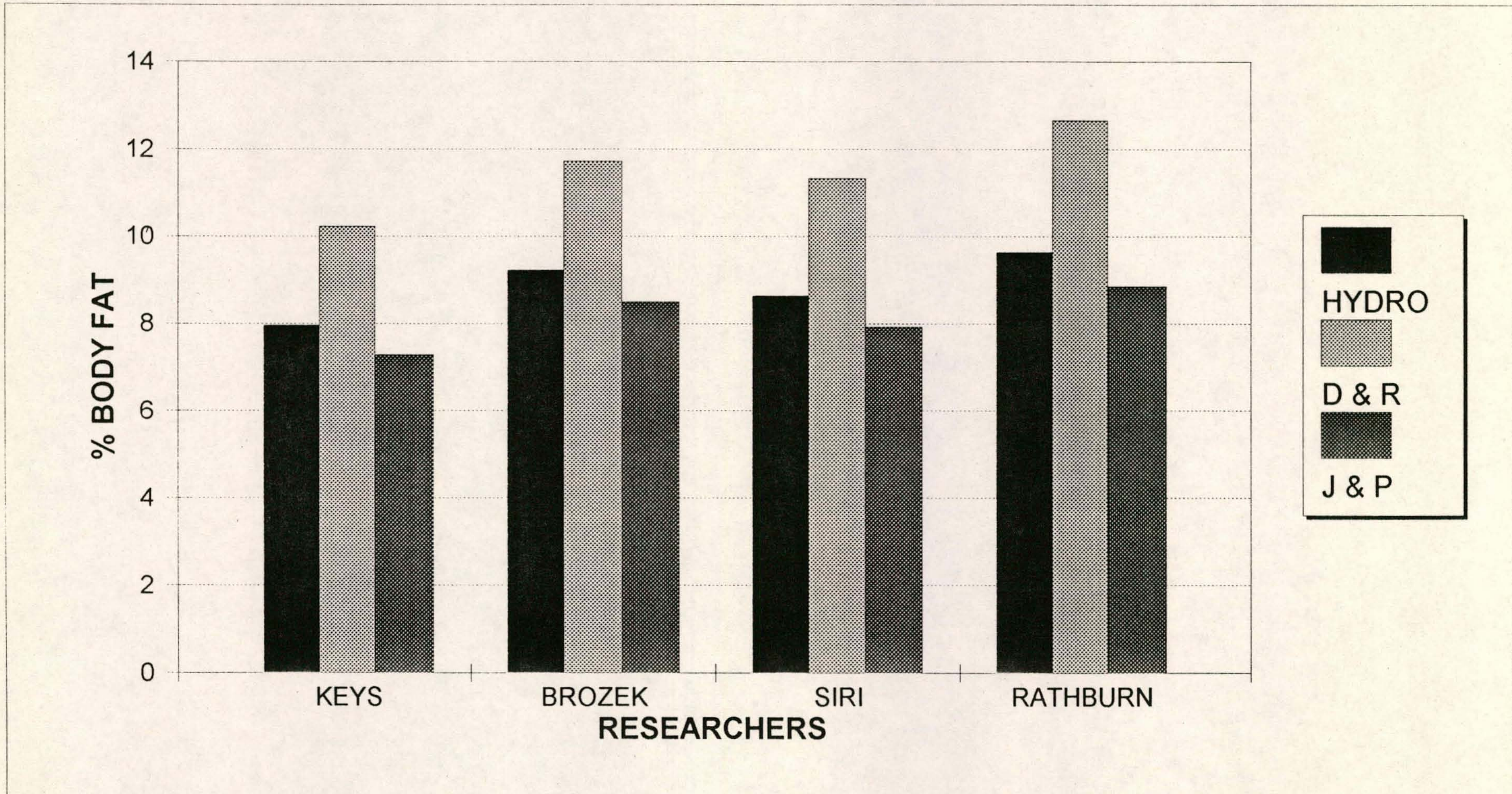

Figure 9. **COMPARISON OF % BODY FAT BY VARIOUS BODY DENSITY FORMULAE**

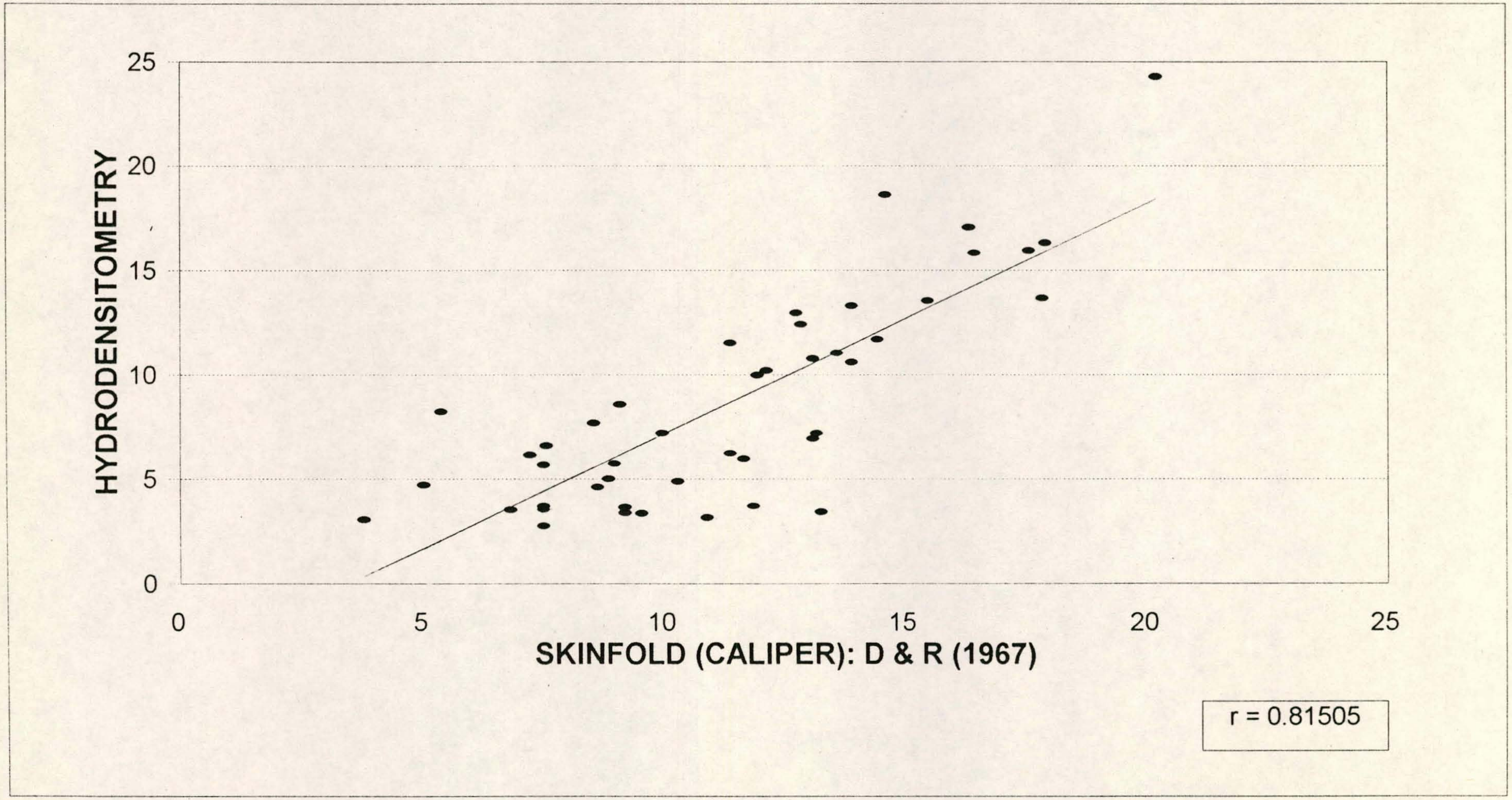

Figure 10. **% FAT: SIRI (1961)**

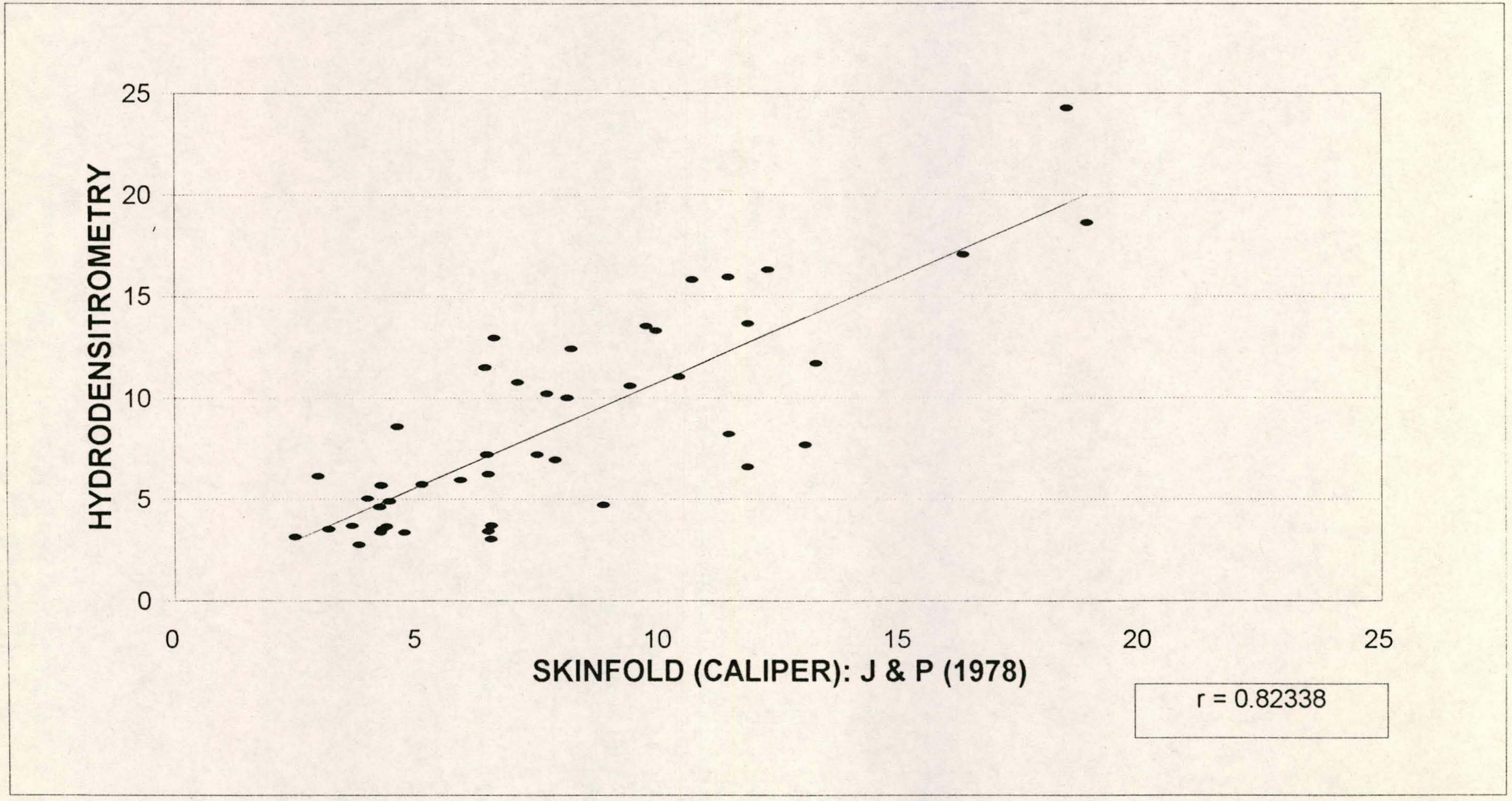

Figure 11. **% FAT: SIRI (1961)**

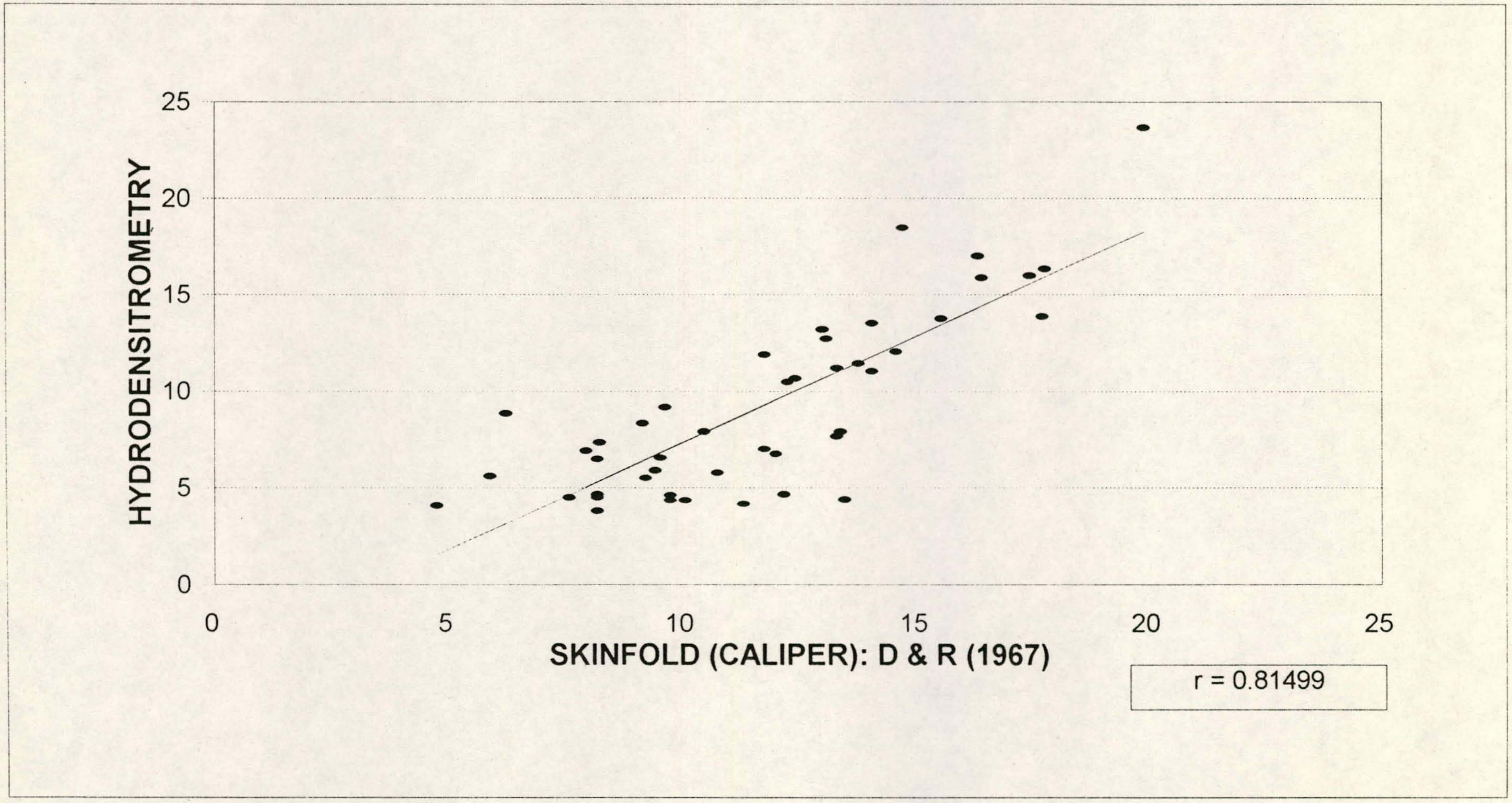

Figure 12. **% FAT: BROZEK (1963)**

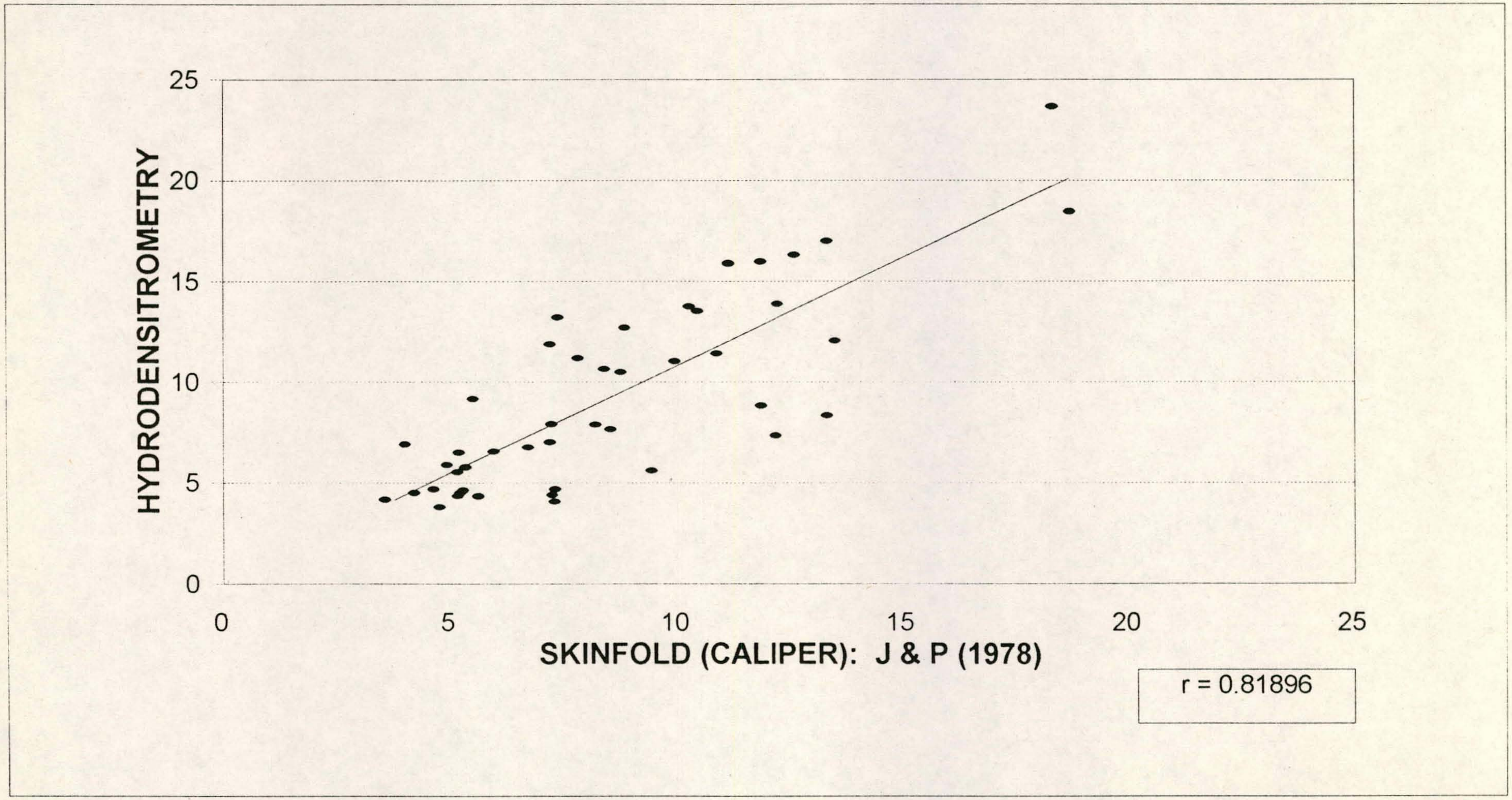

Figure 13. **% FAT: BROZEK (1963)**

Sonar

The same procedure was followed with the sonar measurements and different combinations, such as fat, 1x skin + fat and 2x skin + fat. Due to the absence of formulae developed for sonar measurements, these scores were also applied to the formulae of Durnin & Rahaman and Jackson & Pollock and percentage body fat was calculated with the formulae of Brozek (1953) and Siri (1961). Correlations with hydrodensitometry were remarkably high, since these formulae were developed for the use of skinfold calipers, and ranged from r=0,77198 (Durnin & Rahaman and Brozek) to r=0,84545 (Jackson & Pollock and Siri) (see Figures 14a to 17c).

In each case the body density, according to Durnin & Rahaman (1967), when applied to the percentage body fat formula of Brozek (1953) and correlated with hydrodensitometry, yielded the lowest results. It was then decided that the rest of the investigation would continue with the use of only the formulae of Jackson & Pollock (1978), for determination of body density, and Siri (1961) for the computation of percentage body fat.

Body Density: Hydrodensitometry vs Jackson & Pollock

The following correlations with hydrodensitometry were found when different parameters were used in the Jackson & Pollock (1978) formula:

1.	Sonar (Fat)	:	r=0,84555	(Figure 18a+b)
2.	Sonar (Fat) (S(P) & MT)	:	r=0,83575	(Figure 19a+b)
3.	Sonar (1 x Skin + Fat)	:	r=0,83697	(Figure 20a+b)
4.	Sonar (2 x Skin + Fat)	:	r=0,81987	(Figure 21a+b)
5.	Skinfold (Caliper)	:	r=0,89224	(Figure 22a+b)
6.	Skinfold (Caliper) (S(P) & MT)	:	r=0,86924	(Figure 23a+b)
7.	Skinfold (Caliper) - Sonar (2 x Skin)	:	r=0,78217	(Figure 24a +b)

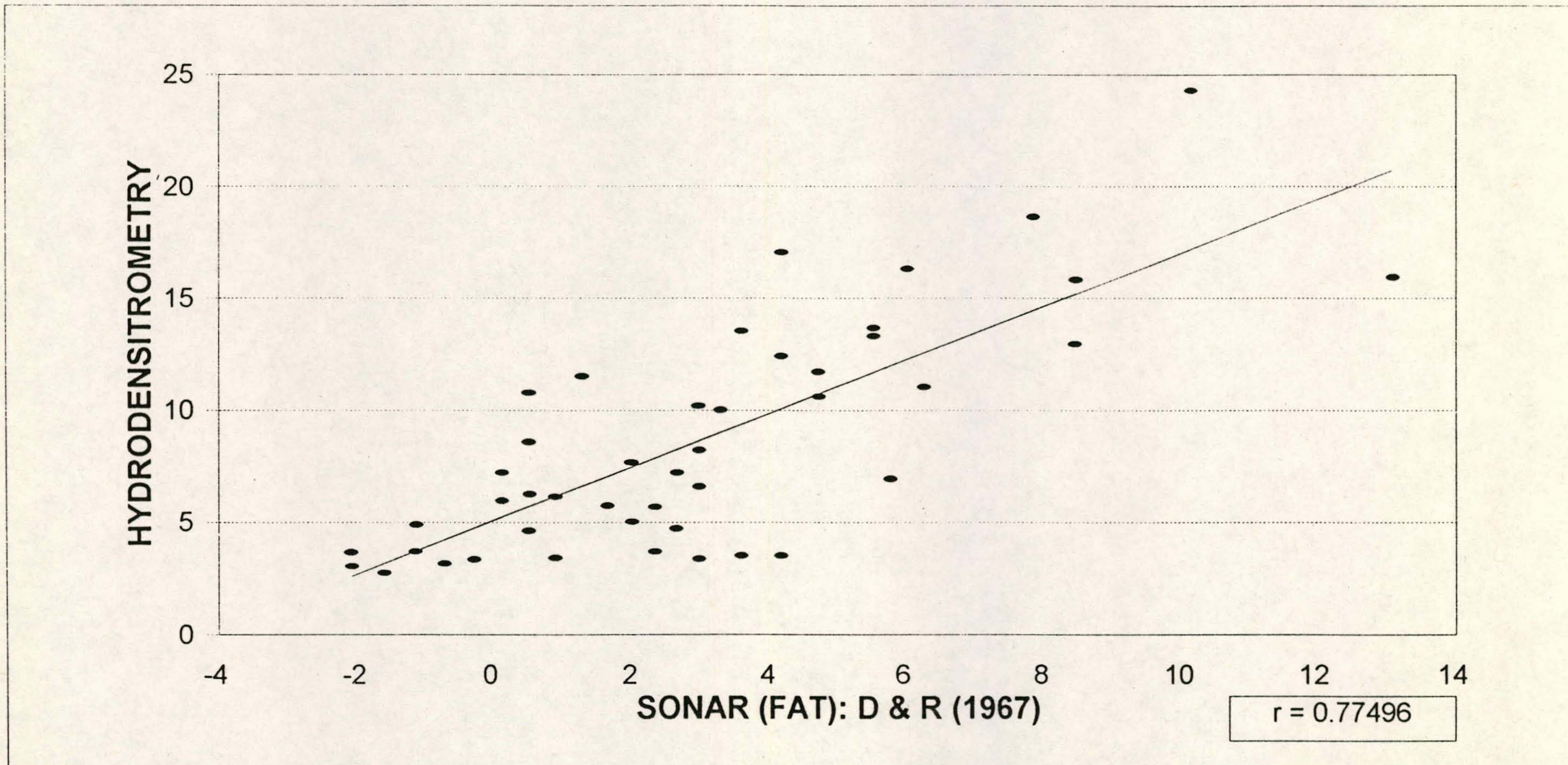

Figure 14a. **% FAT: SIRI (1961)**

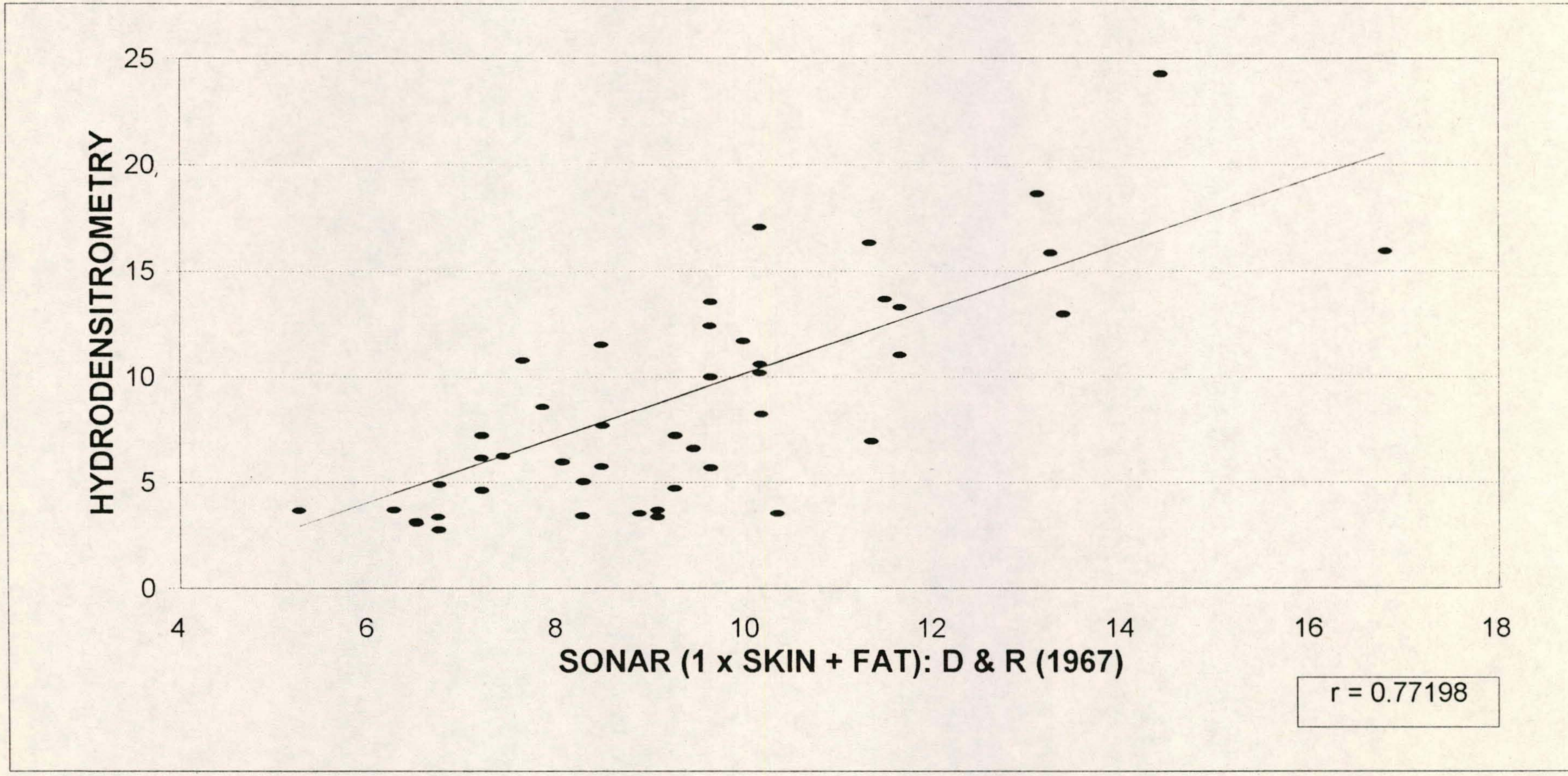

Figure 14b. **% FAT: SIRI (1961)**

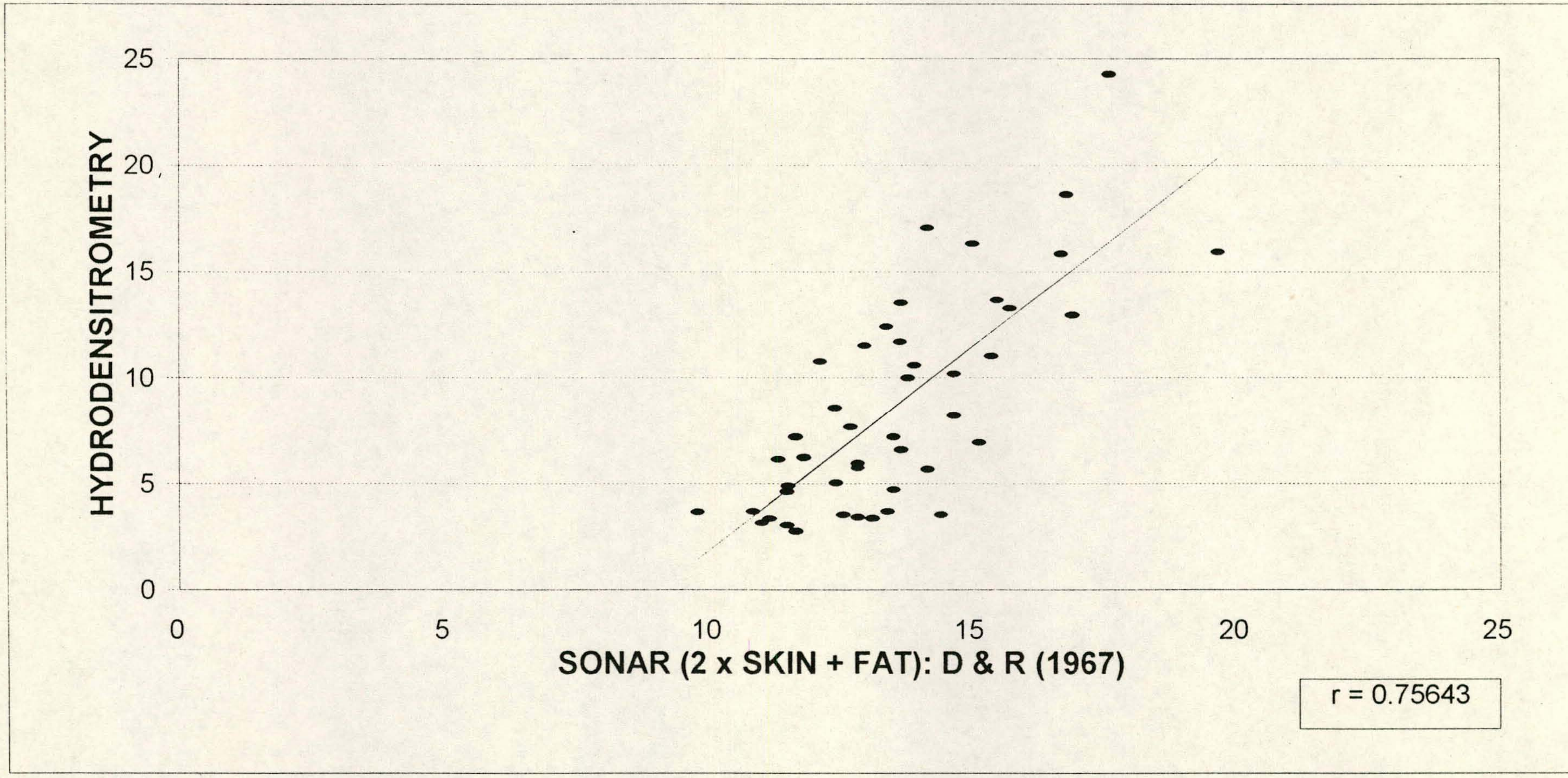

Figure 14c. **% FAT: SIRI (1961)**

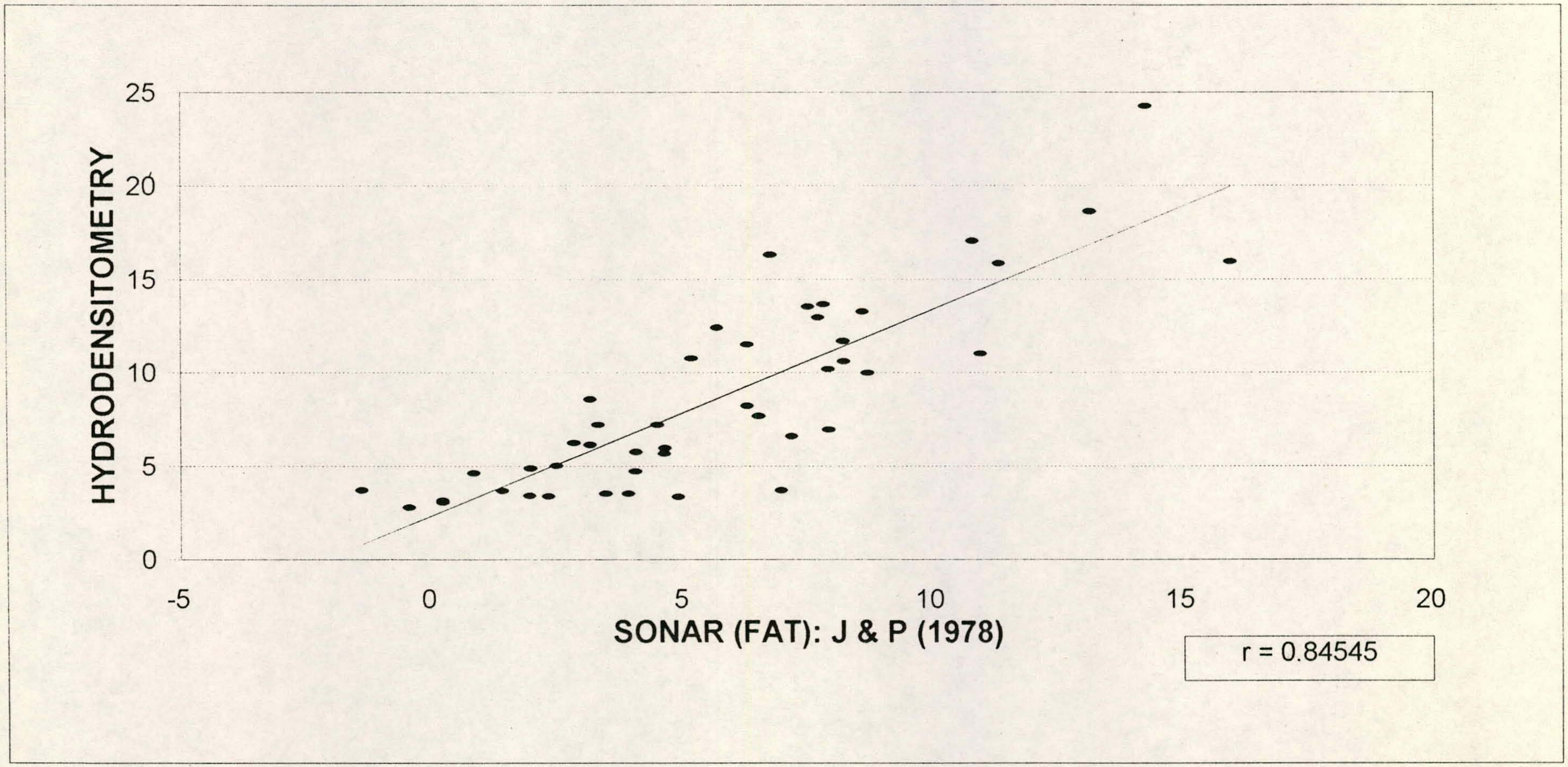

Figure 15a. **% FAT: SIRI (1961)**

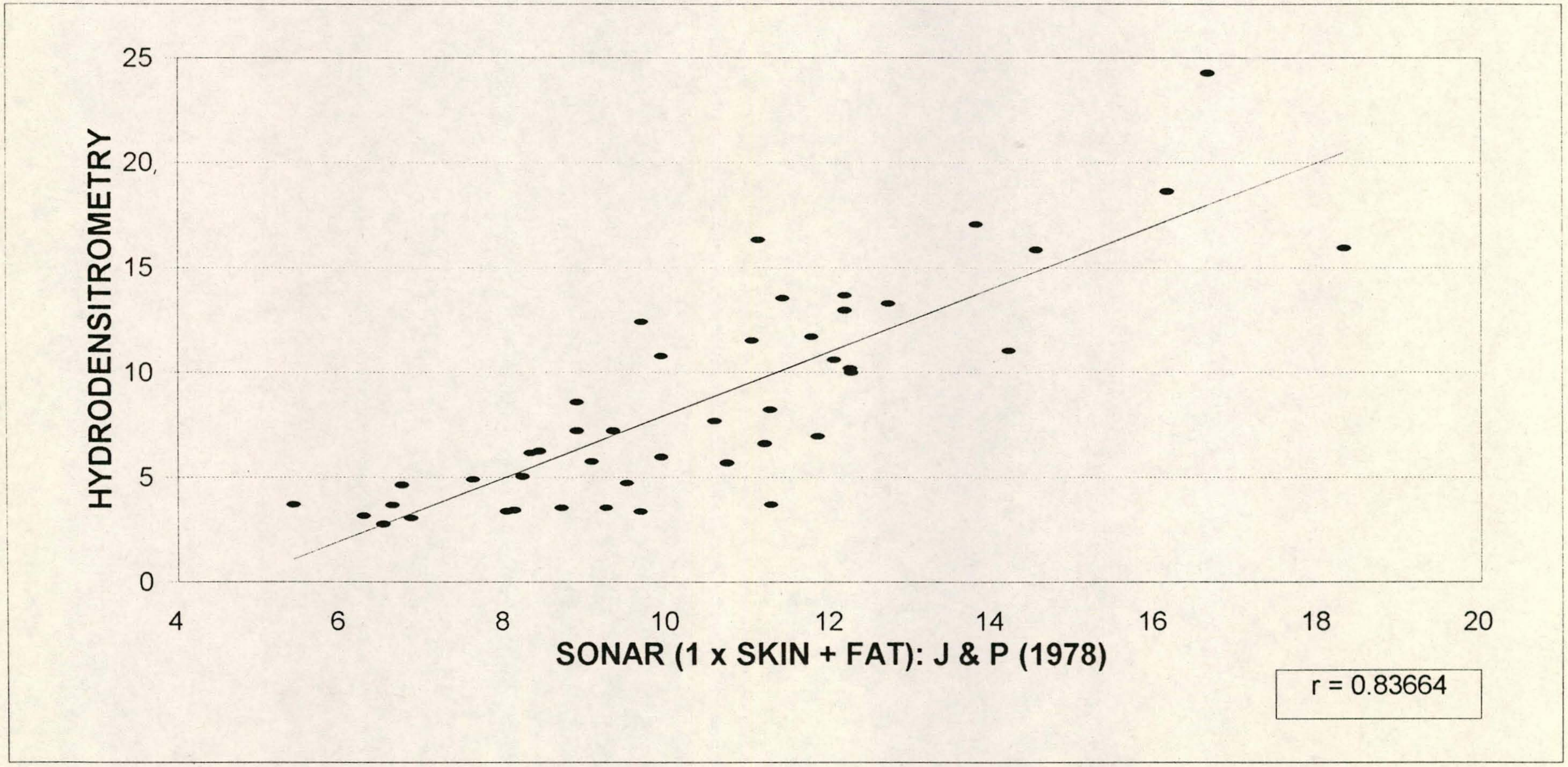

Figure 15b. **% FAT: SIRI (1961)**

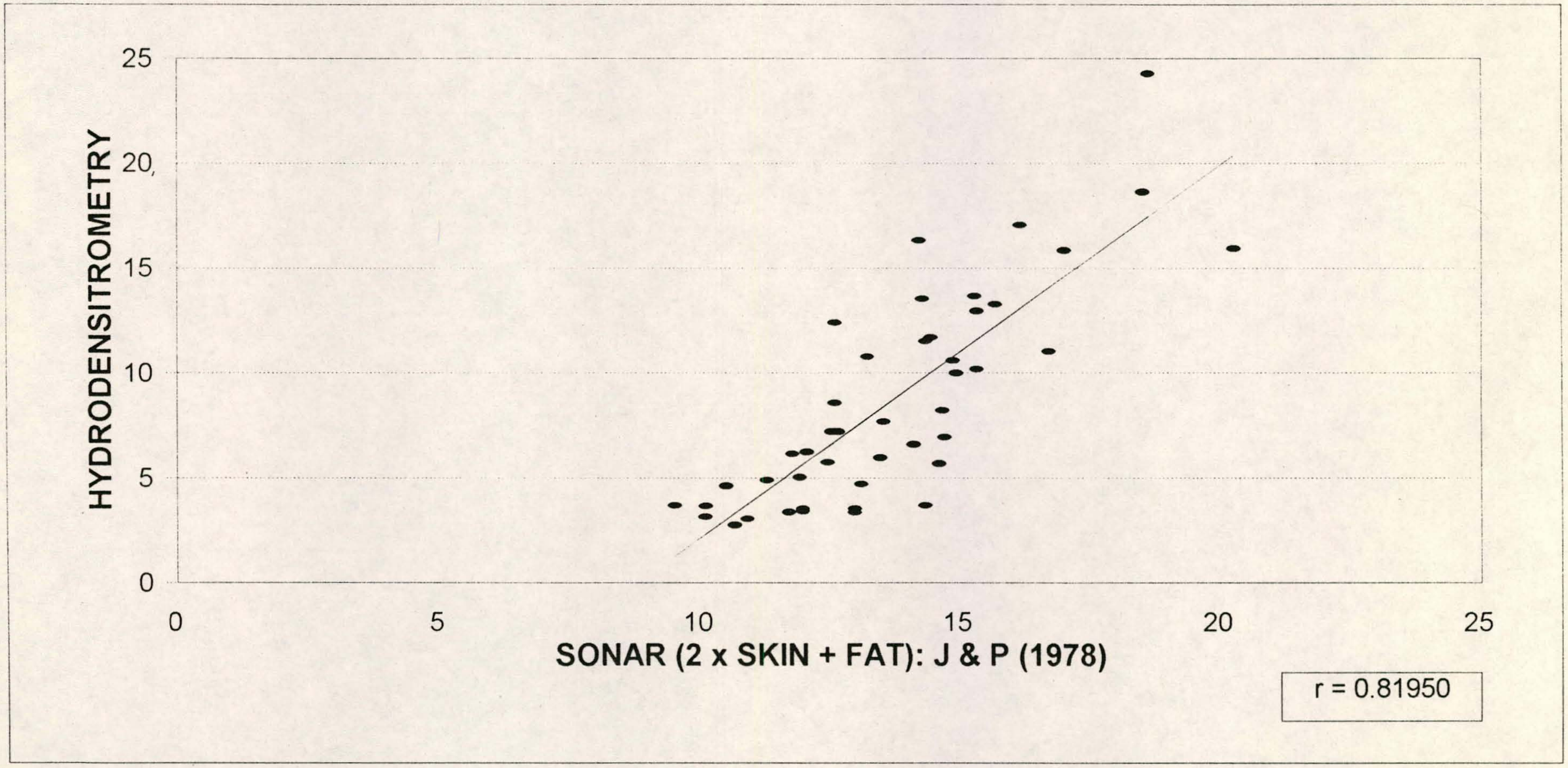

Figure 15c. **% FAT: SIRI (1961)**

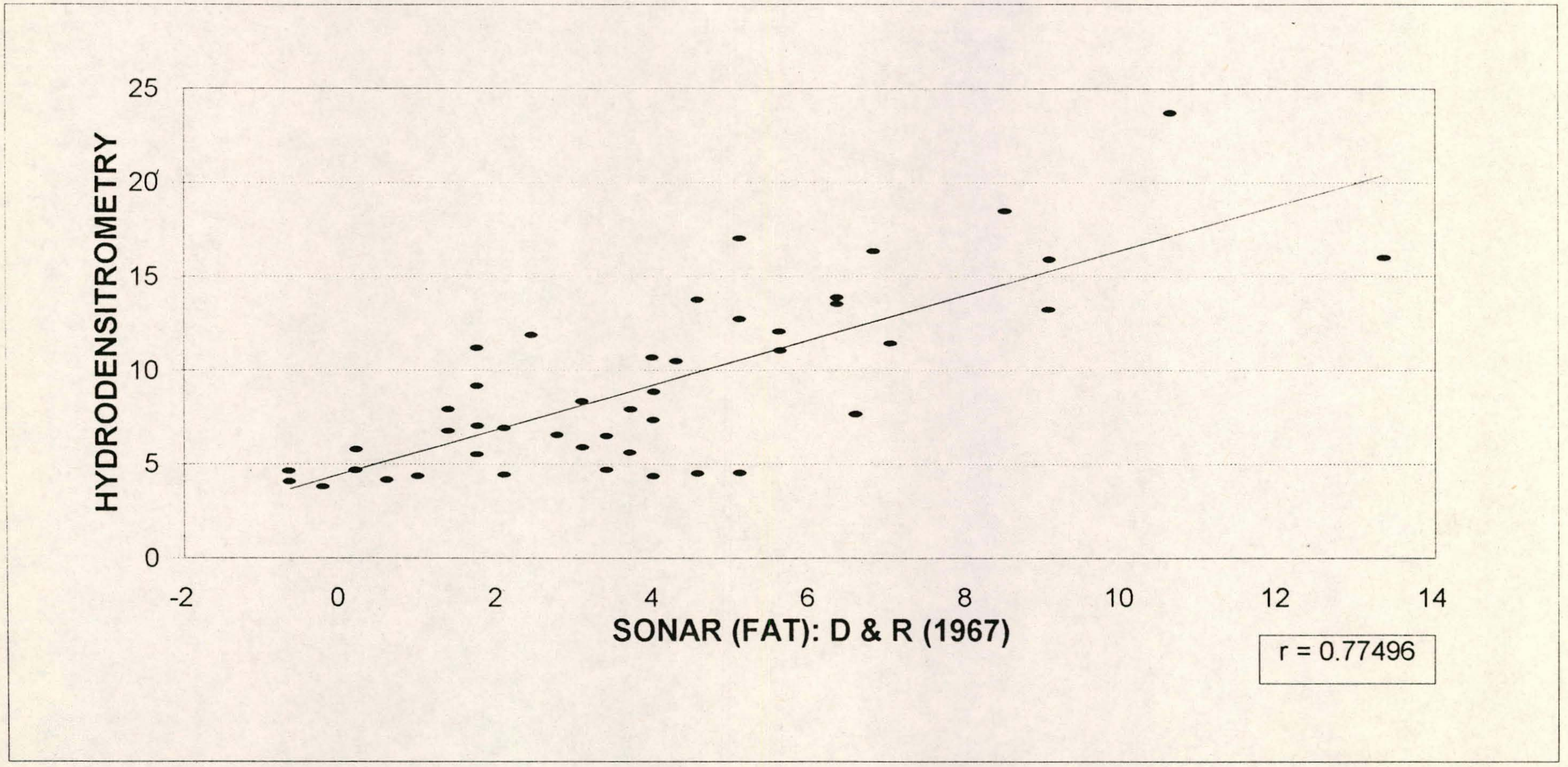

Figure 16a. **% FAT: BROZEK (1963)**

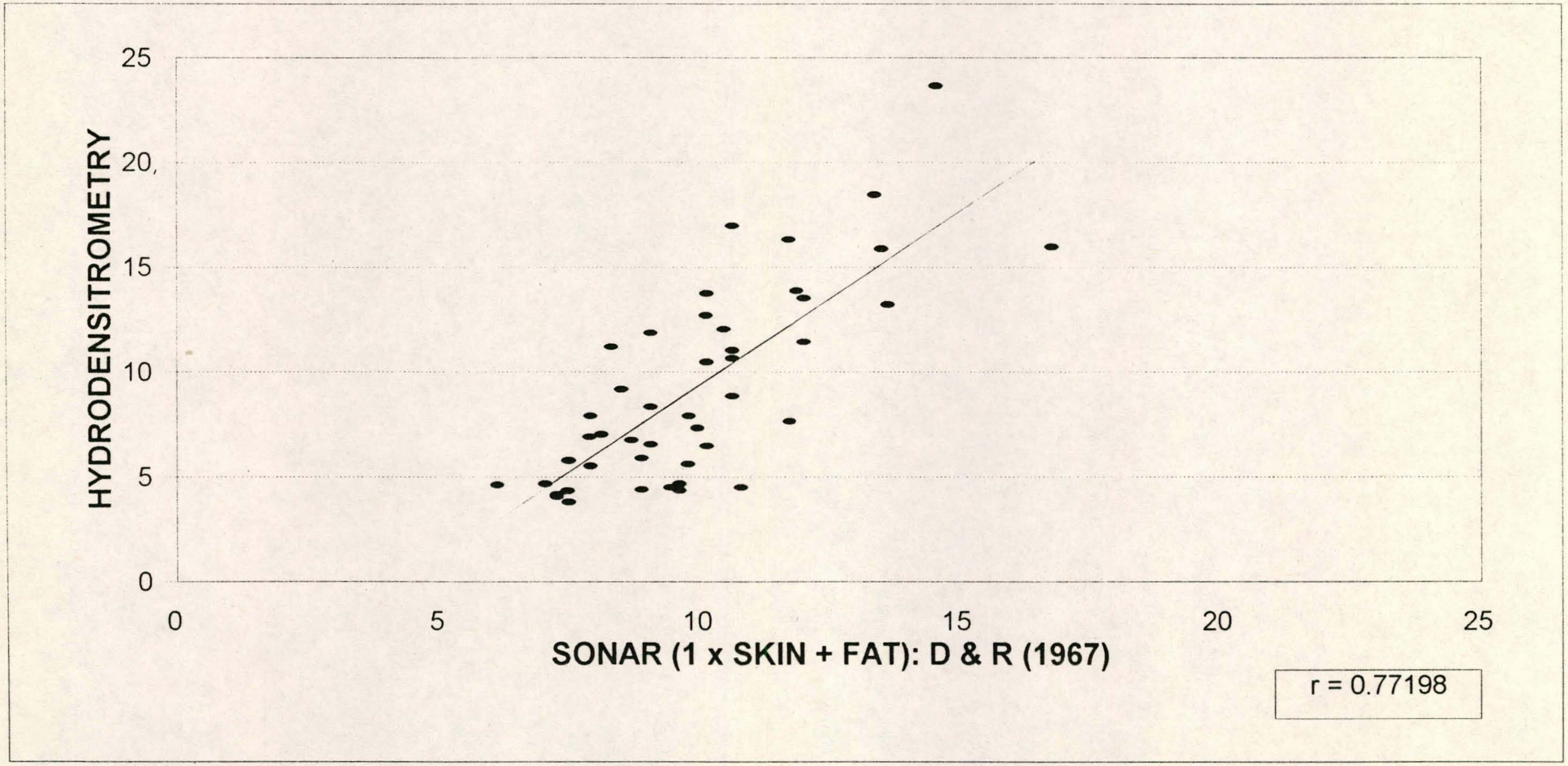

Figure 16b. **% FAT: BROZEK (1963)**

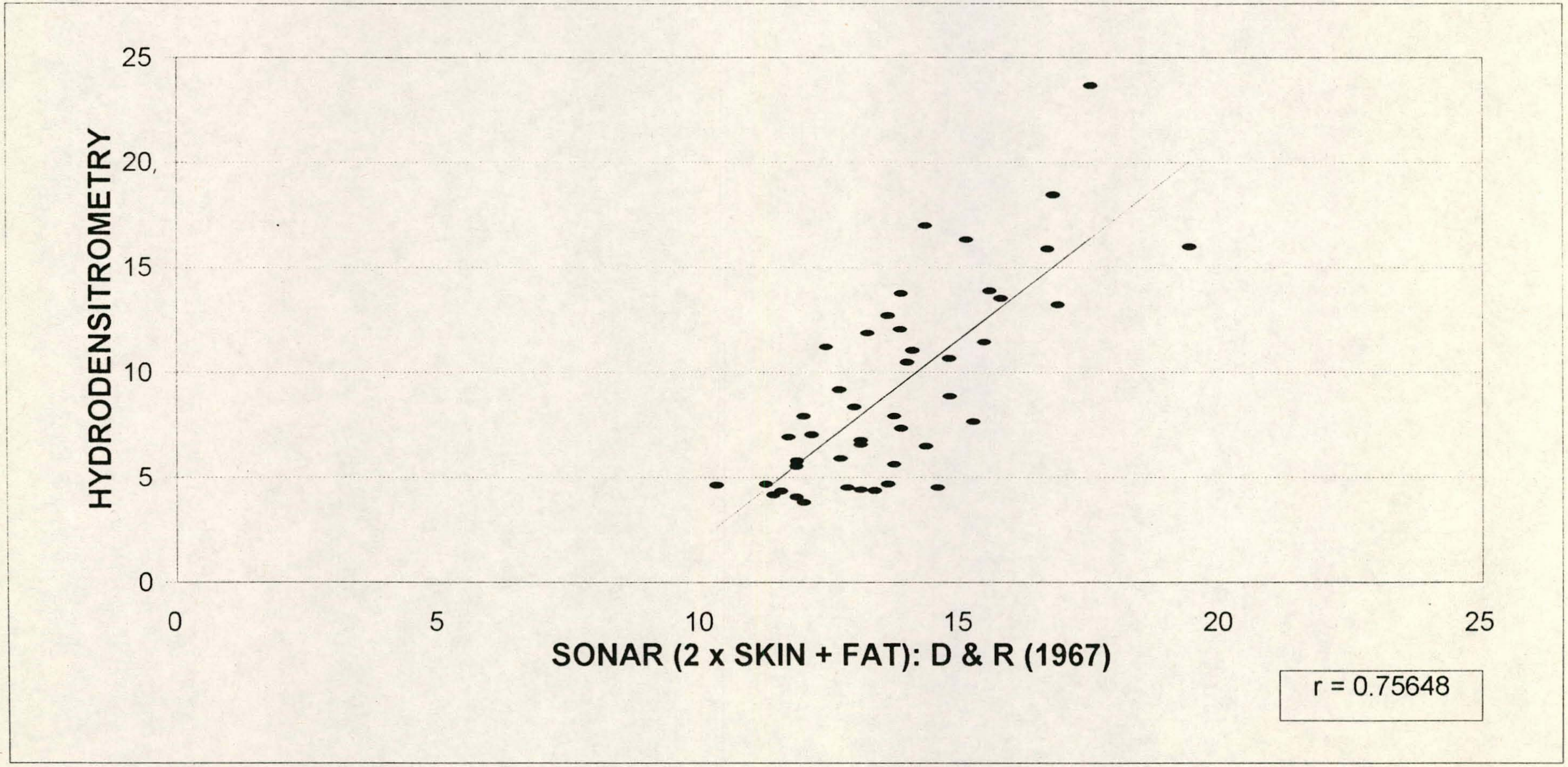

Figure 16c. **% FAT: BROZEK (1963)**

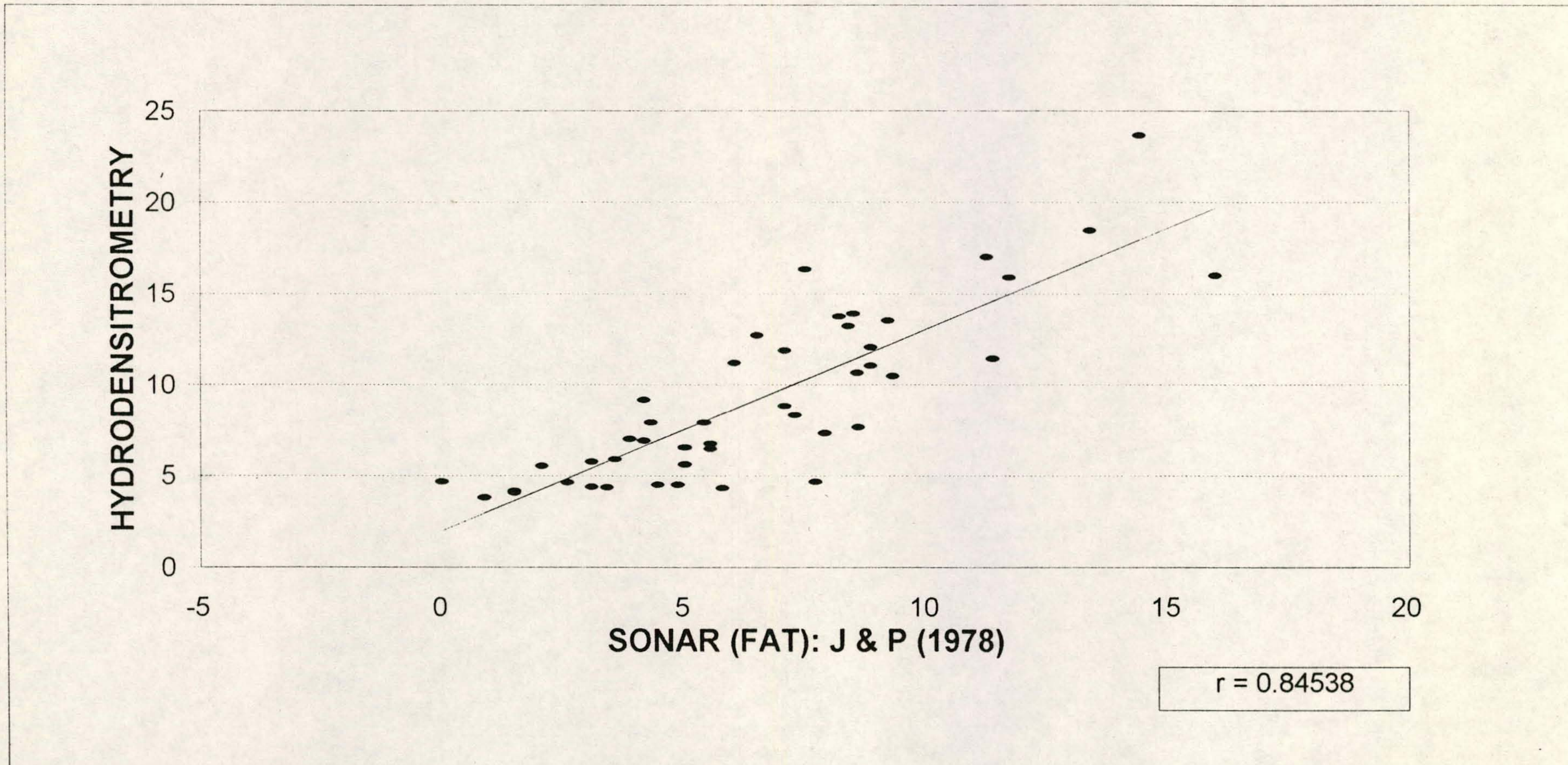

Figure 17a. **% FAT: BROZEK (1963)**

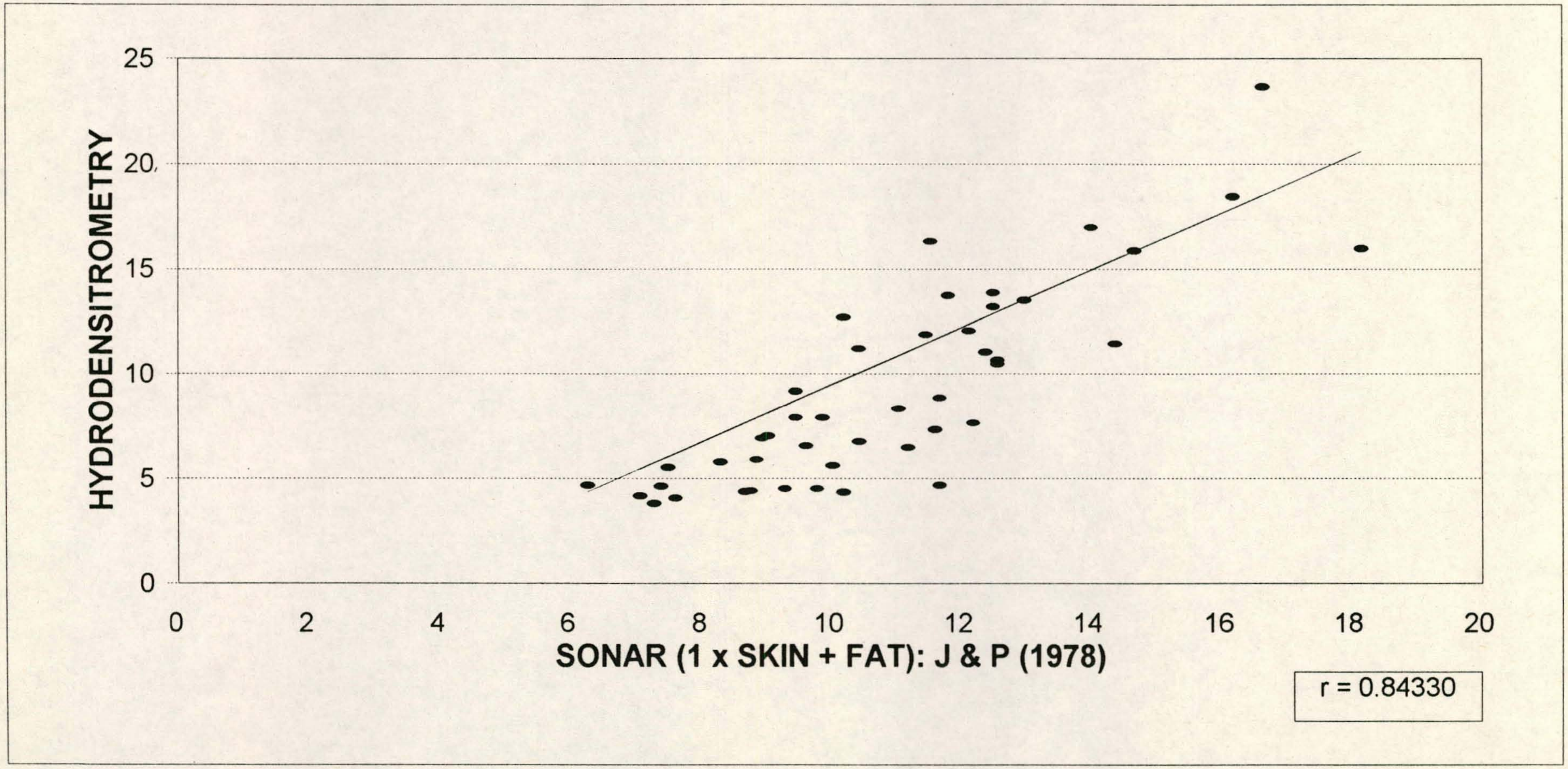

Figure 17b. **% FAT: BROZEK (1963)**

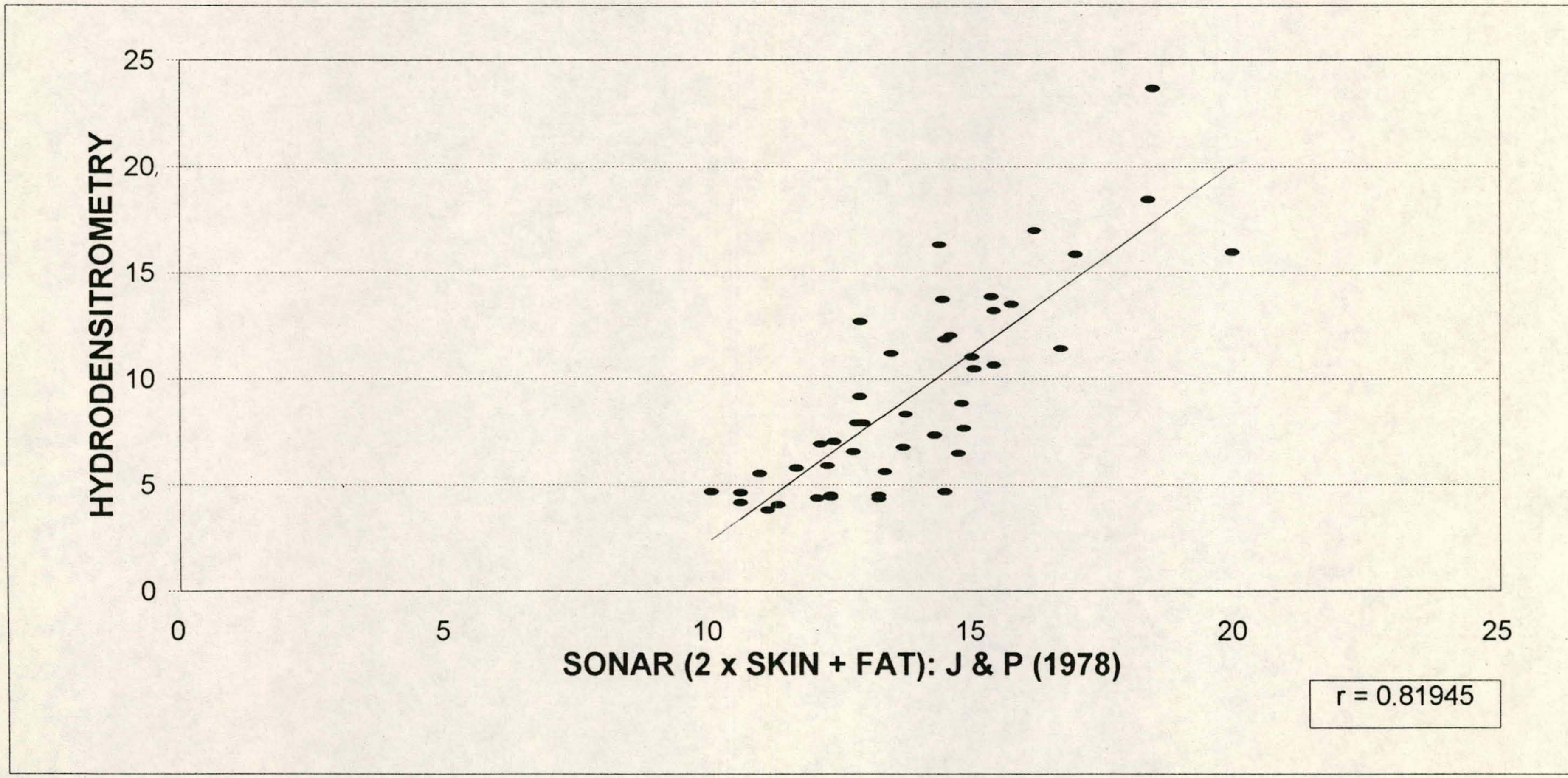

Figure 17c. **% FAT: BROZEK (1963)**

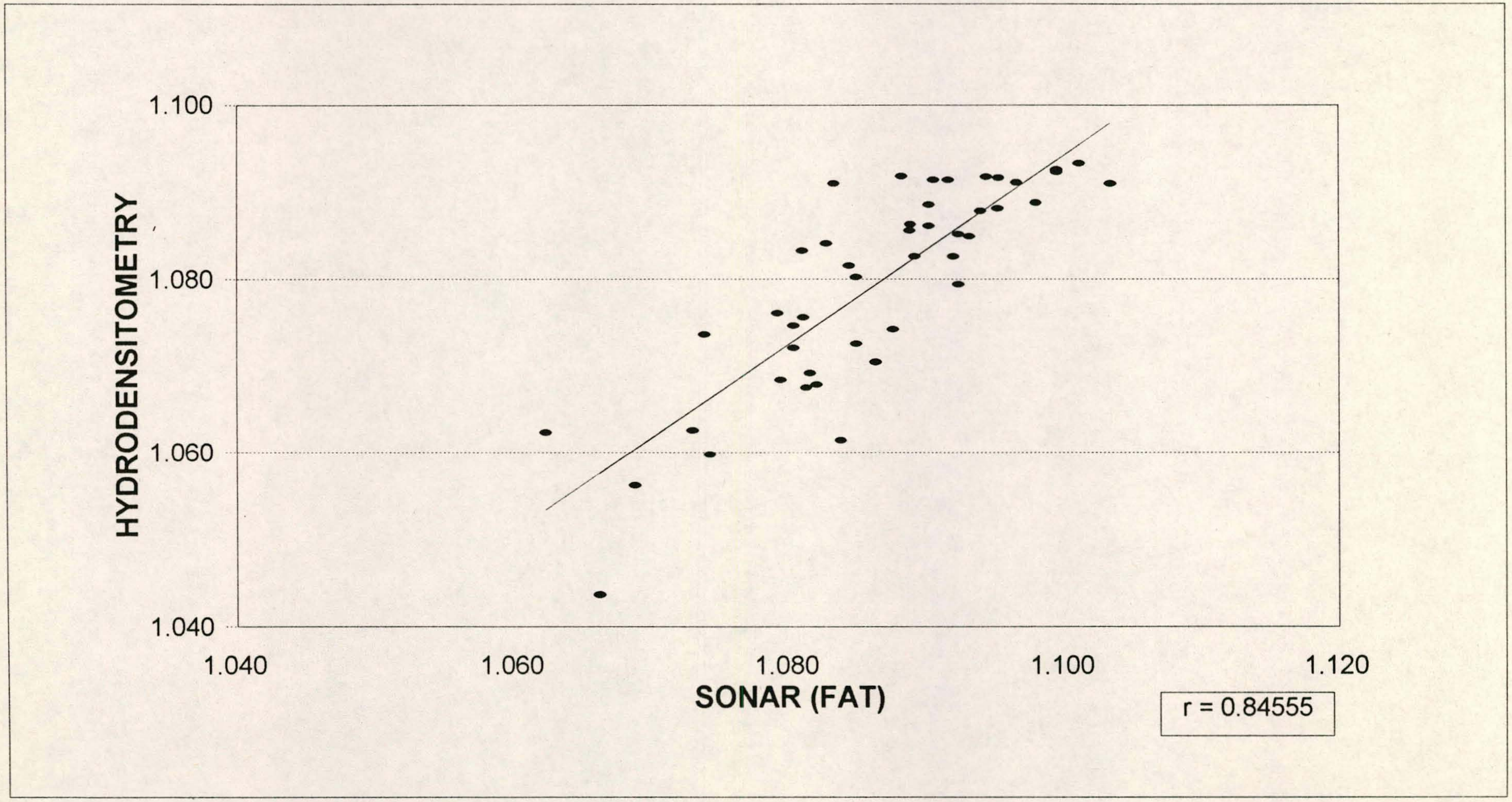

Figure 18a. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

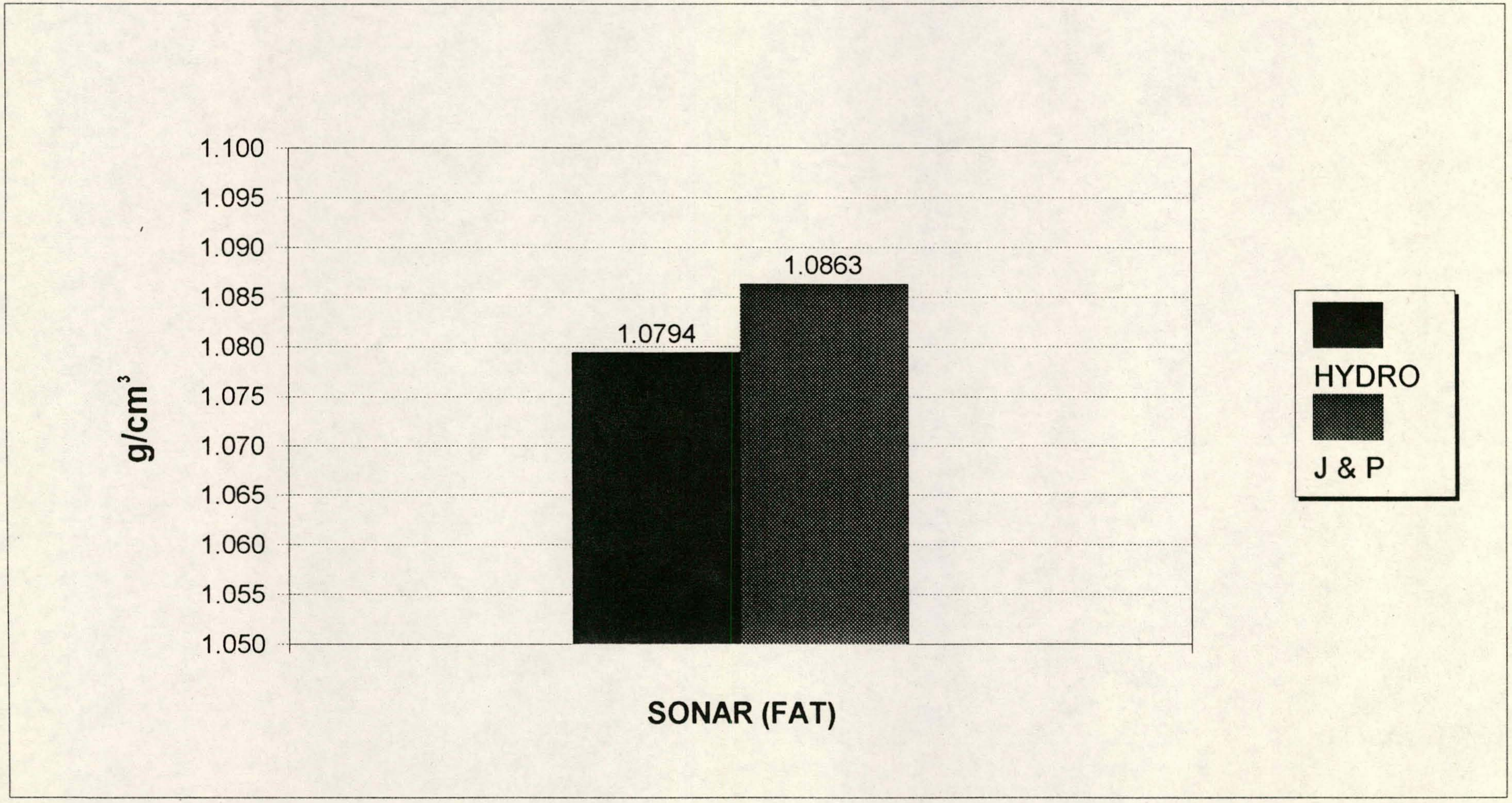

Figure 18b. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

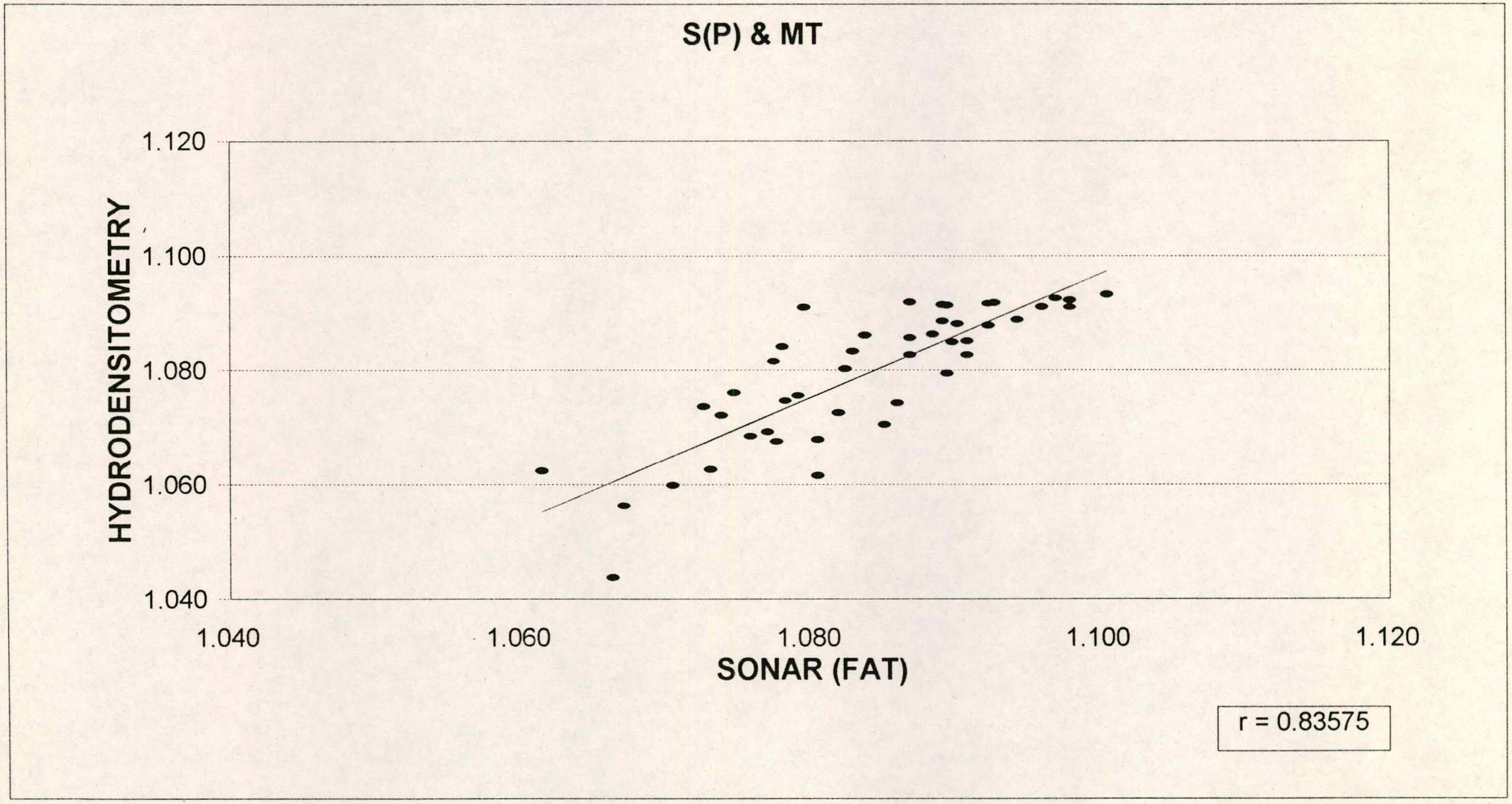

Figure 19a. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

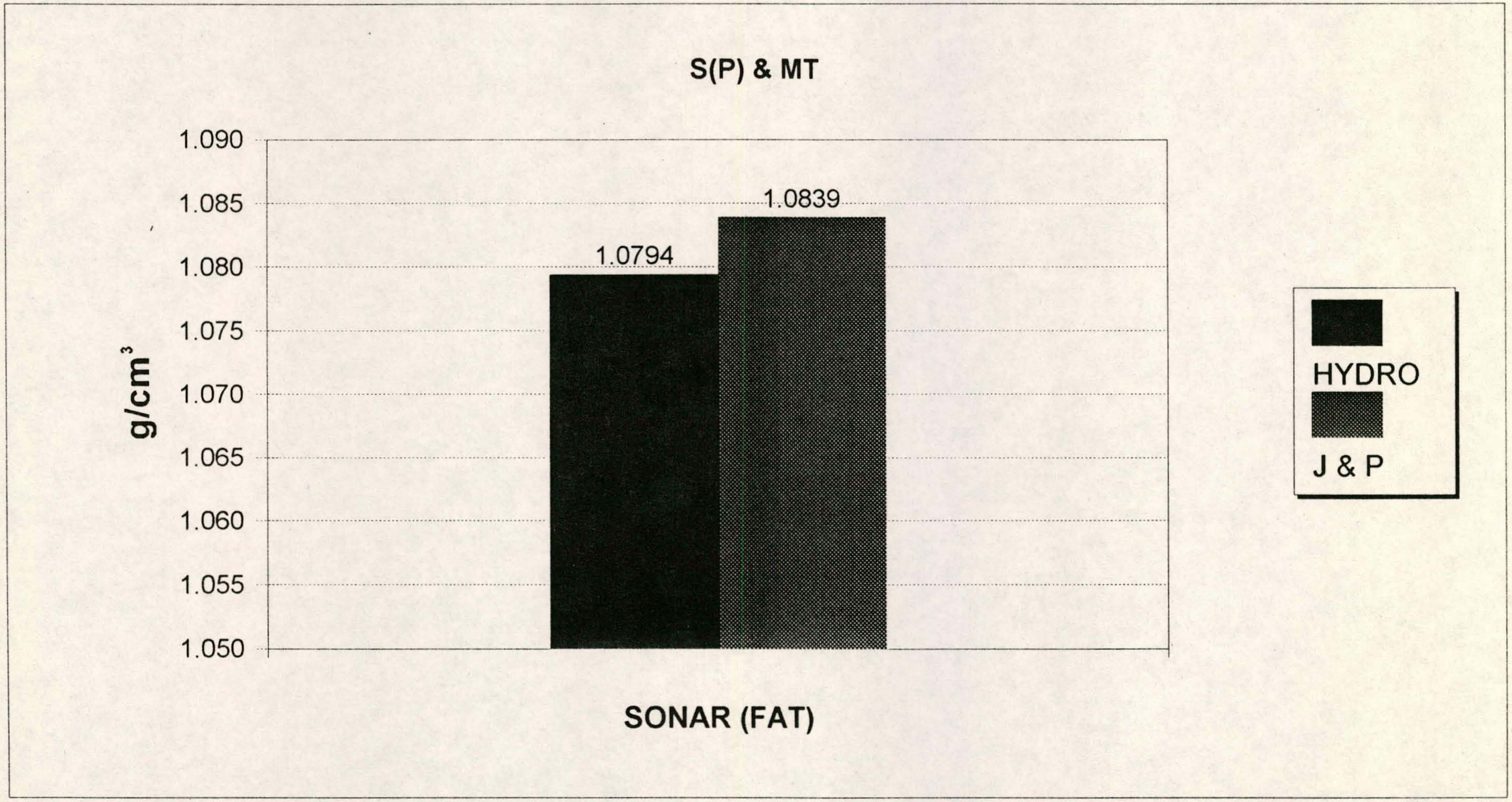

Figure 19b. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

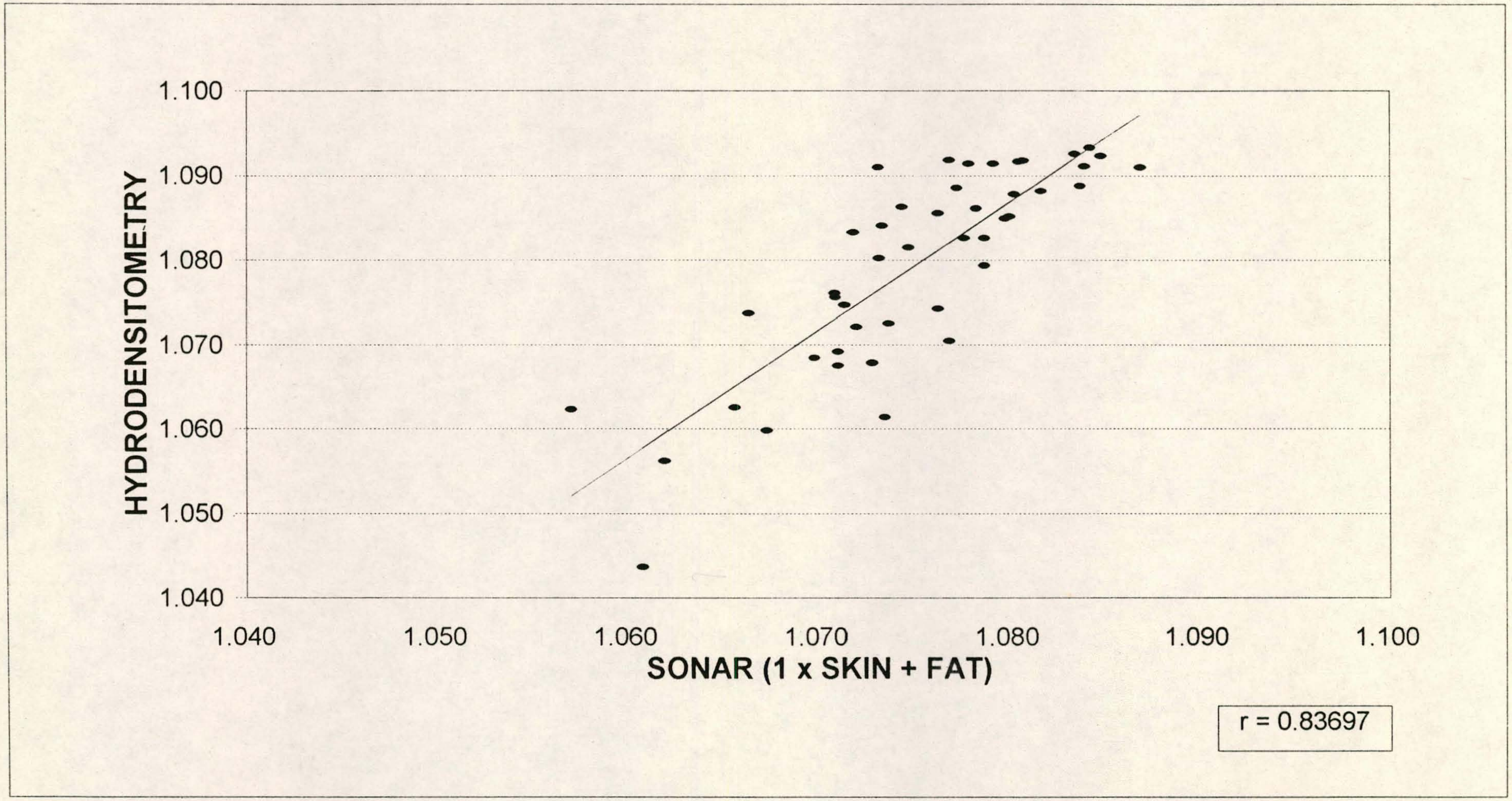

Figure 20a. **BODY DENSITY IN g/cm³: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

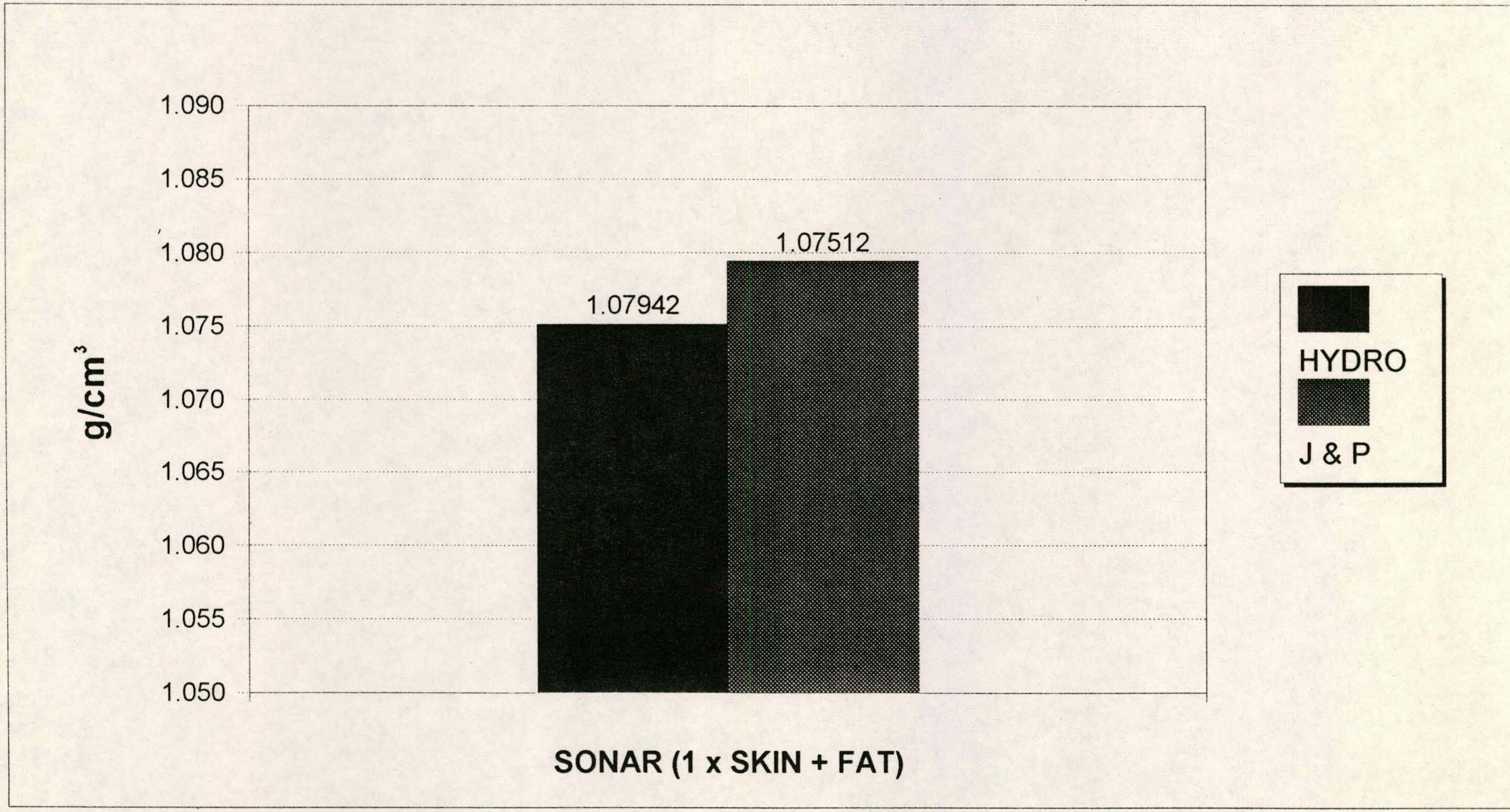

Figure 20b. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

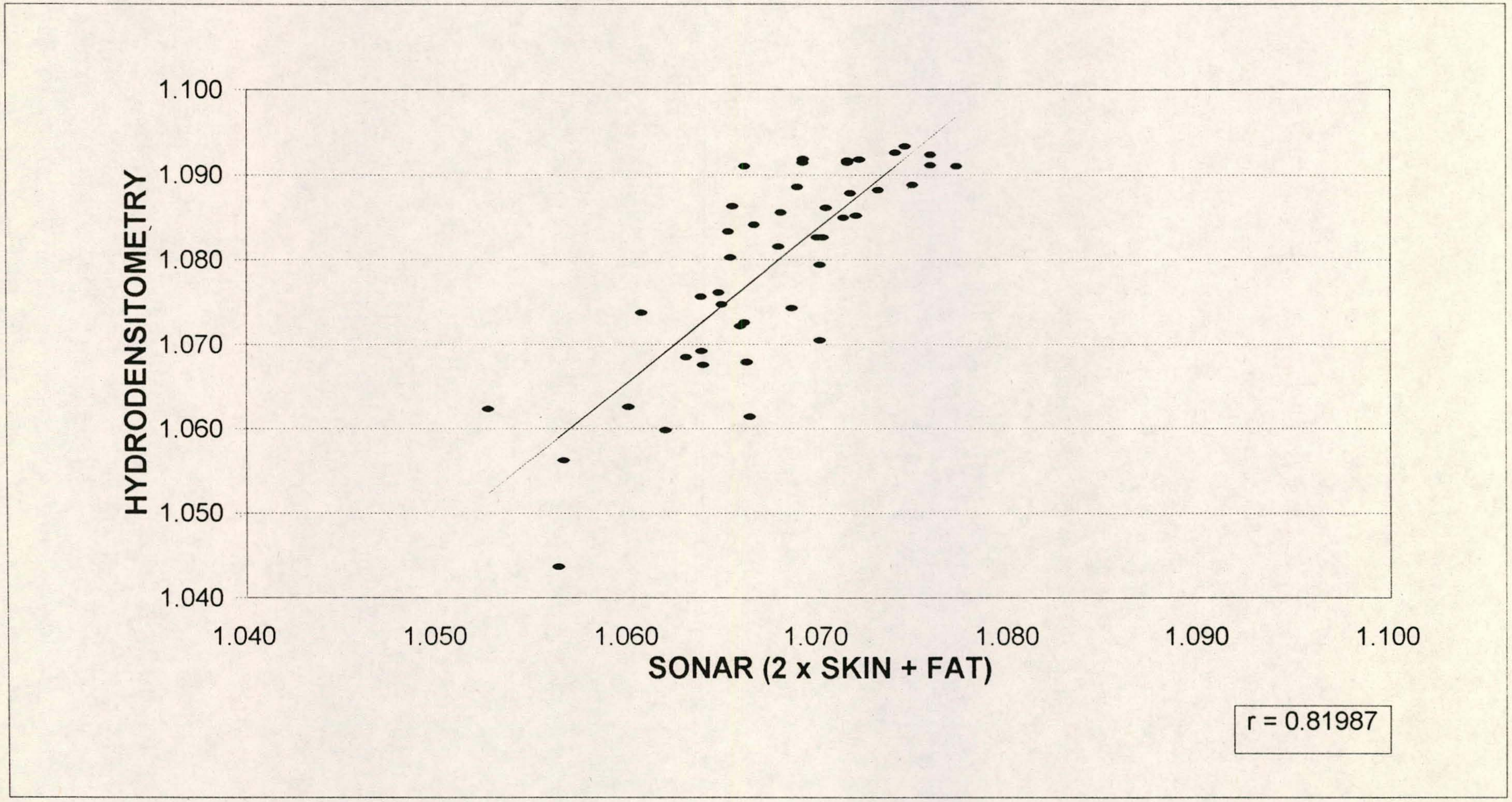

Figure 21a. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

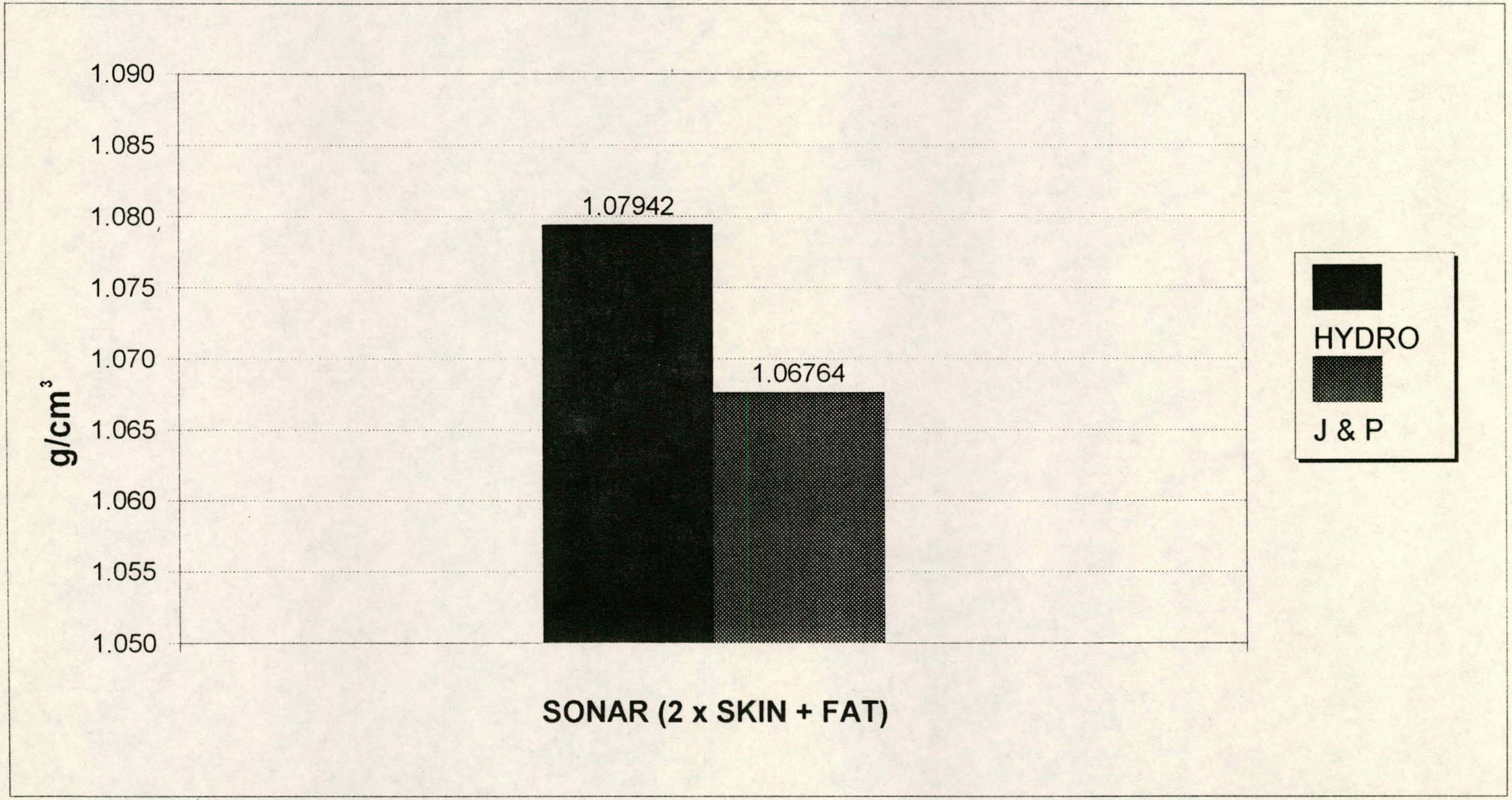

Figure 21b. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

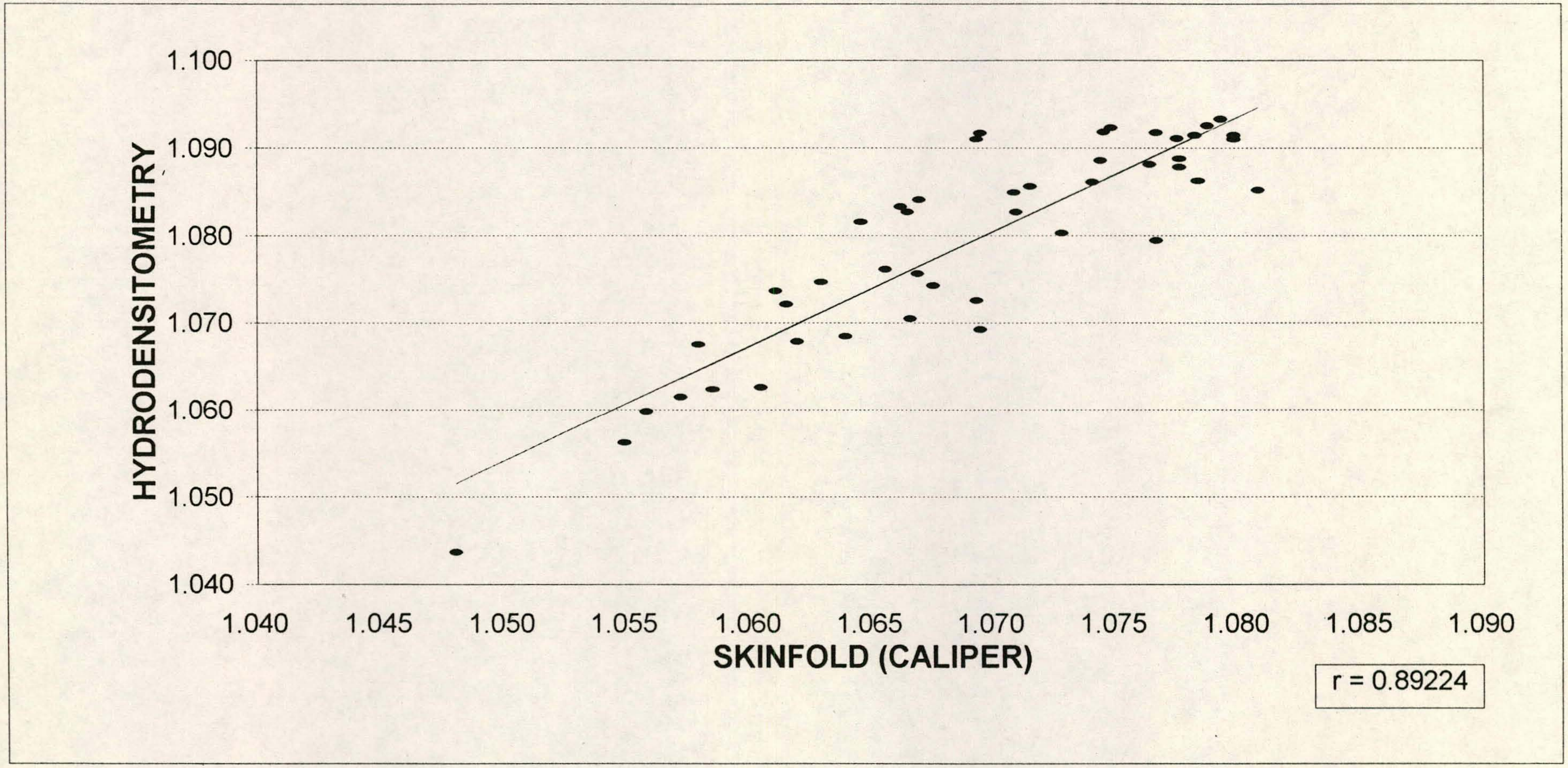

Figure 22a. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

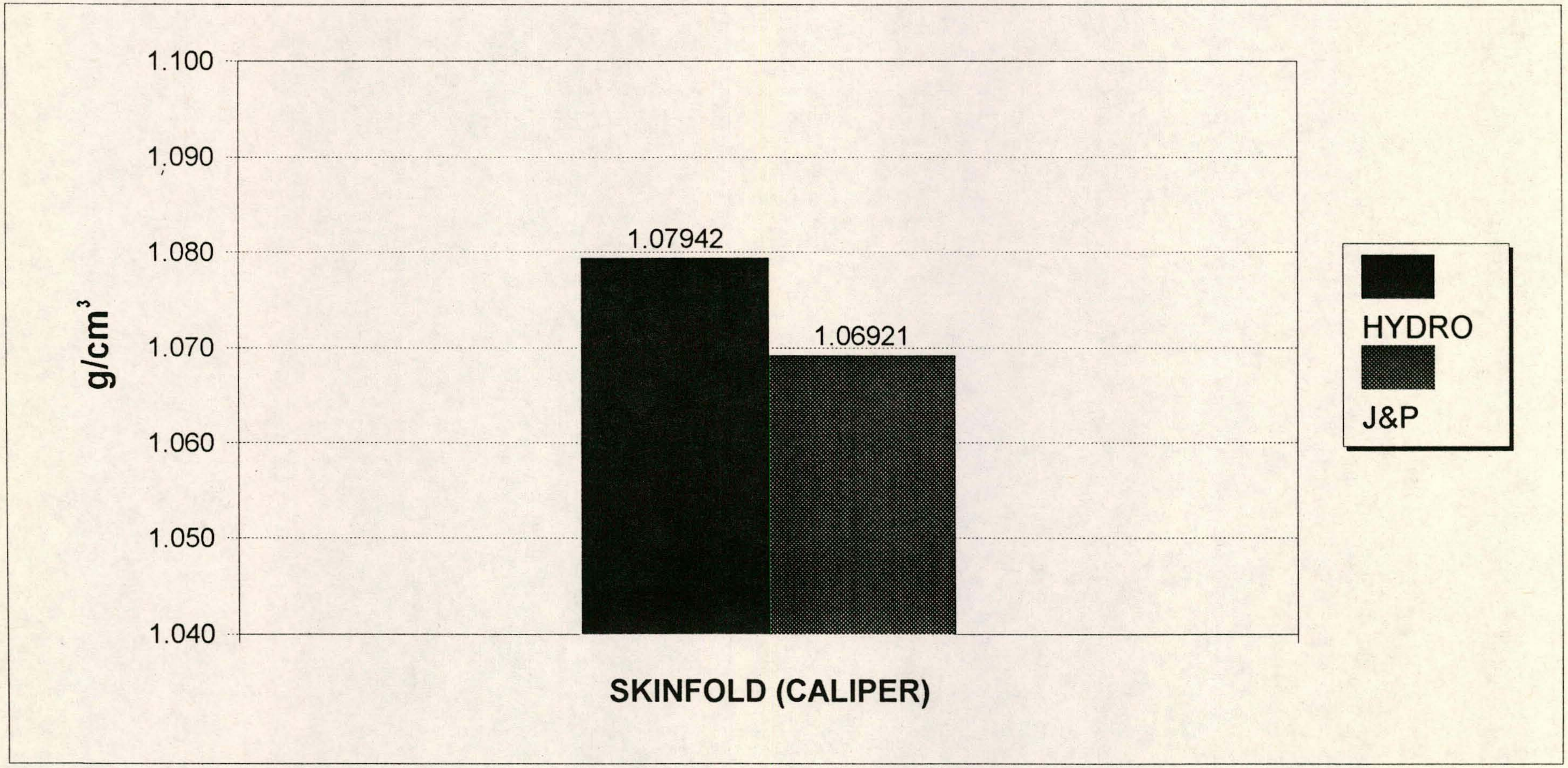

Figure 22b. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

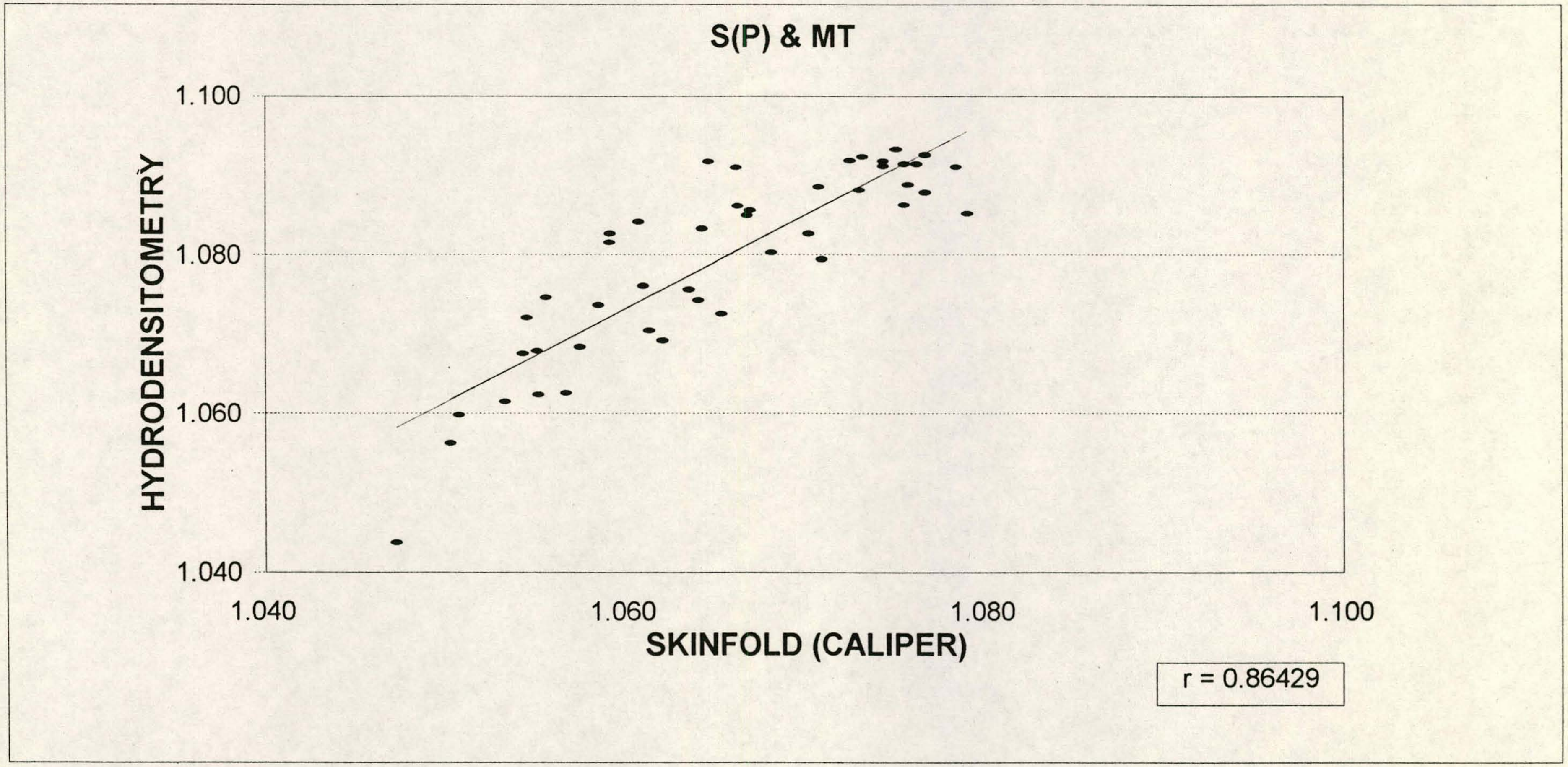

Figure 23a. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

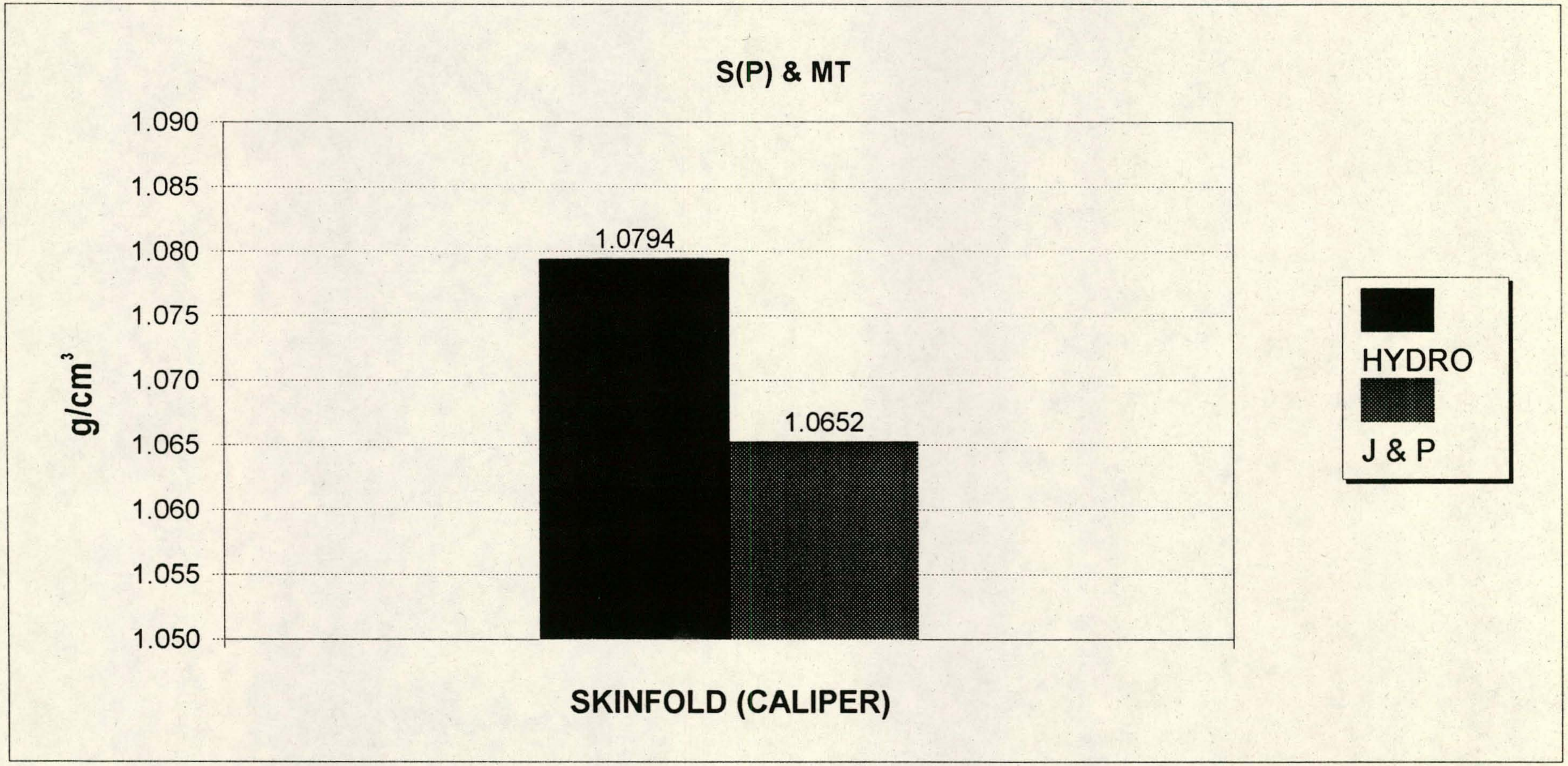

Figure 23b. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

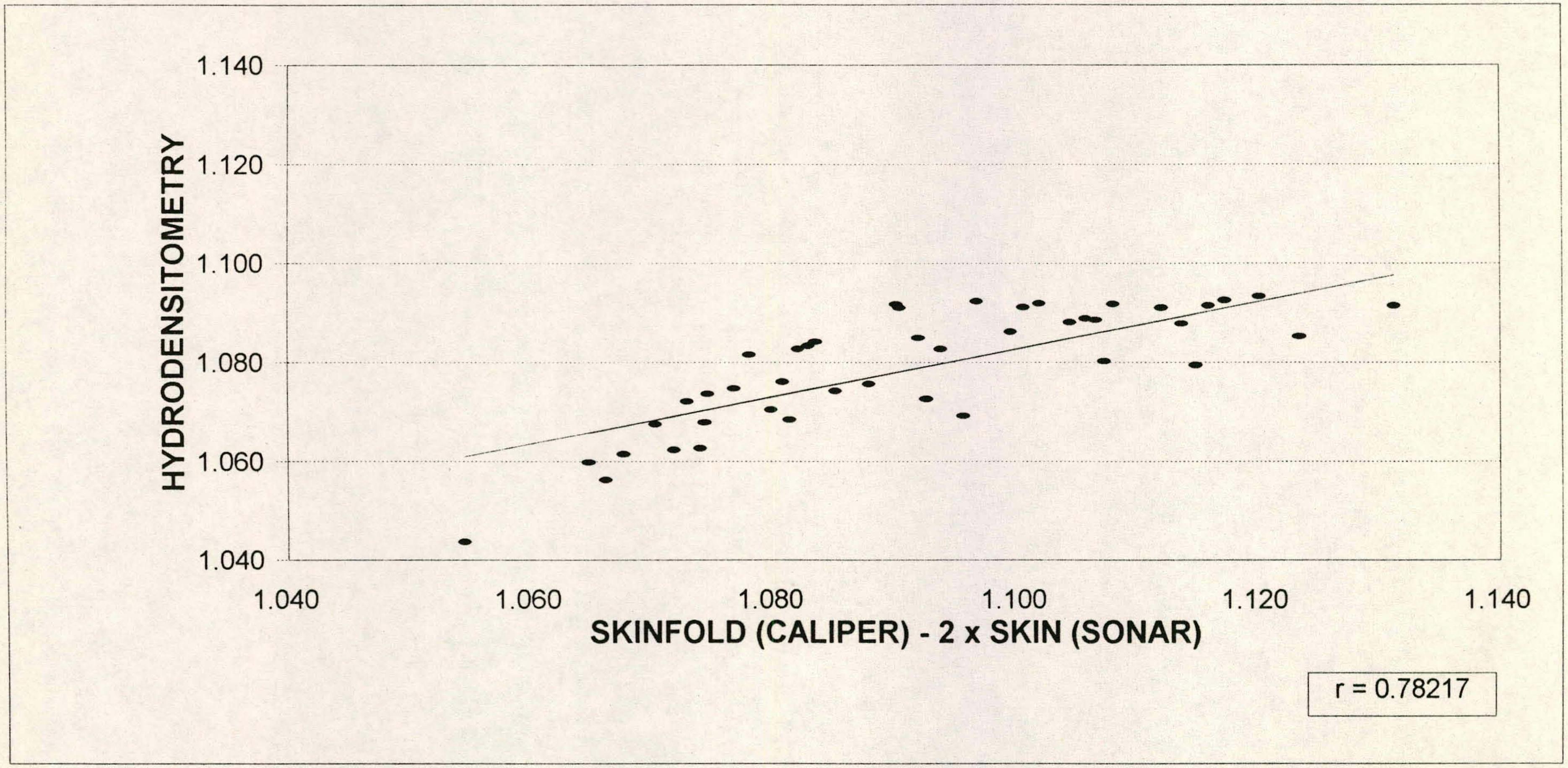

Figure 24a. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

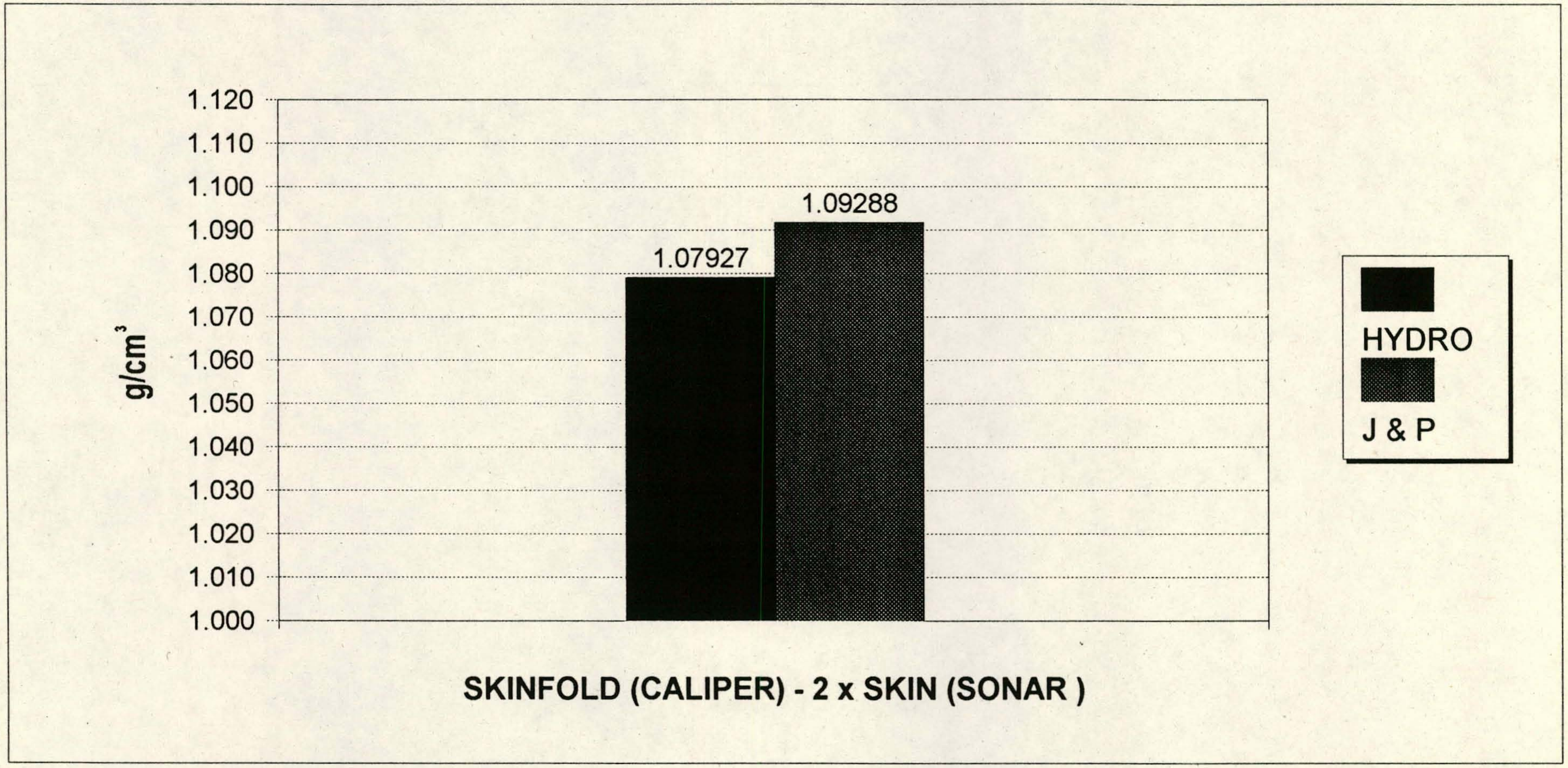

Figure 24b. **BODY DENSITY IN g/cm^3: HYDRODENSITOMETRY VS JACKSON & POLLOCK (1978)**

When applying the sonar (fat) measurements to the formula of Jackson & Pollock, it resulted in a relatively high correlation (r=0,8455), as when compared to other combinations of sonar measurements, namely sonar (1x skin + fat) and sonar (2x skin + fat), which resulted r=0,83697 and r=0,81987 respectively. When substituting the supra iliac (anterior) and medial thigh body locations with the supra iliac (posterior) and anterior thigh values respectively, a good correlation (r=0,83575) was found.

Although all of these variations yielded good results, it can be seen that the formula of Jackson & Pollock were developed for the use of skinfolds (r=0,89224). When substituting the supra iliac (anterior) and medial thigh body locations with the supra iliac (posterior) and anterior thigh values respectively, a good correlation (r=0,86924) is found. This indicates that more attention could be given to these fat deposit areas not formerly investigated.

Correlation of Various Methods and Body Sites with BD (Hydrodensitometry)

Product moment correlations between body density, as determined by hydrostatic weighing, and individual anthropometrical variables are shown in the series of figures 25a-n, 26a-n, 27a-n according to the different parameter used. Each of the 14 body locations was individually correlated with body density via three different methods, namely:

1. Skinfold measurements: Harpenden caliper (Figures 25a-n),
2. Fat measurements: Sonar (Figures 26a-n),
3. 2 x Skin and fat: Sonar (Figures 27a-n).

Skinfolds correlated the highest with body density, ranging from r=0,827 (abdomen) to r=0,615 (bicep). The second highest correlations were found to be that of fat thickness, varying from r=0,791 (tricep) to r=0,237 (chin). The sonar measurements (2x skin + fat) correlated third highest ranging from r=0,754 (chest) to r=0,239 (chin).

The seven highest correlations of each of the methods above yielded the following results:

Skinfolds (Caliper)

1.	Abdomen	(r=0,827)
2.	Axilla	(r=0,823)
3.	Supra iliac (ant)	(r=0,818)
4.	Supra iliac (post)	(r=0,812)
5.	Subscapula	(r=0,805)
6.	Tricep	(r=0,791)
7.	Chest	(r=0,781)

Sonar (Fat)

1.	Tricep	(r=0,791)
2.	Supra iliac (ant)	(r=0,733)
3.	Chest	(r=0,729)
4.	Bicep	(r=0,726)
5.	Medial thigh	(r=0,723)
6.	Abdomen	(r=0,715)
7.	Anterior thigh	(r=0,707)

Sonar (2x Skin + Fat)

1.	Chest	(r=0,754)
2.	Medial thigh	(r=0,740)
3.	Supra iliac (ant)	(r=0,730)
4.	Tricep	(r=0.728)
5.	Bicep	(r=0,727)
6.	Abdomen	(r=0,705)
7.	Anterior thigh	(r=0,671)

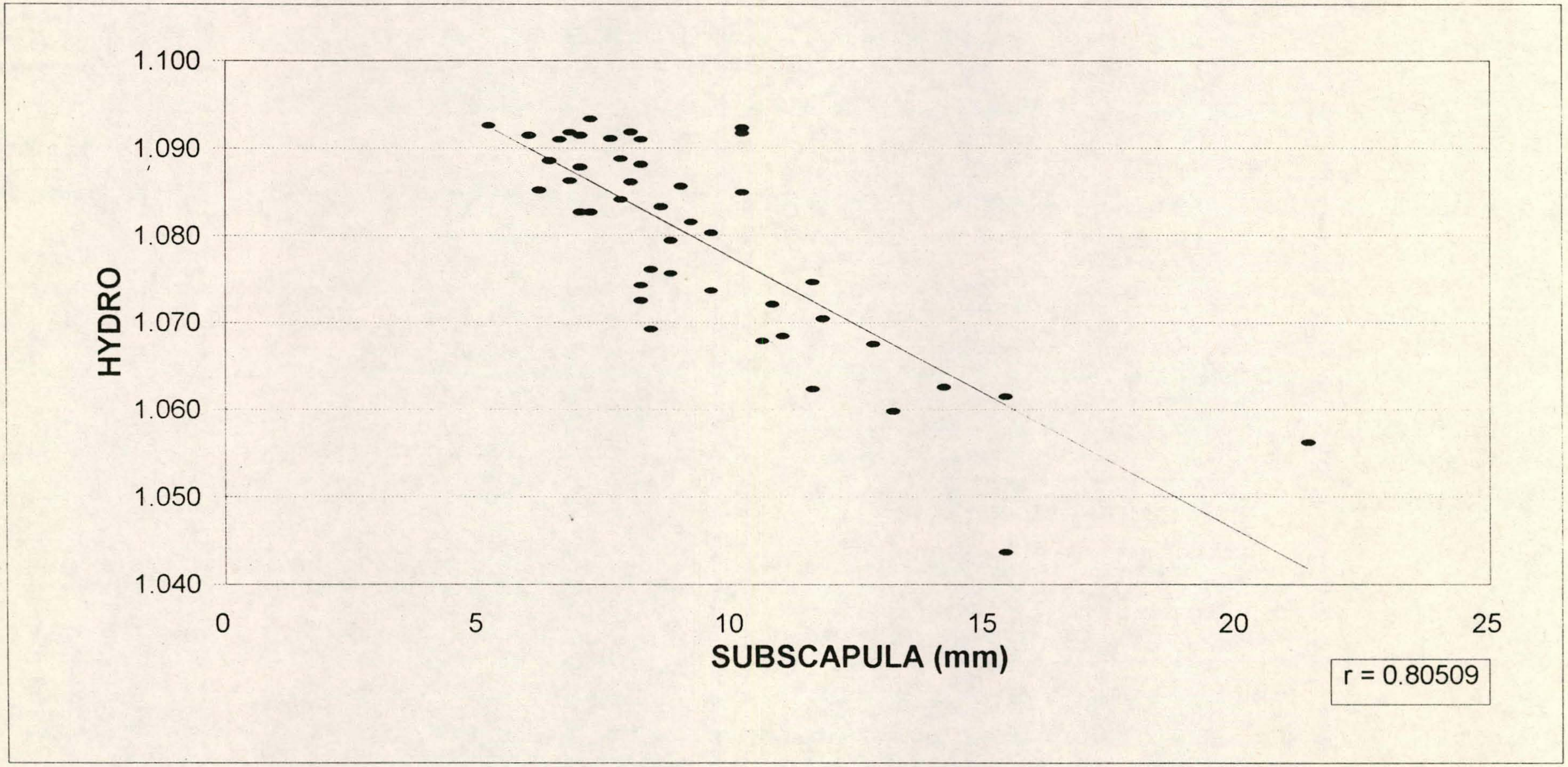

Figure 25a. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

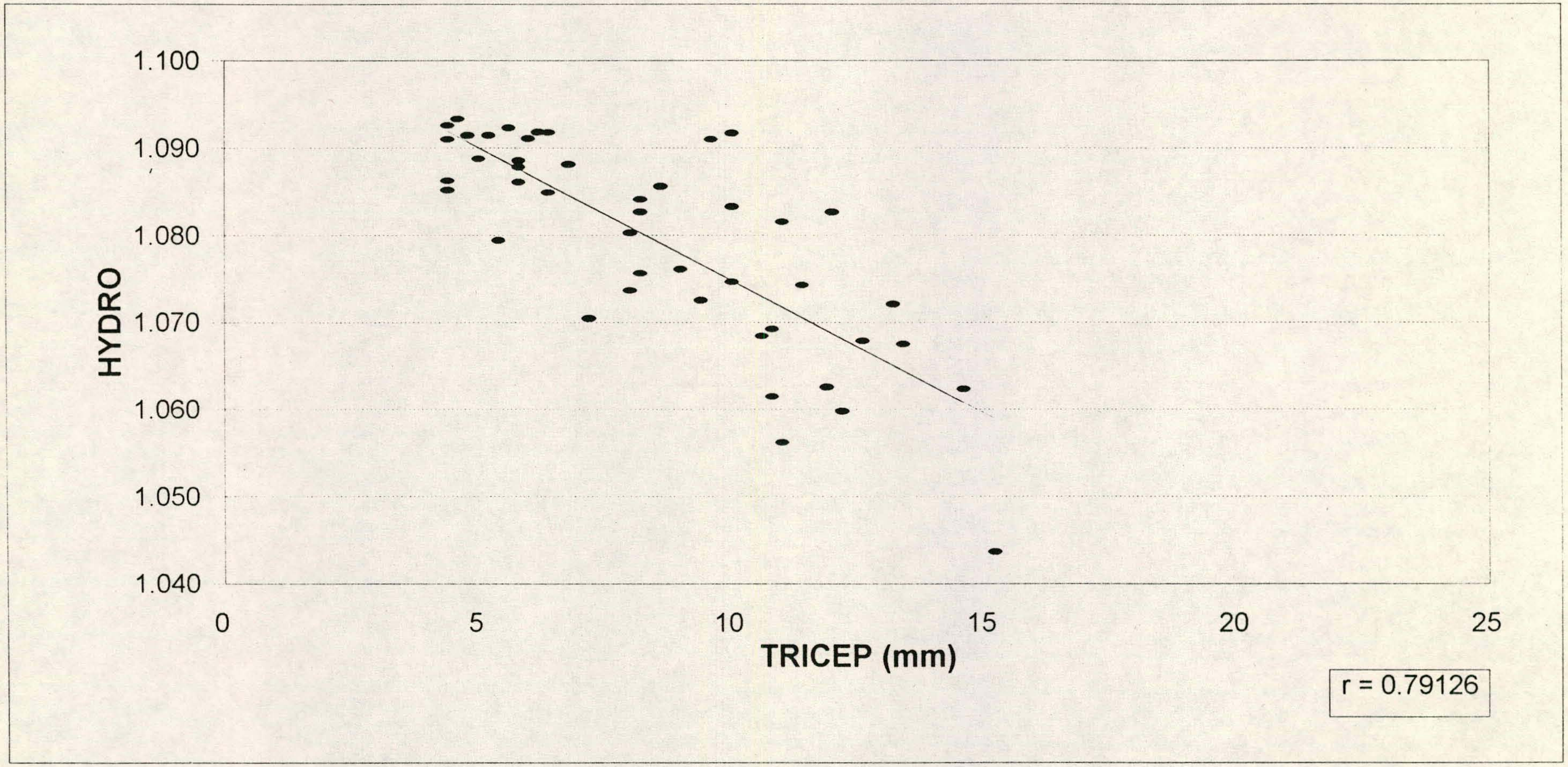

Figure 25b. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

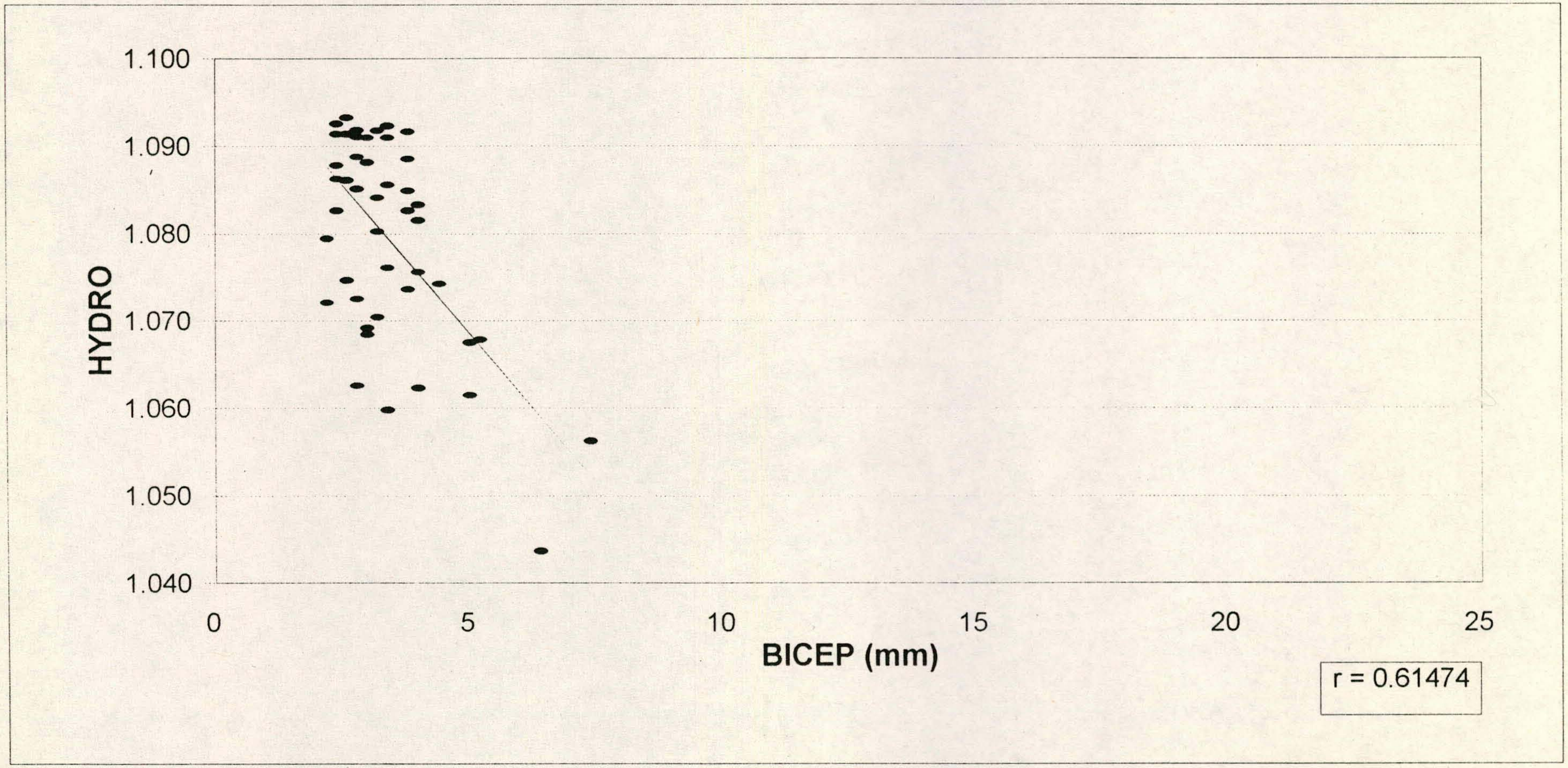

Figure 25c. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

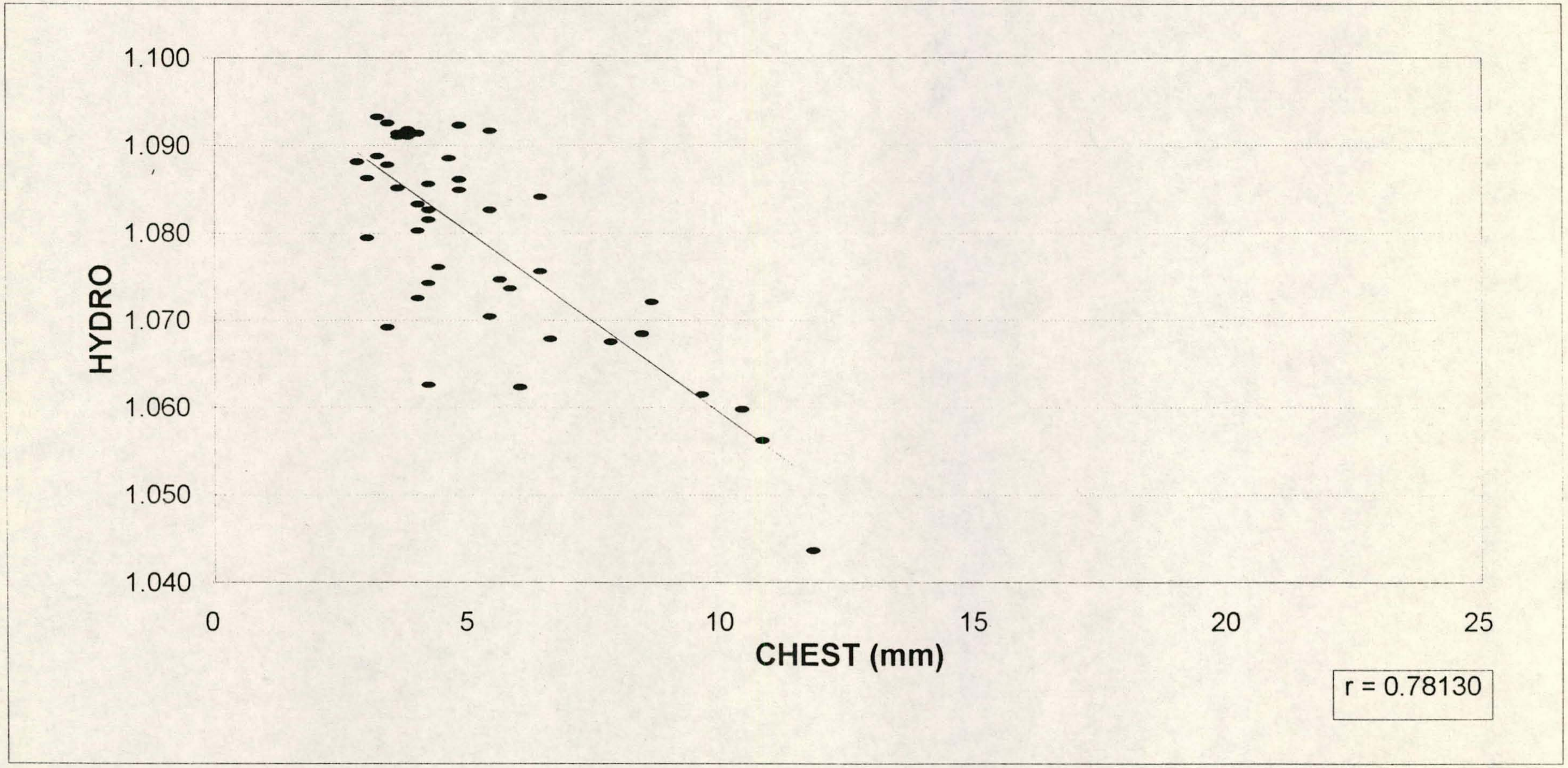

Figure 25d. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

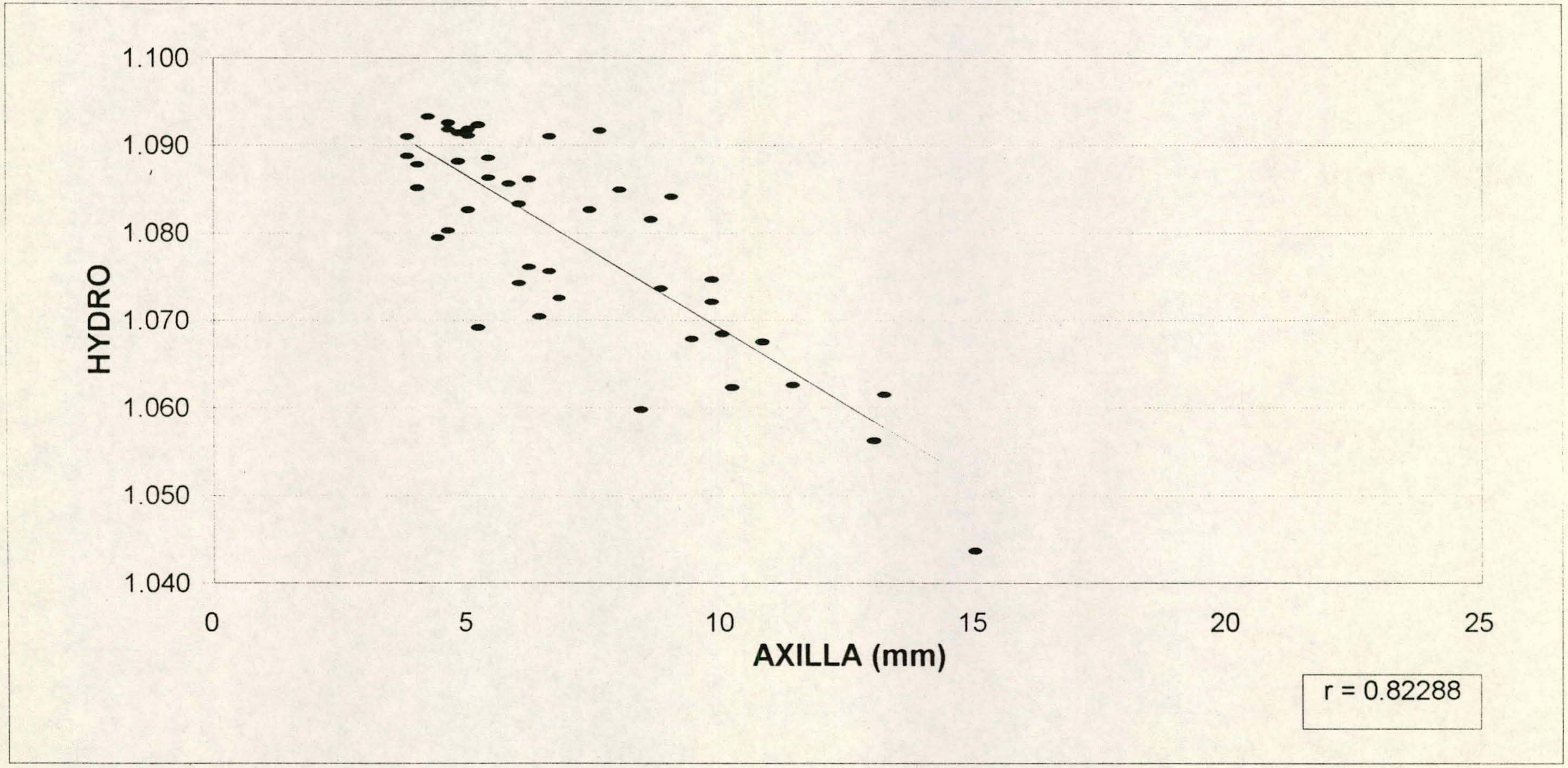

Figure 25e. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

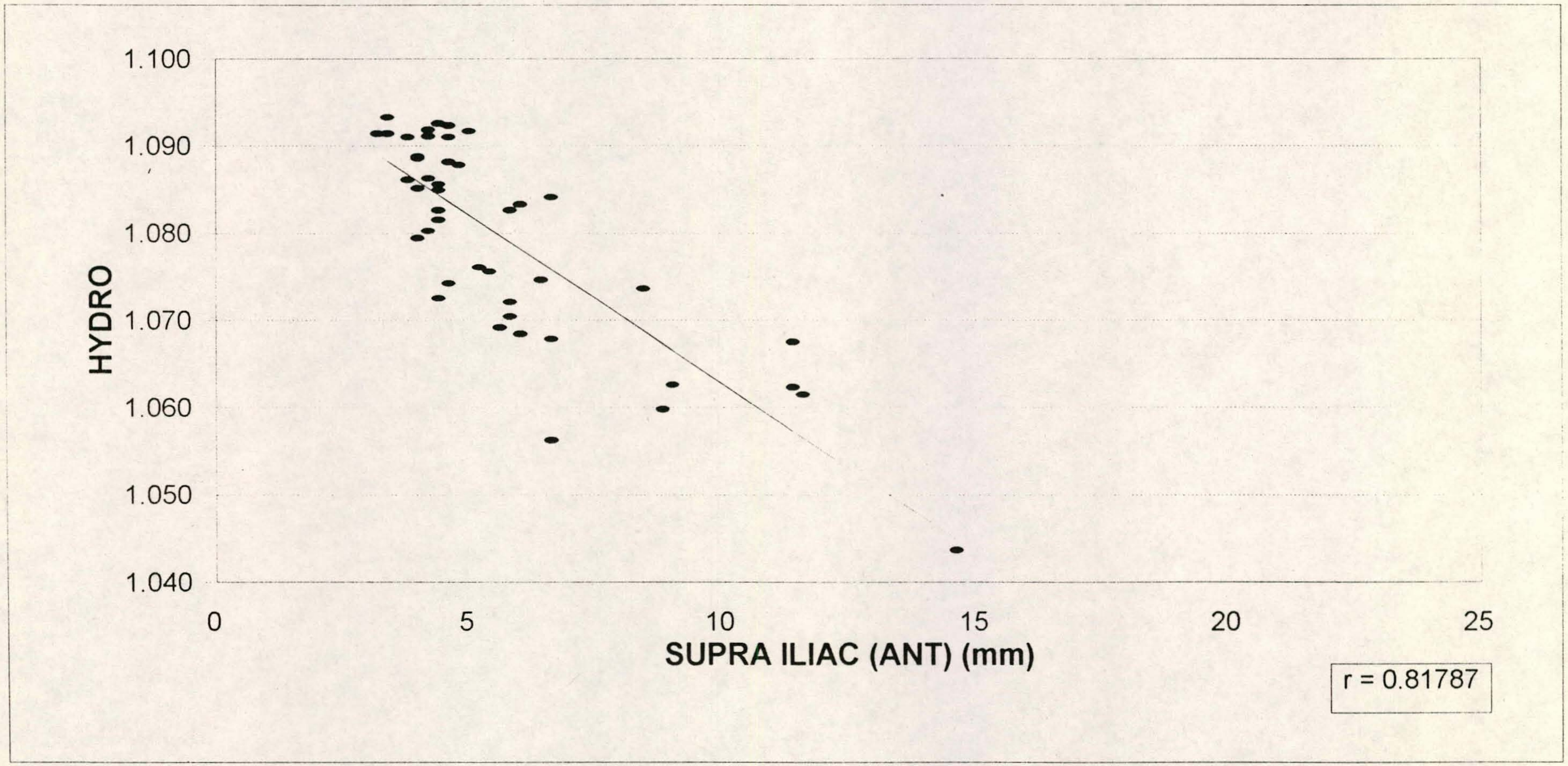

Figure 25f. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

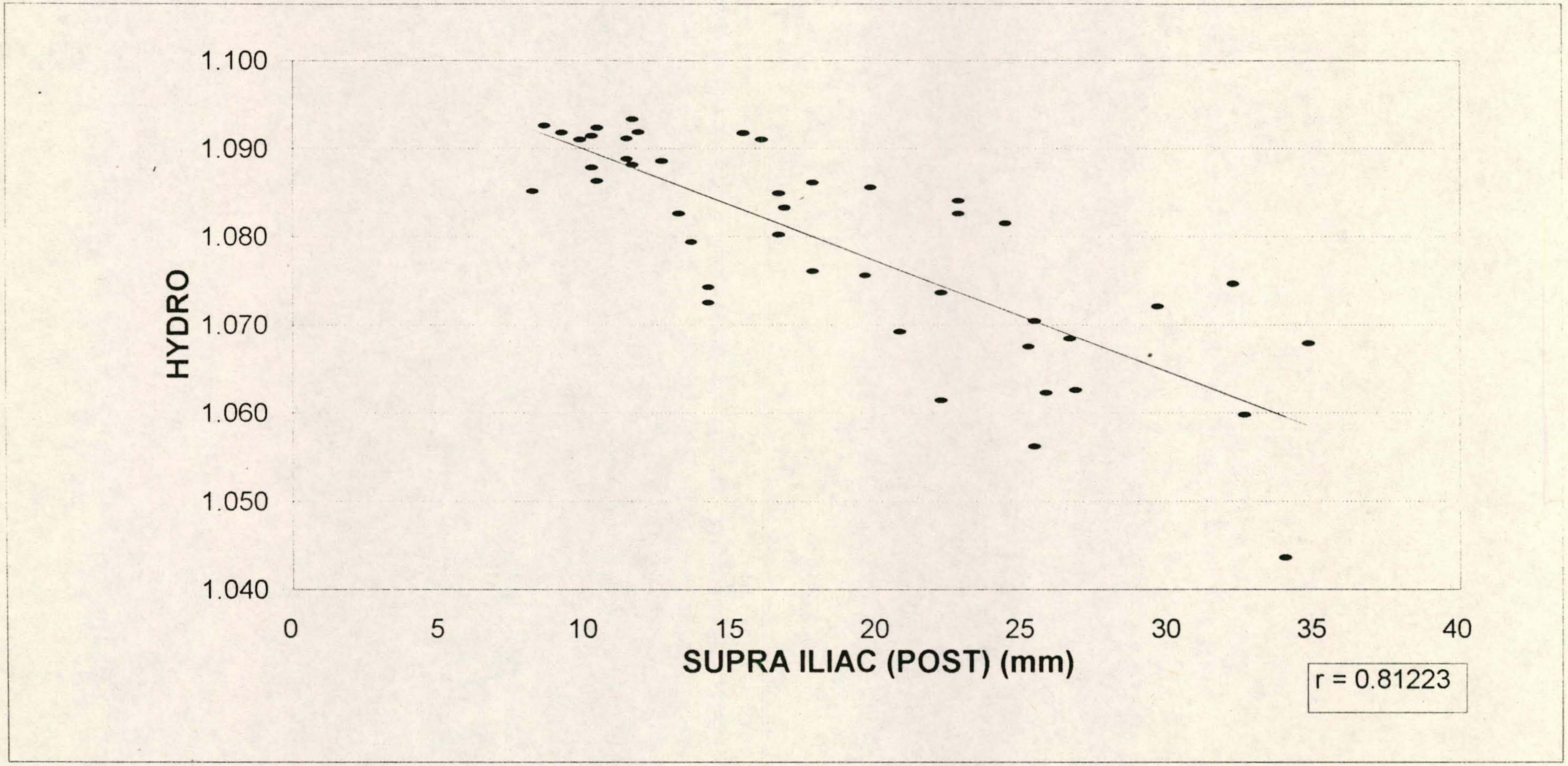

Figure 25g. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

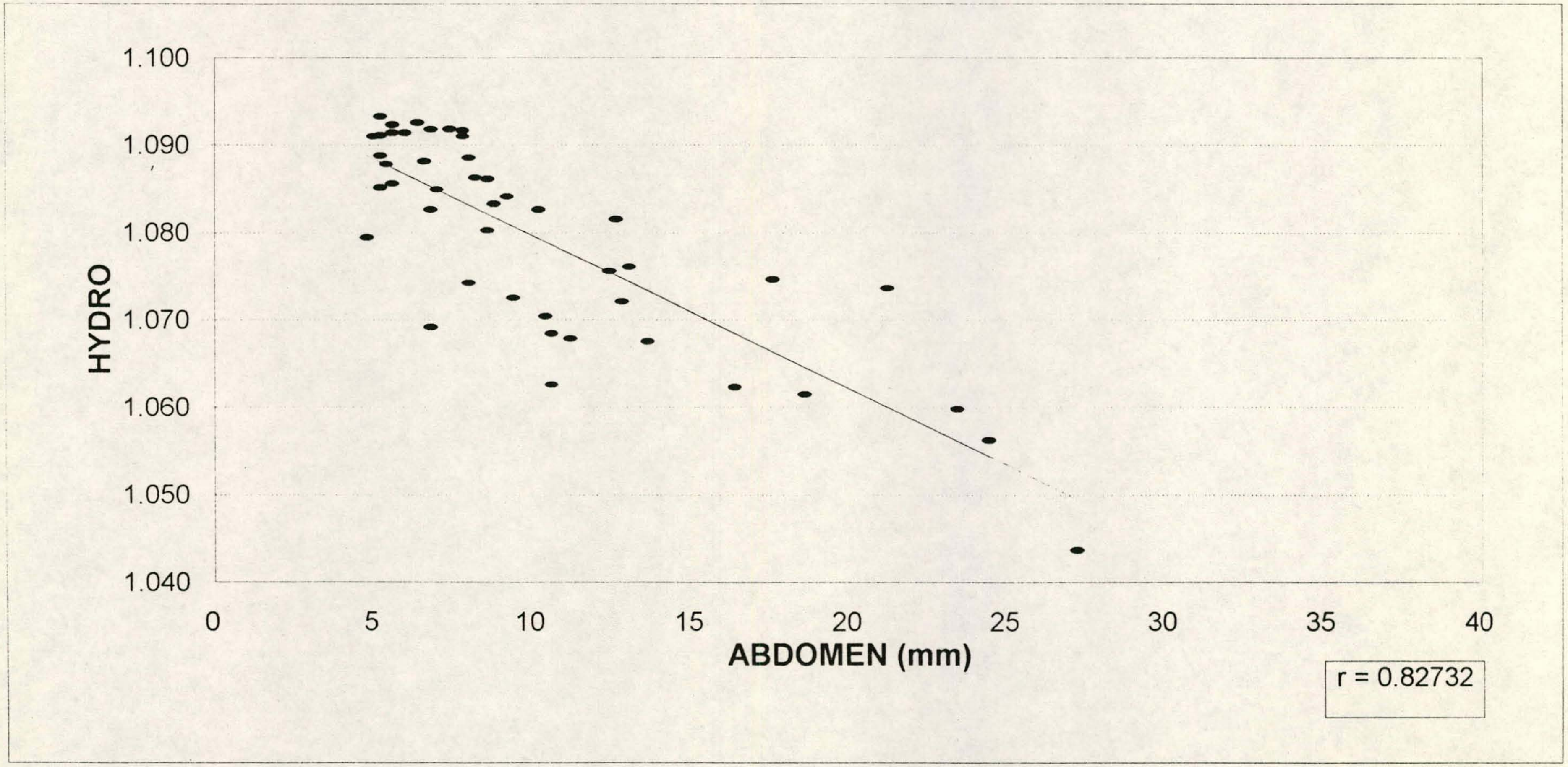

Figure 25h. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

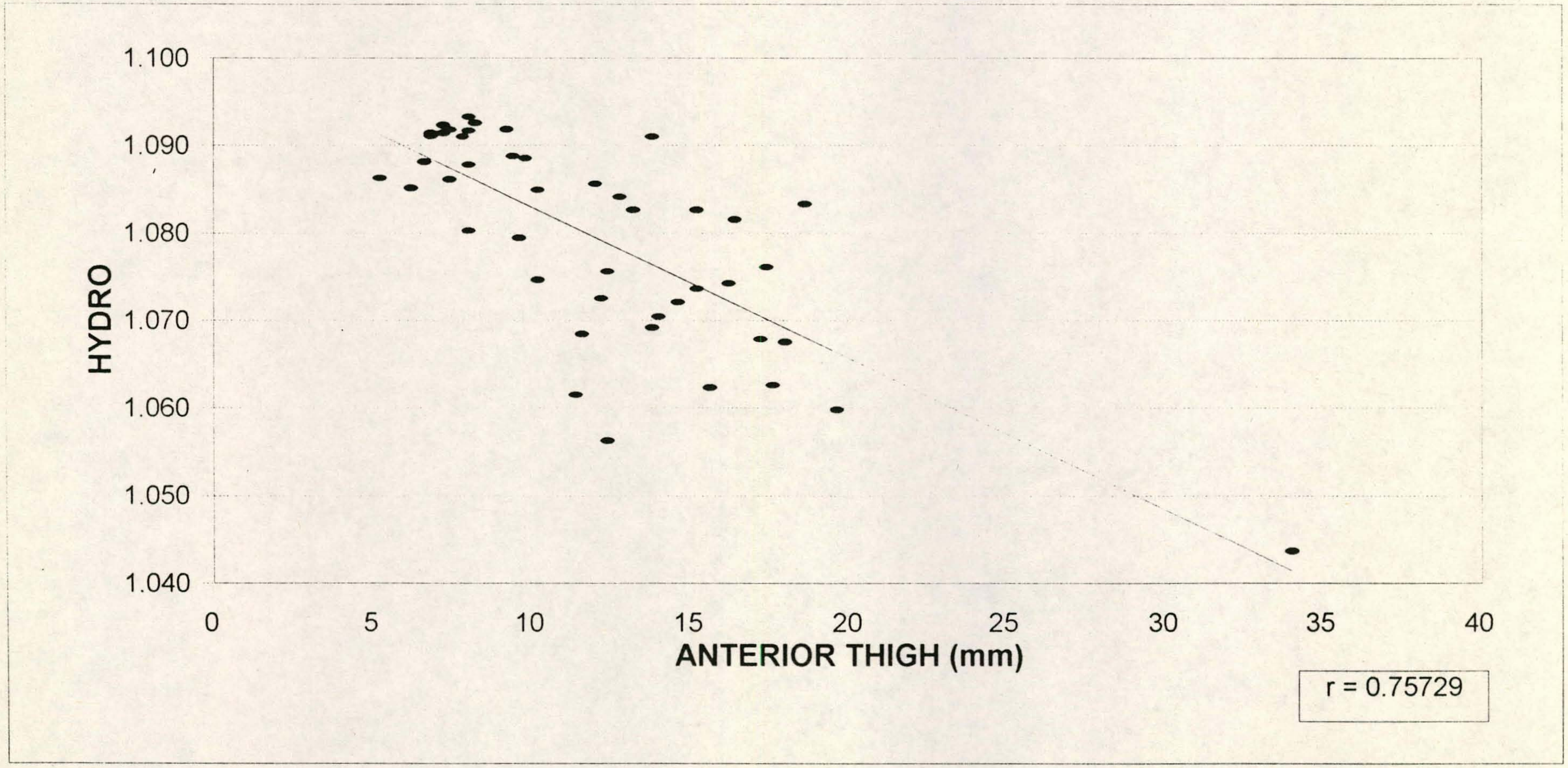

Figure 25i. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

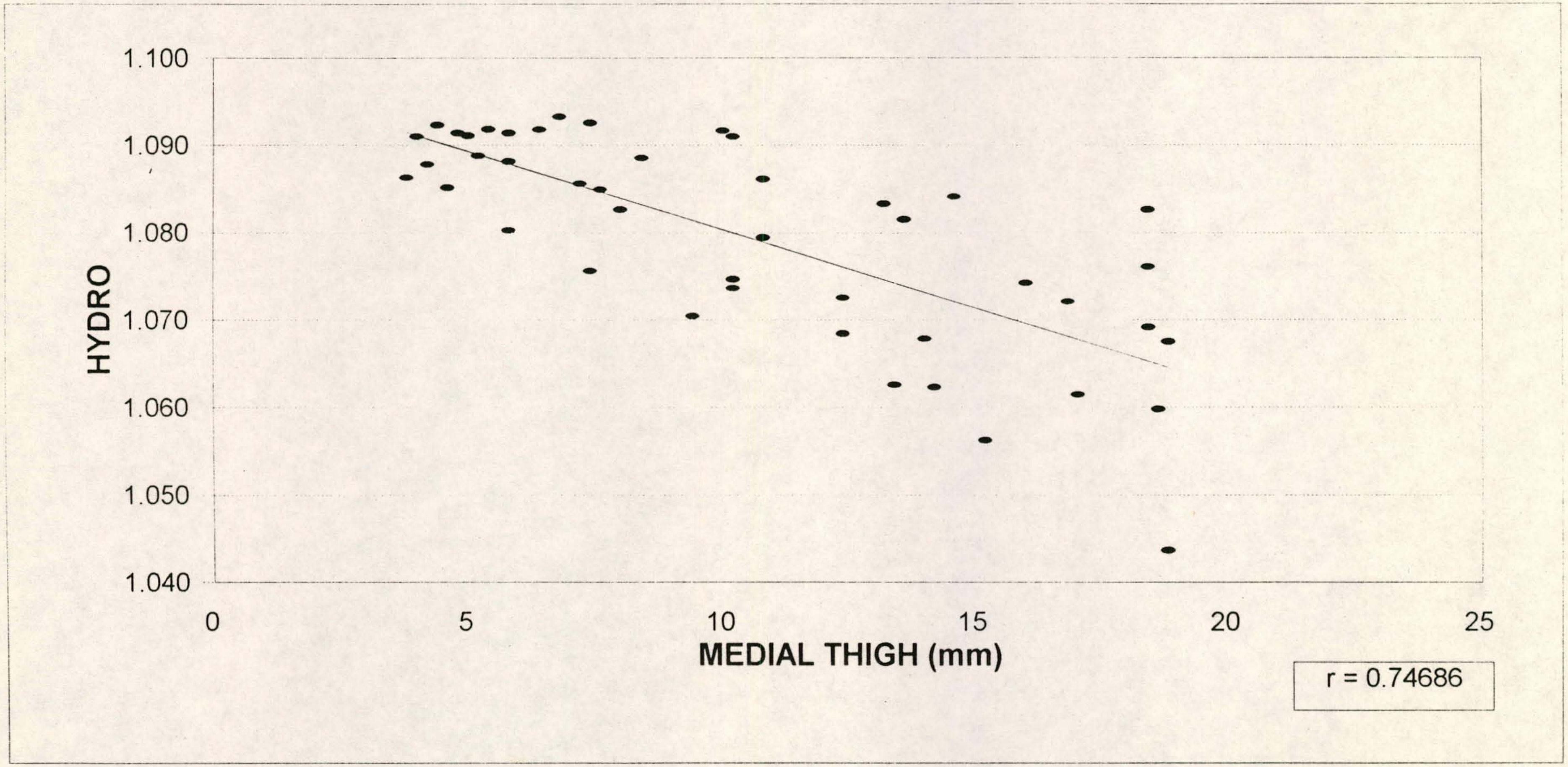

Figure 25j. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

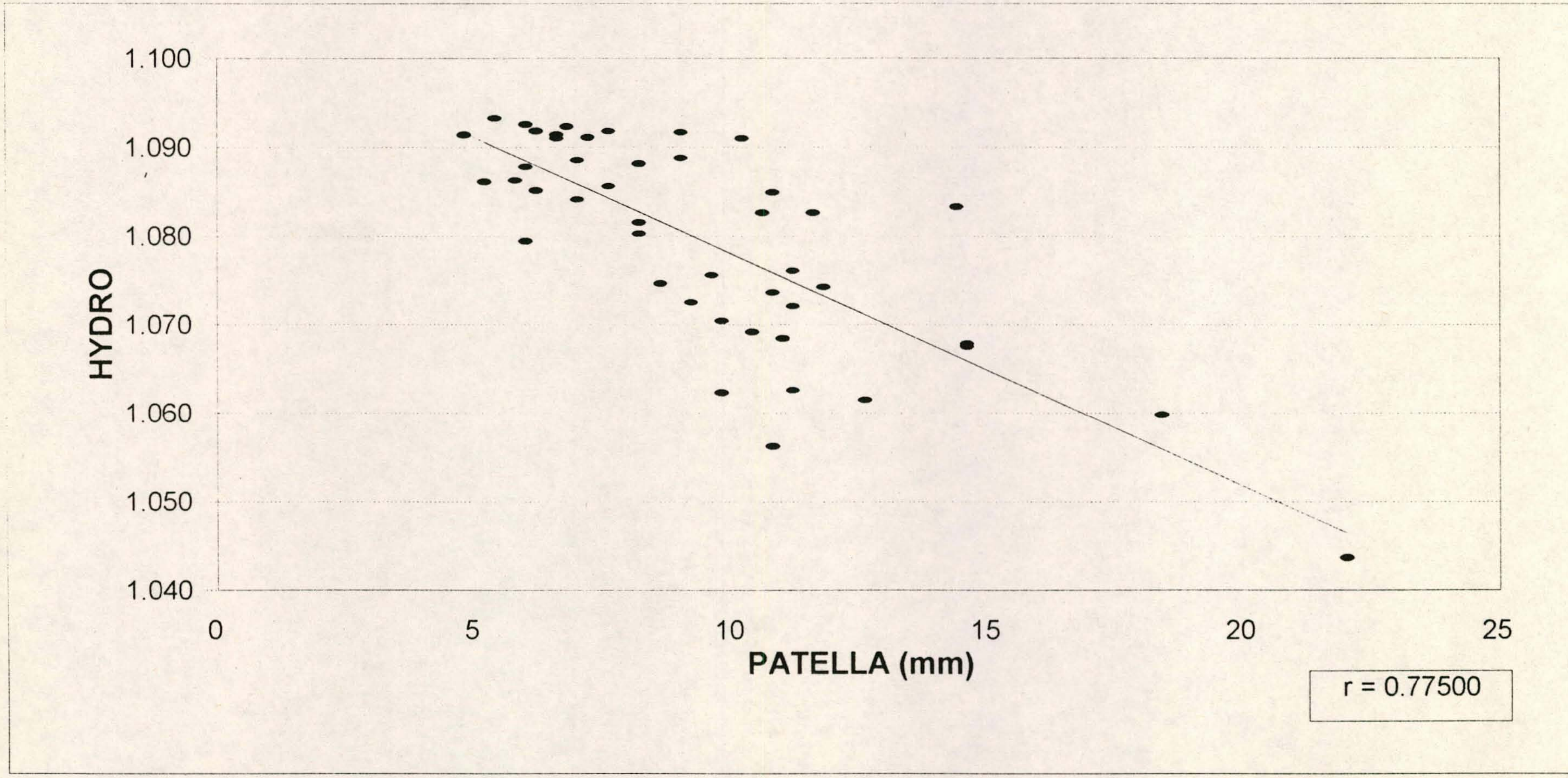

Figure 25k. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

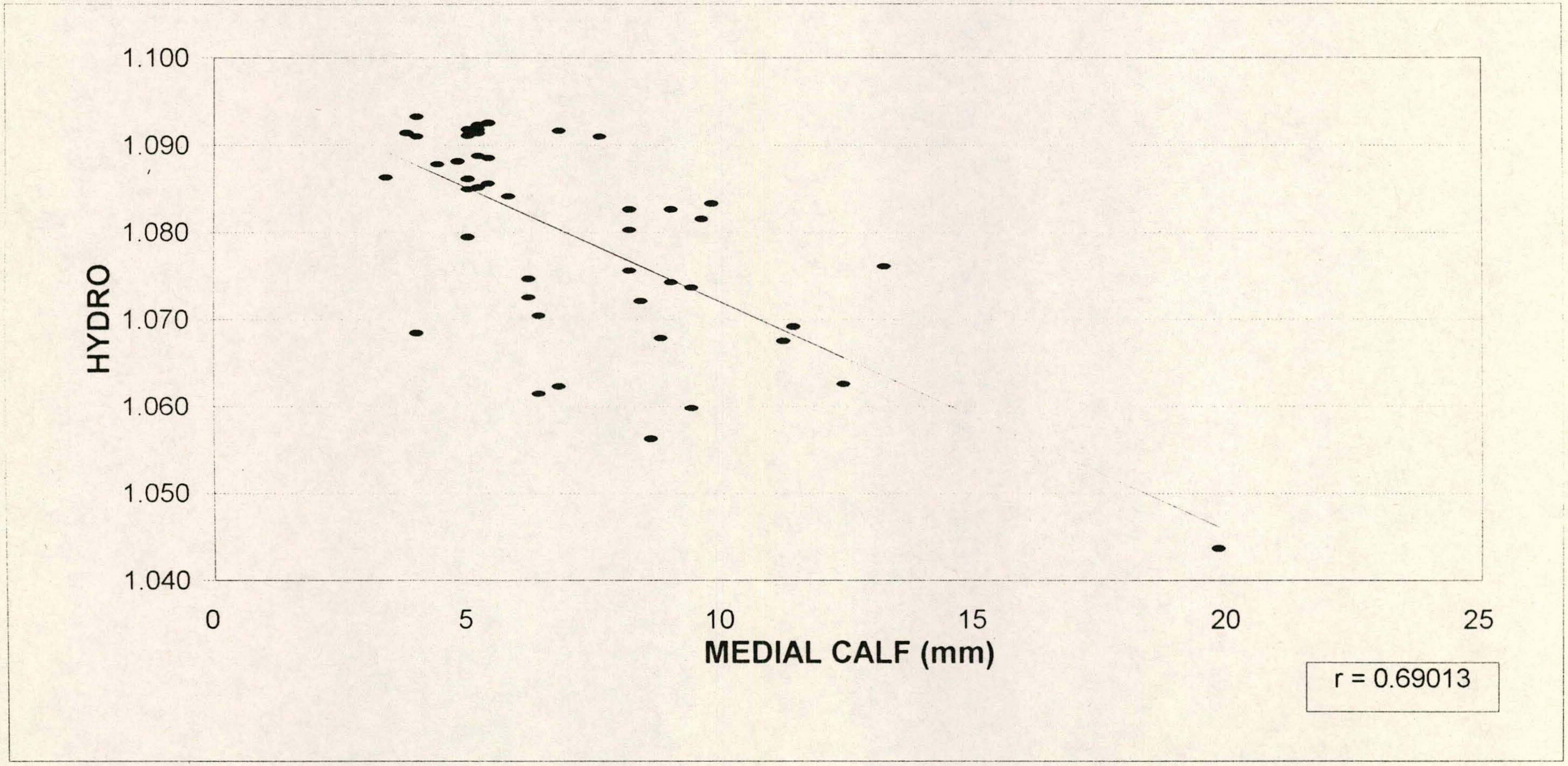

Figure 25I. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

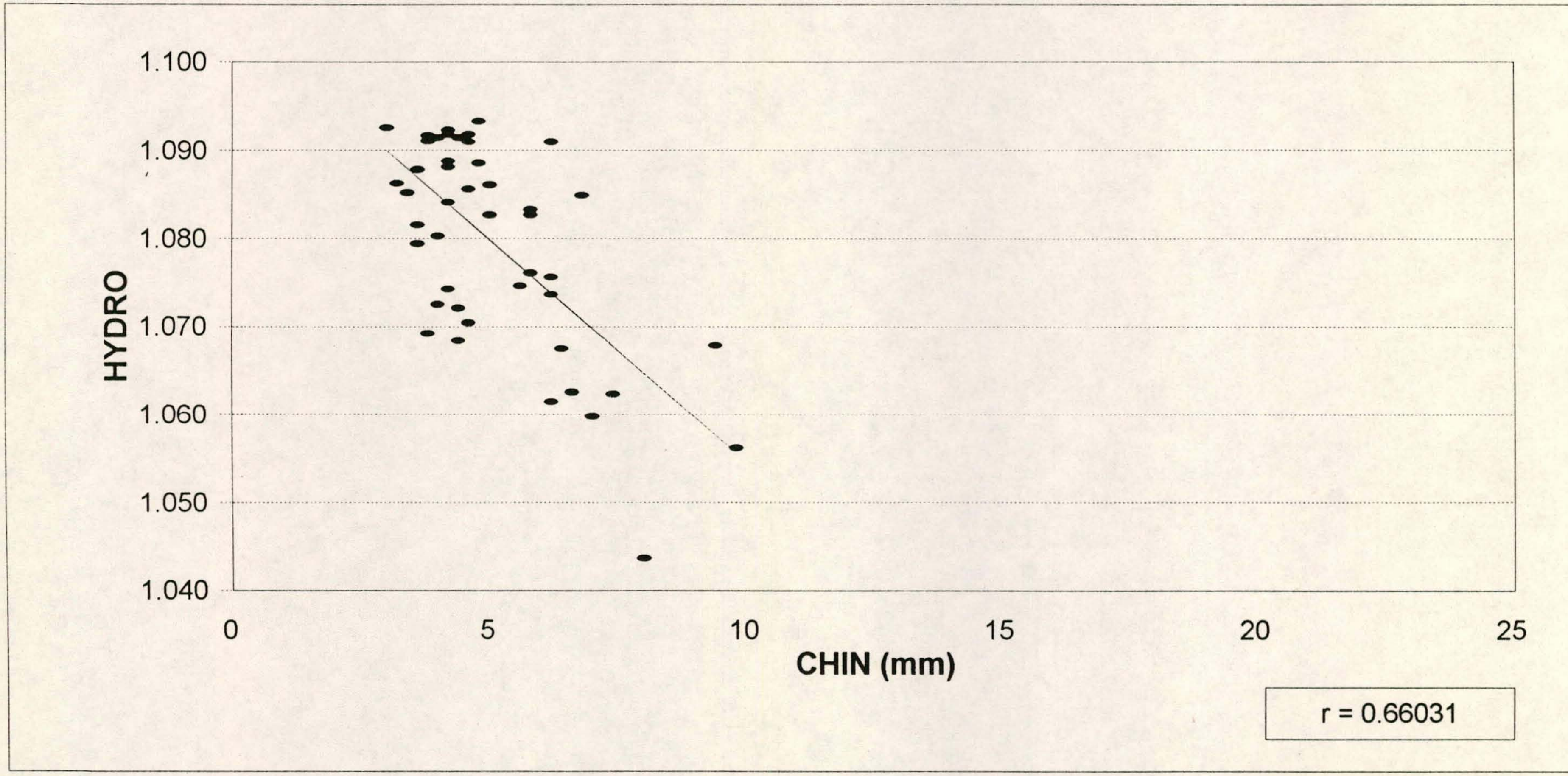

Figure 25m. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

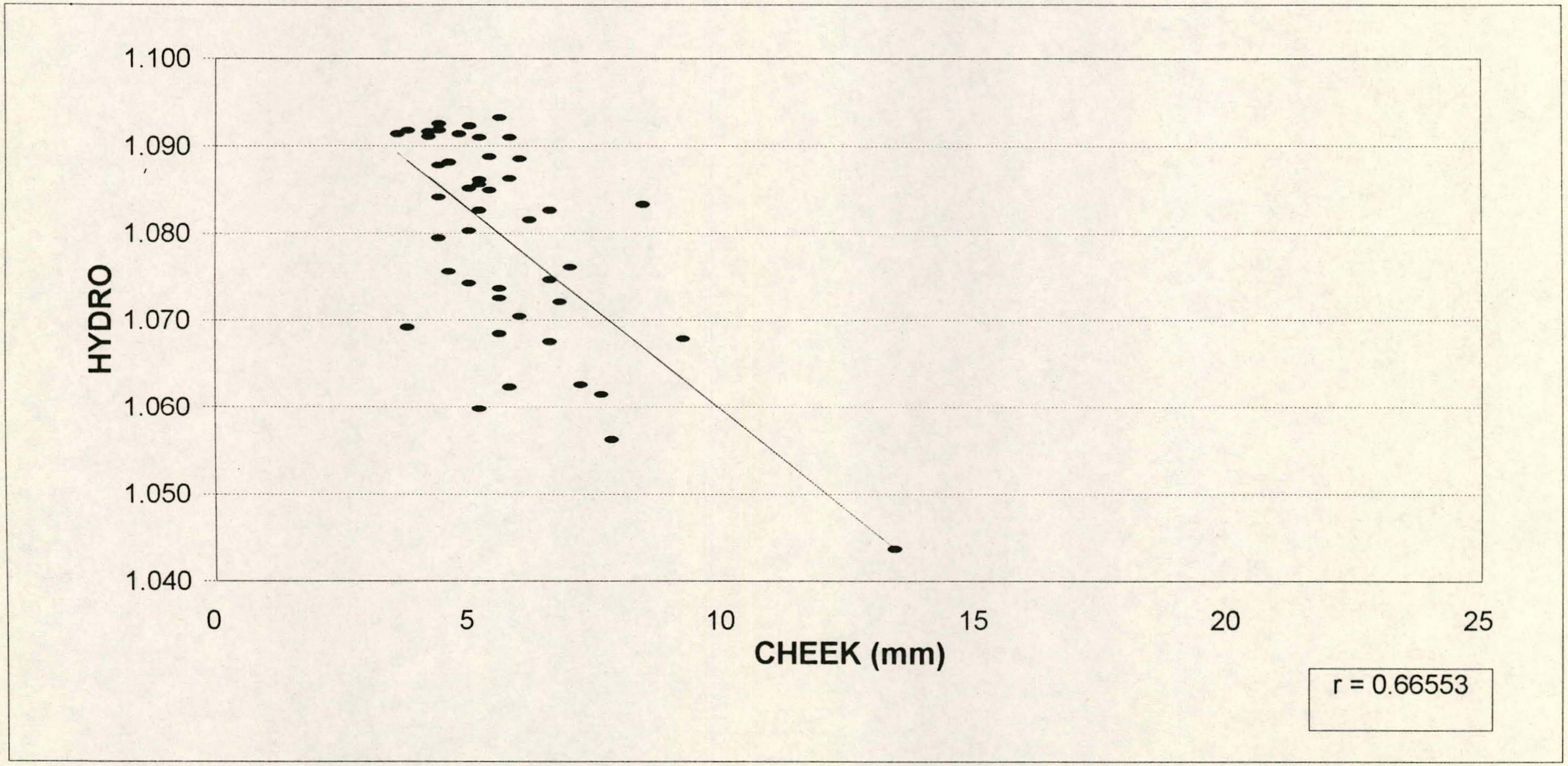

Figure 25n. **CORRELATION OF SKINFOLD (CALIPER) WITH HYDRODENSITOMETRY**

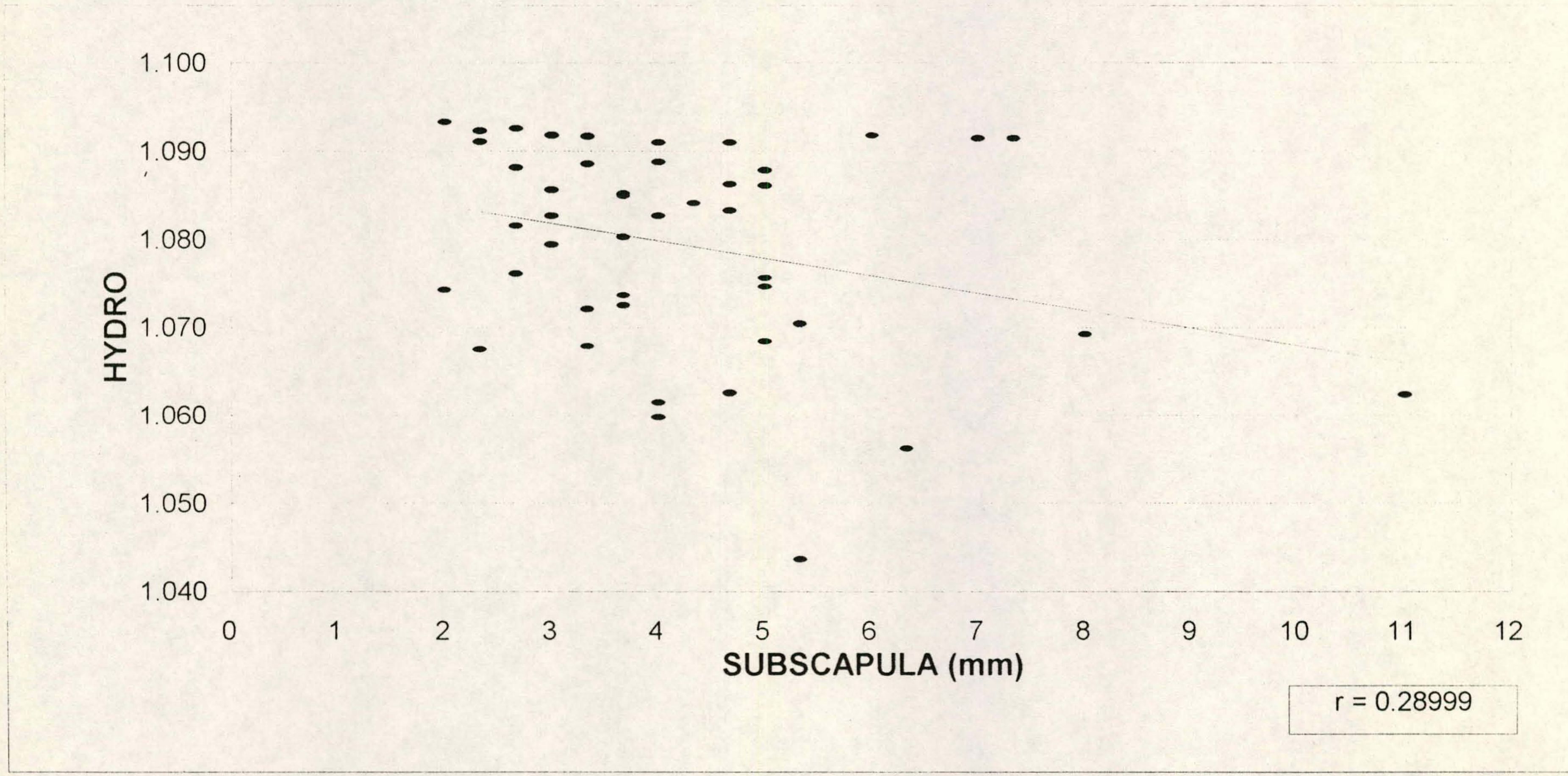

Figure 26a. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

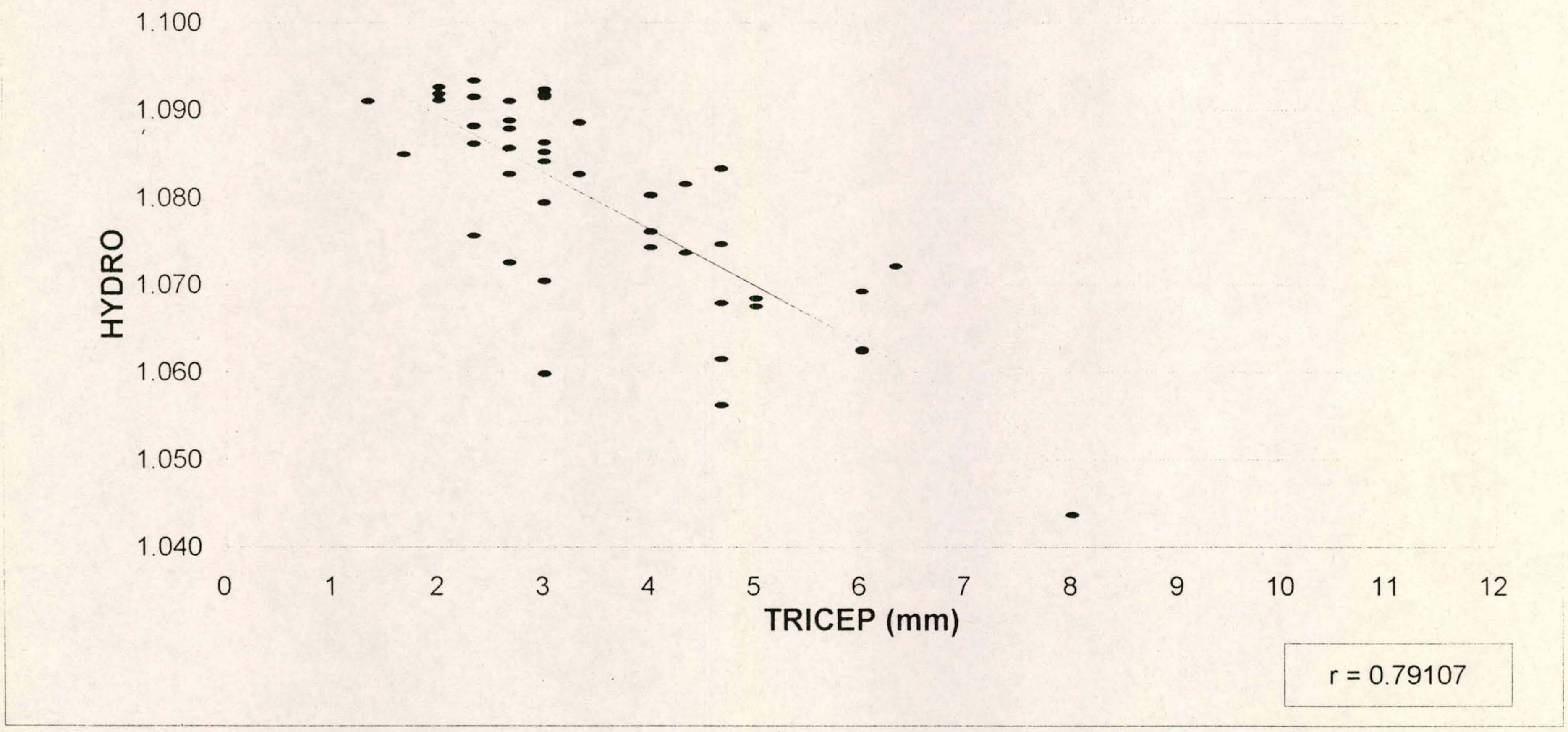

Figure 26b. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

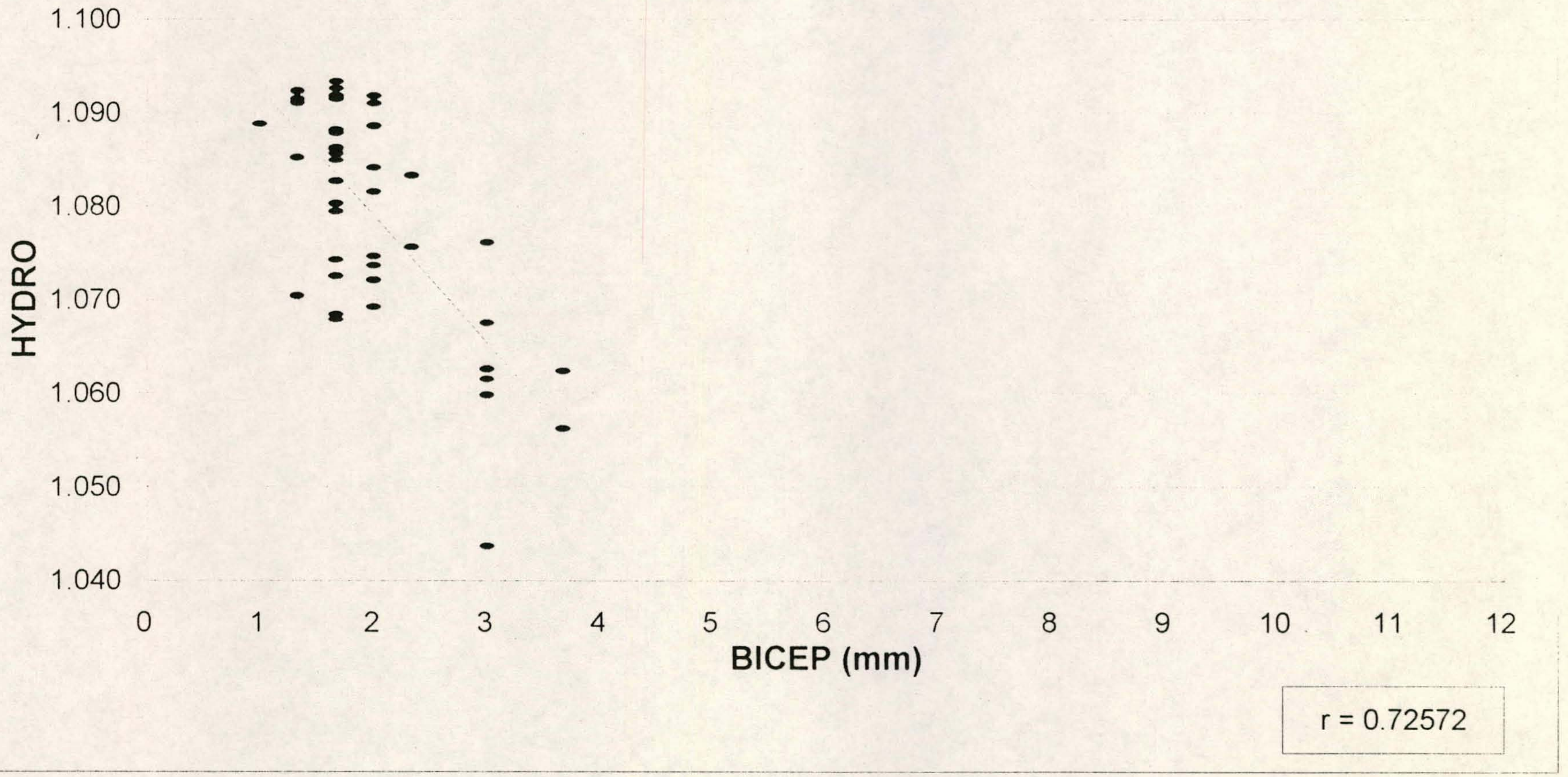

Figure 26c. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

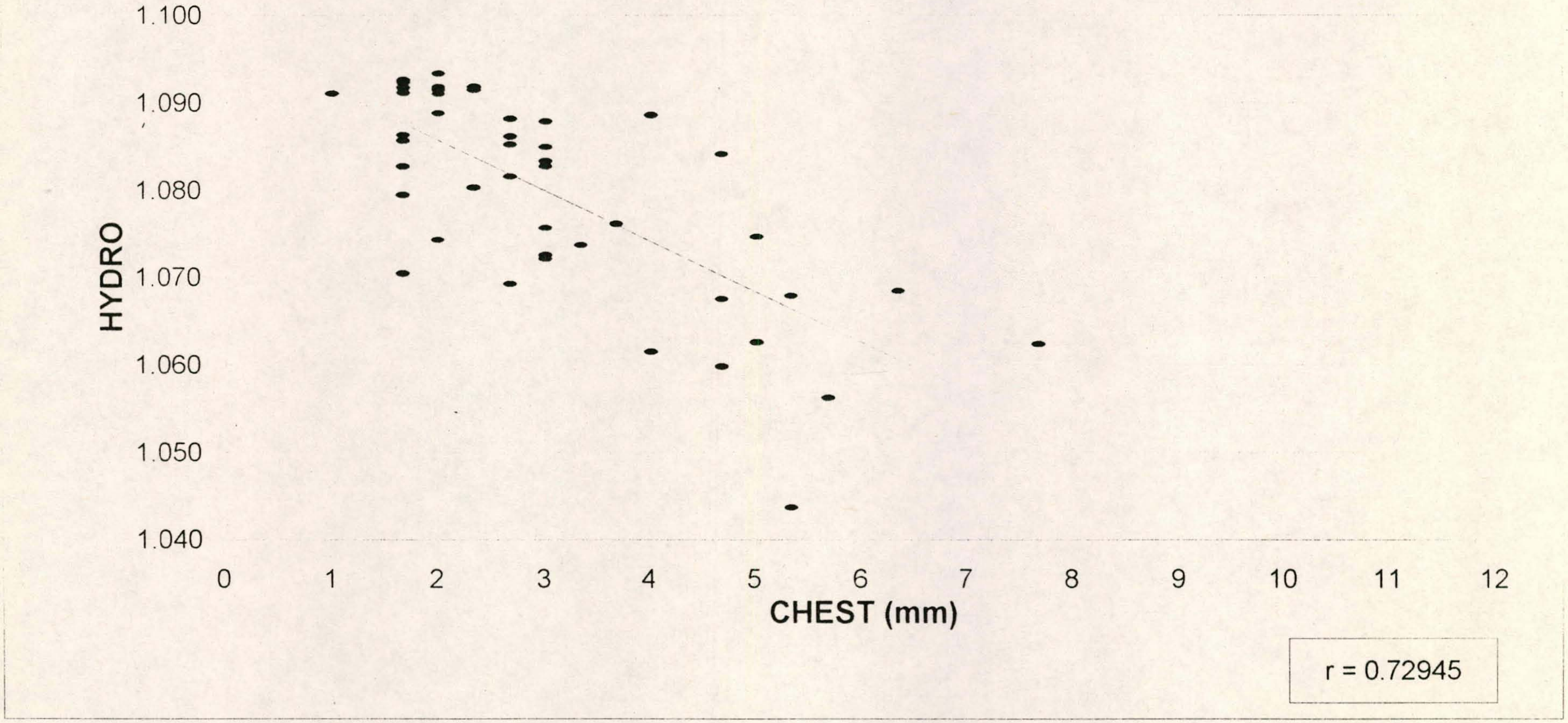

Figure 26d. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

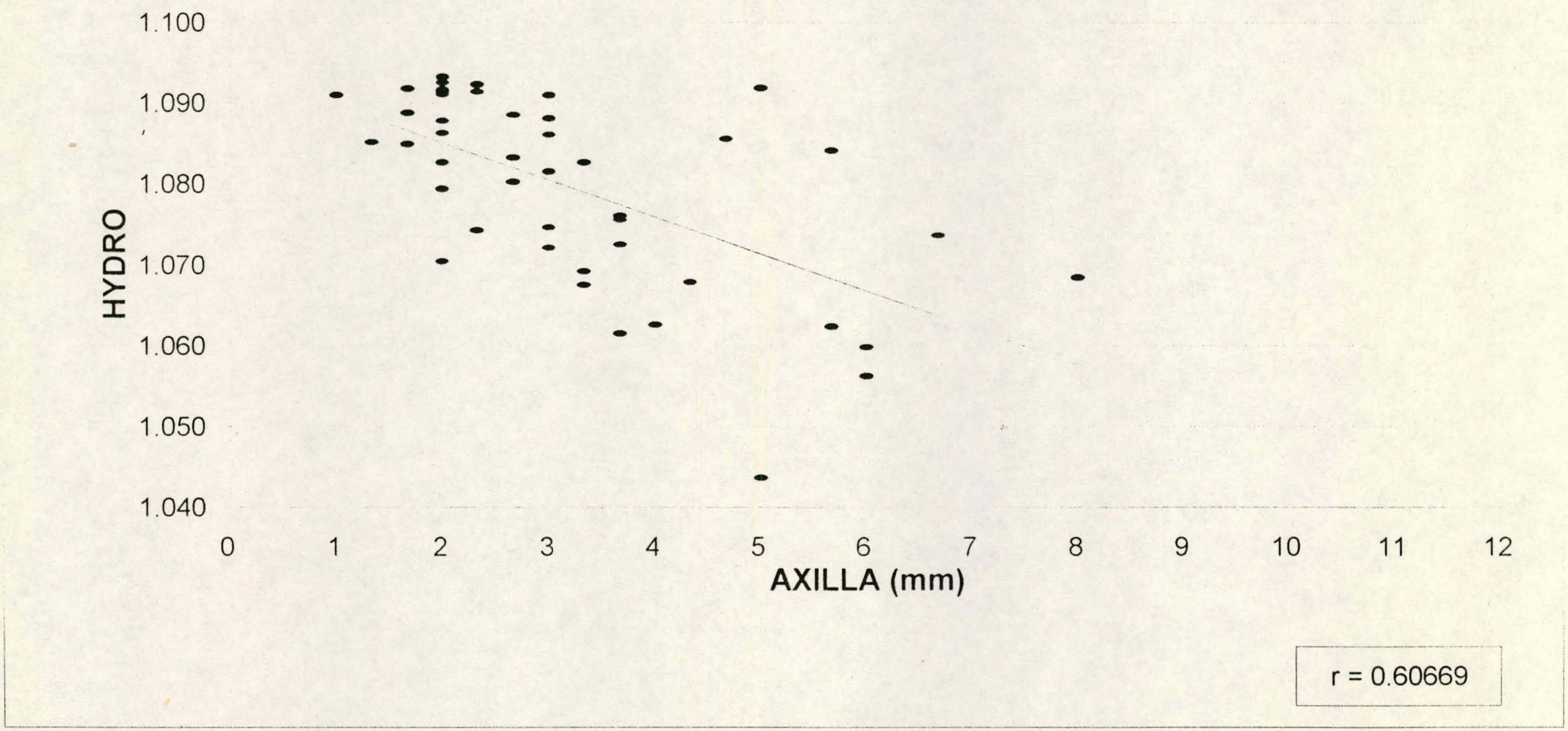

Figure 26e. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

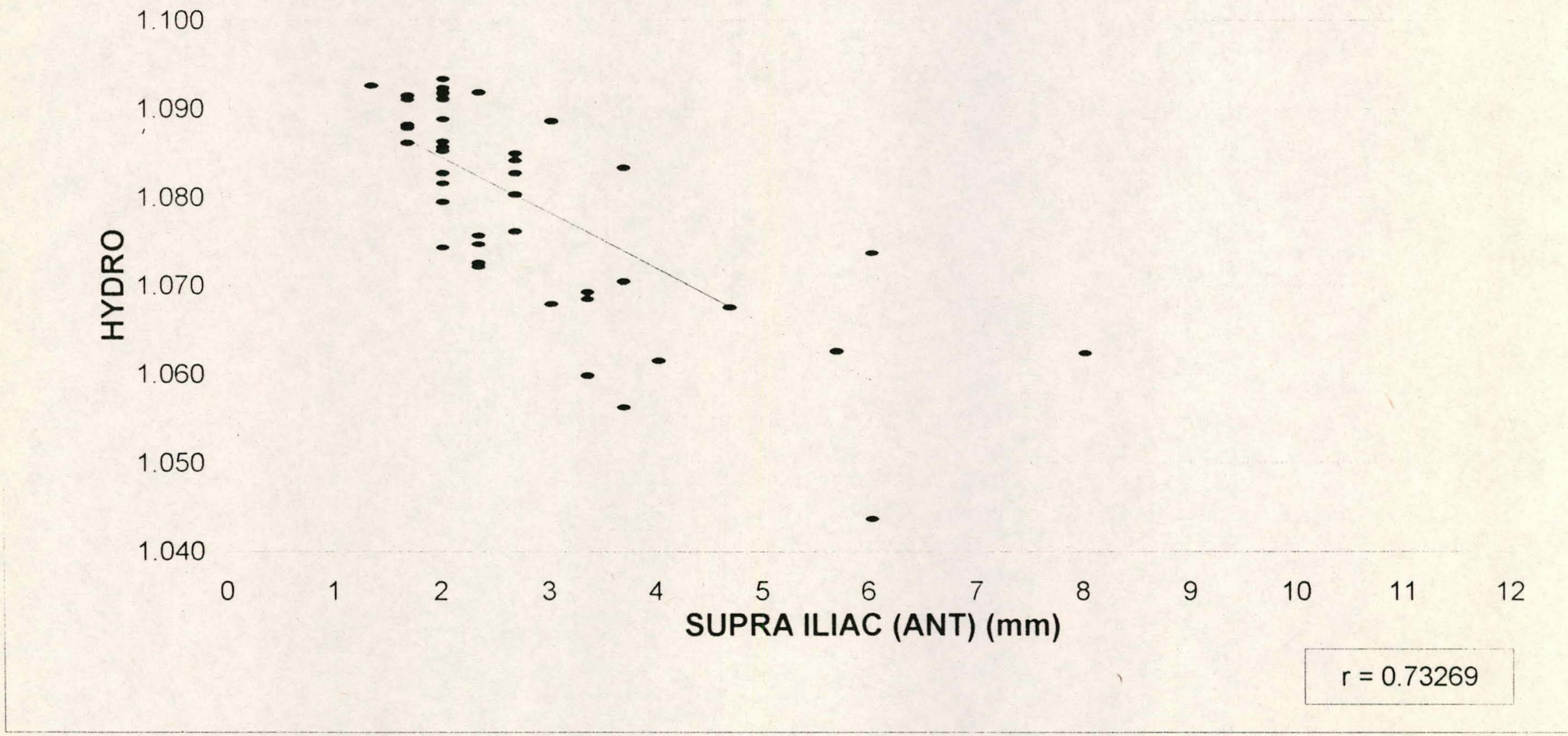

Figure 26f. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

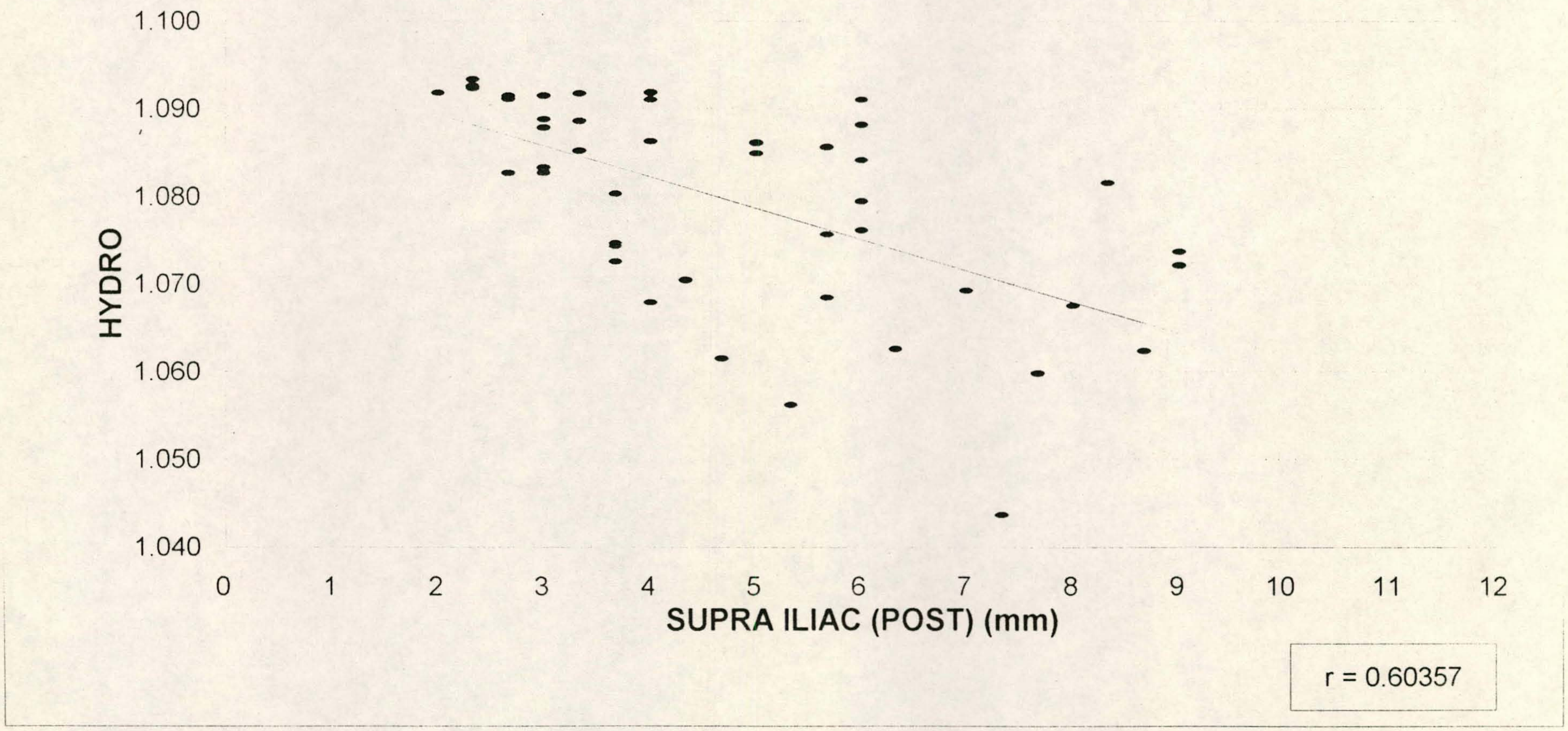

Figure 26g. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

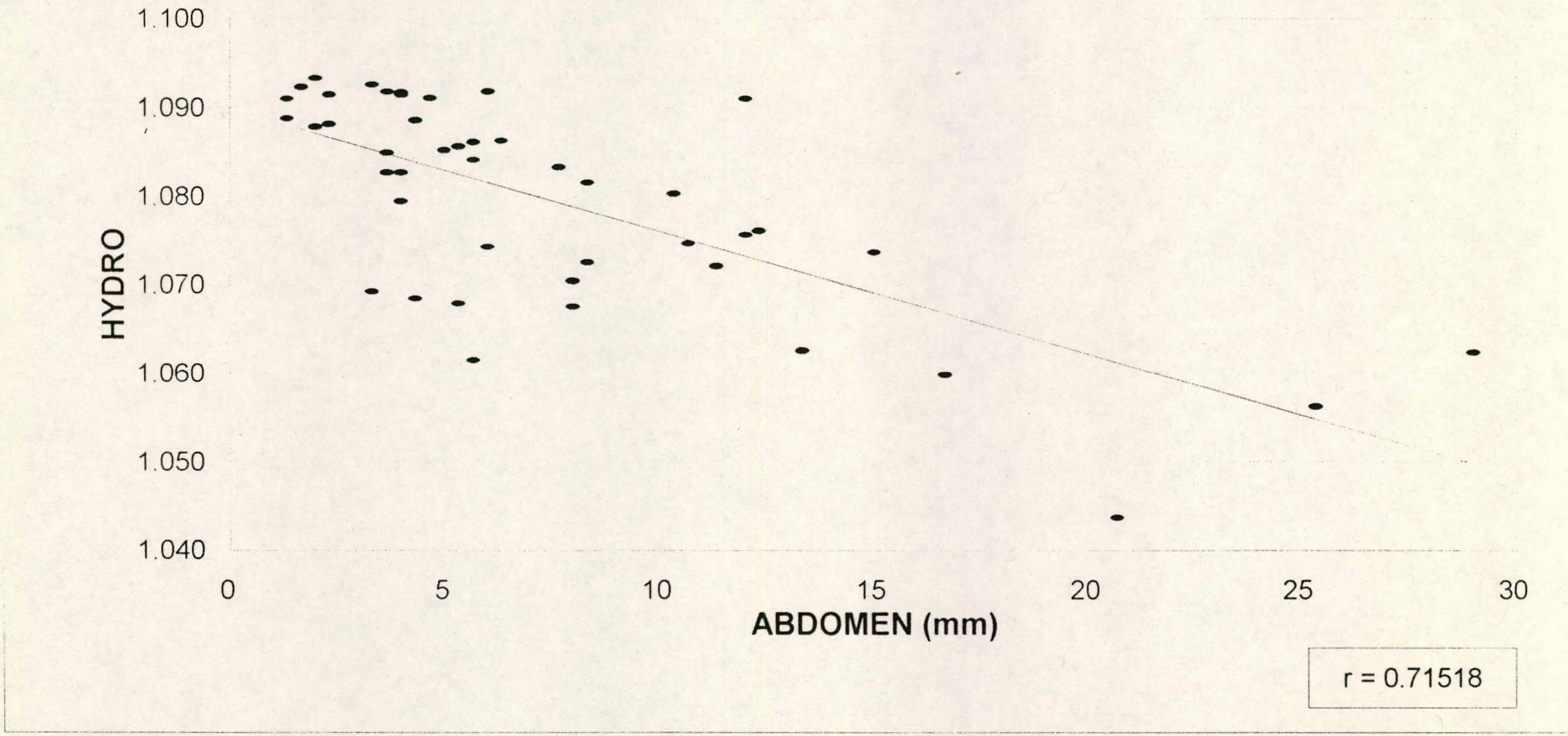

Figure 26h. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

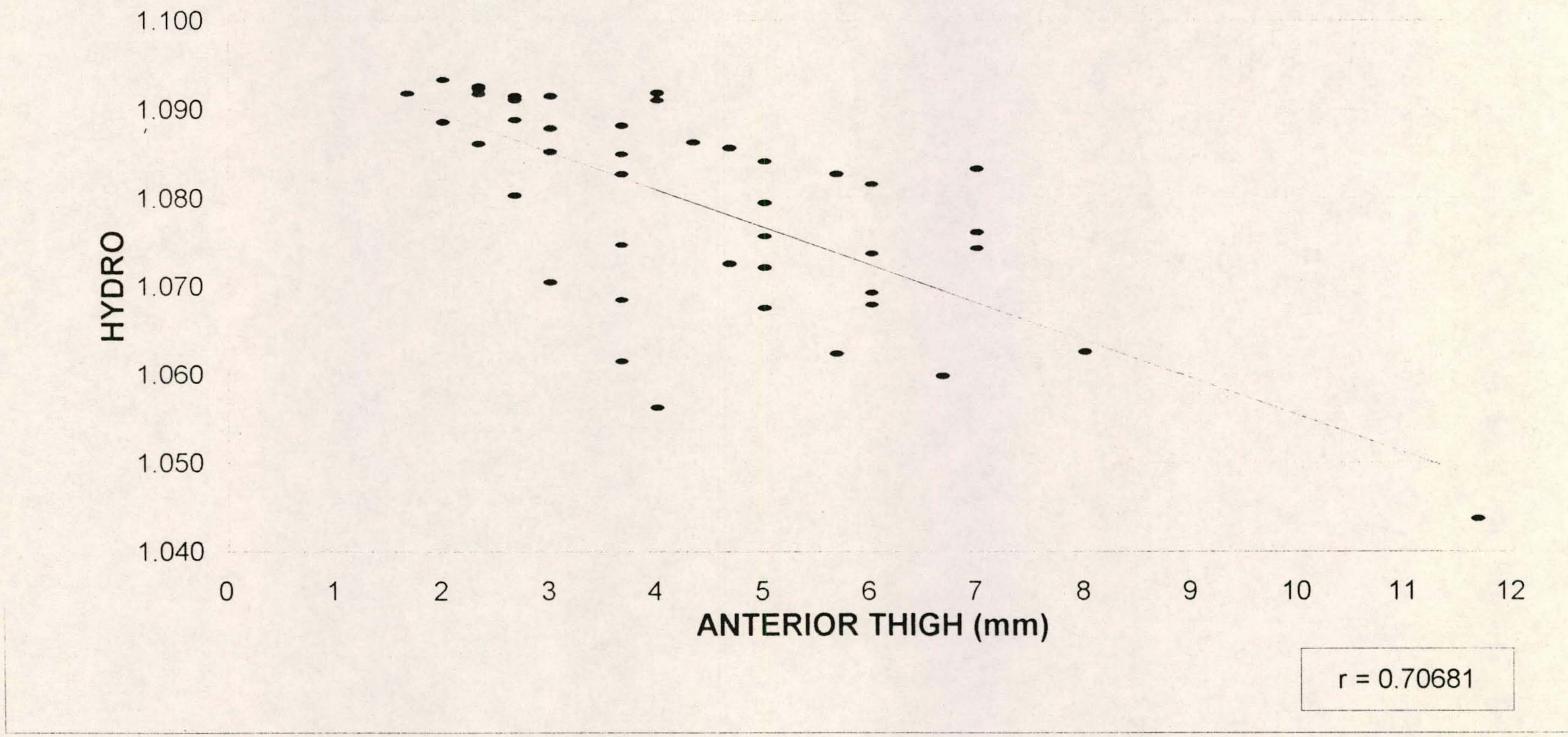

Figure 26i. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

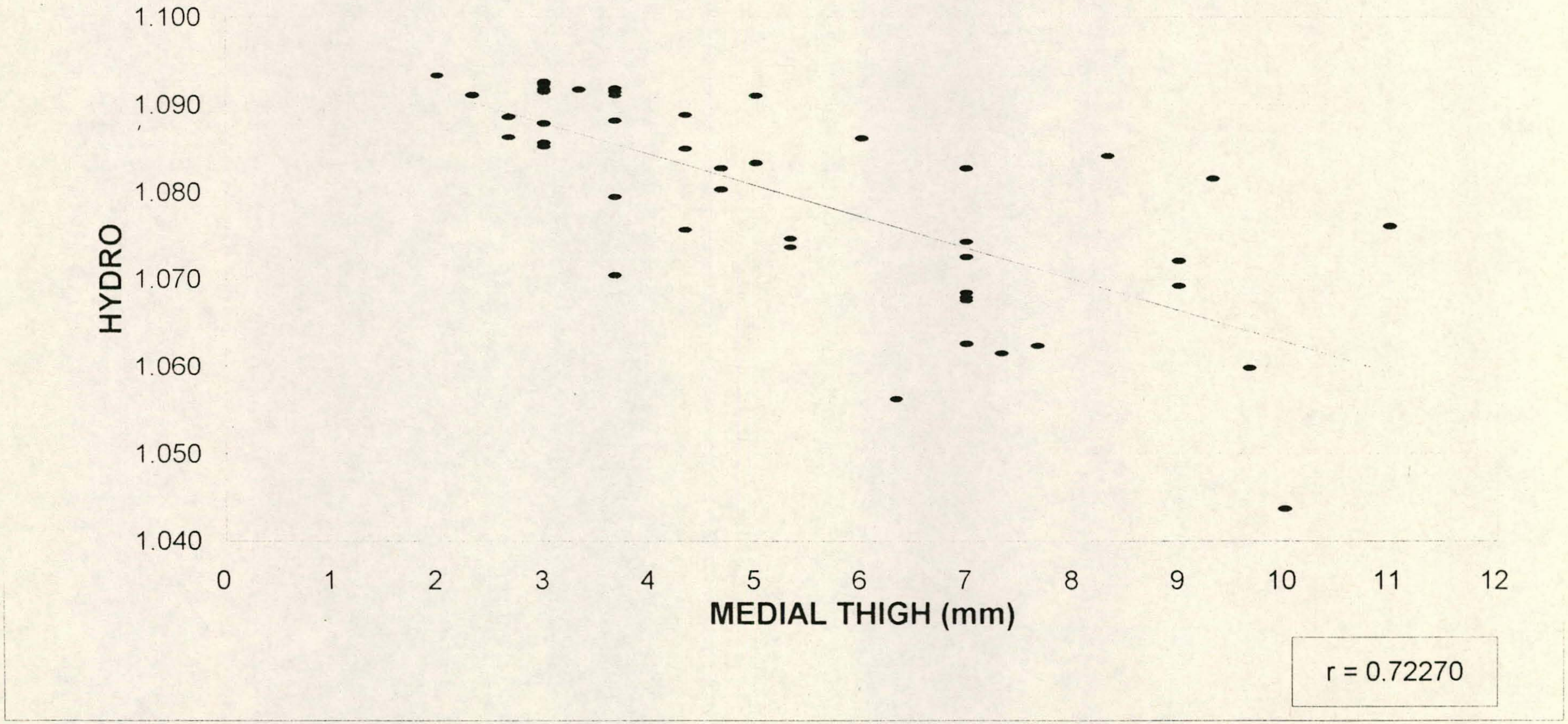

Figure 26j. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

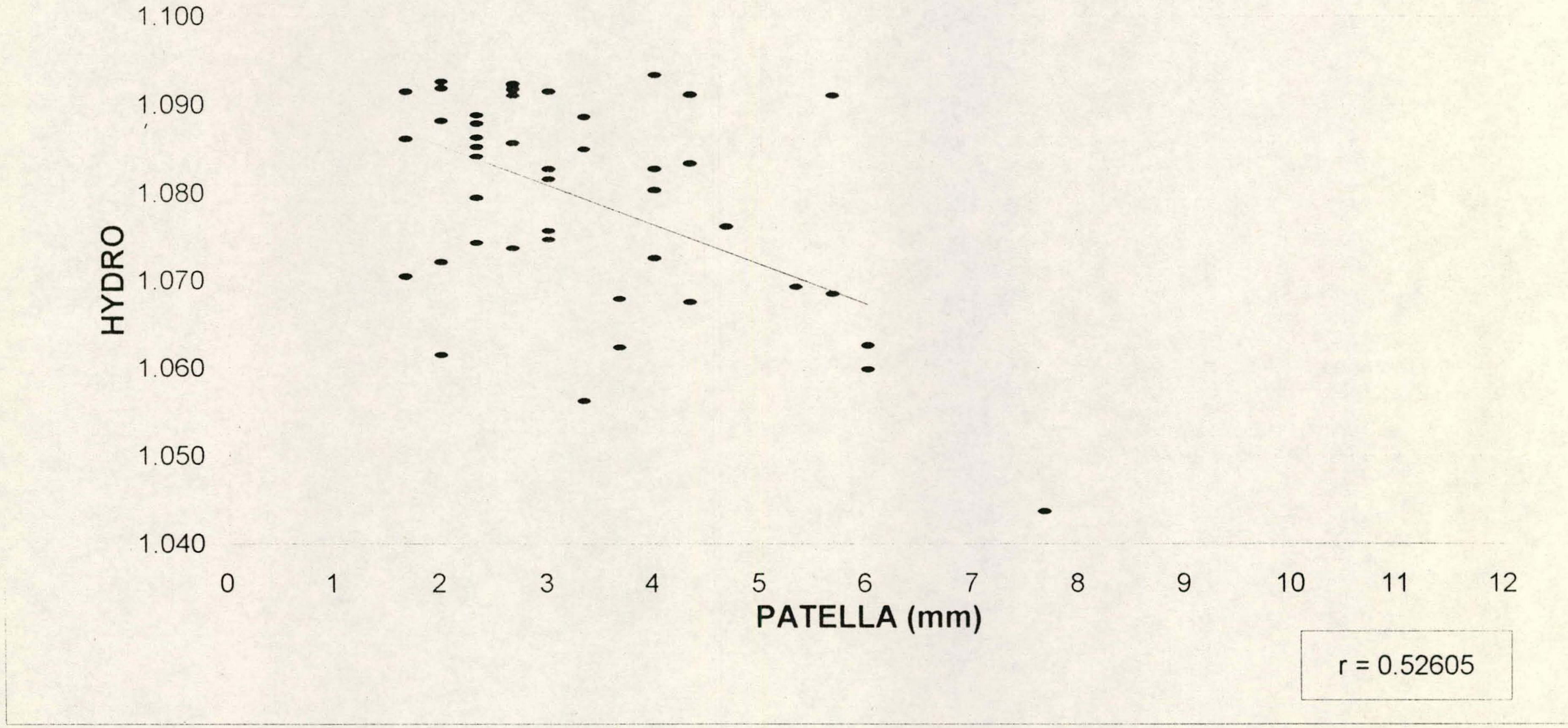

Figure 26k. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

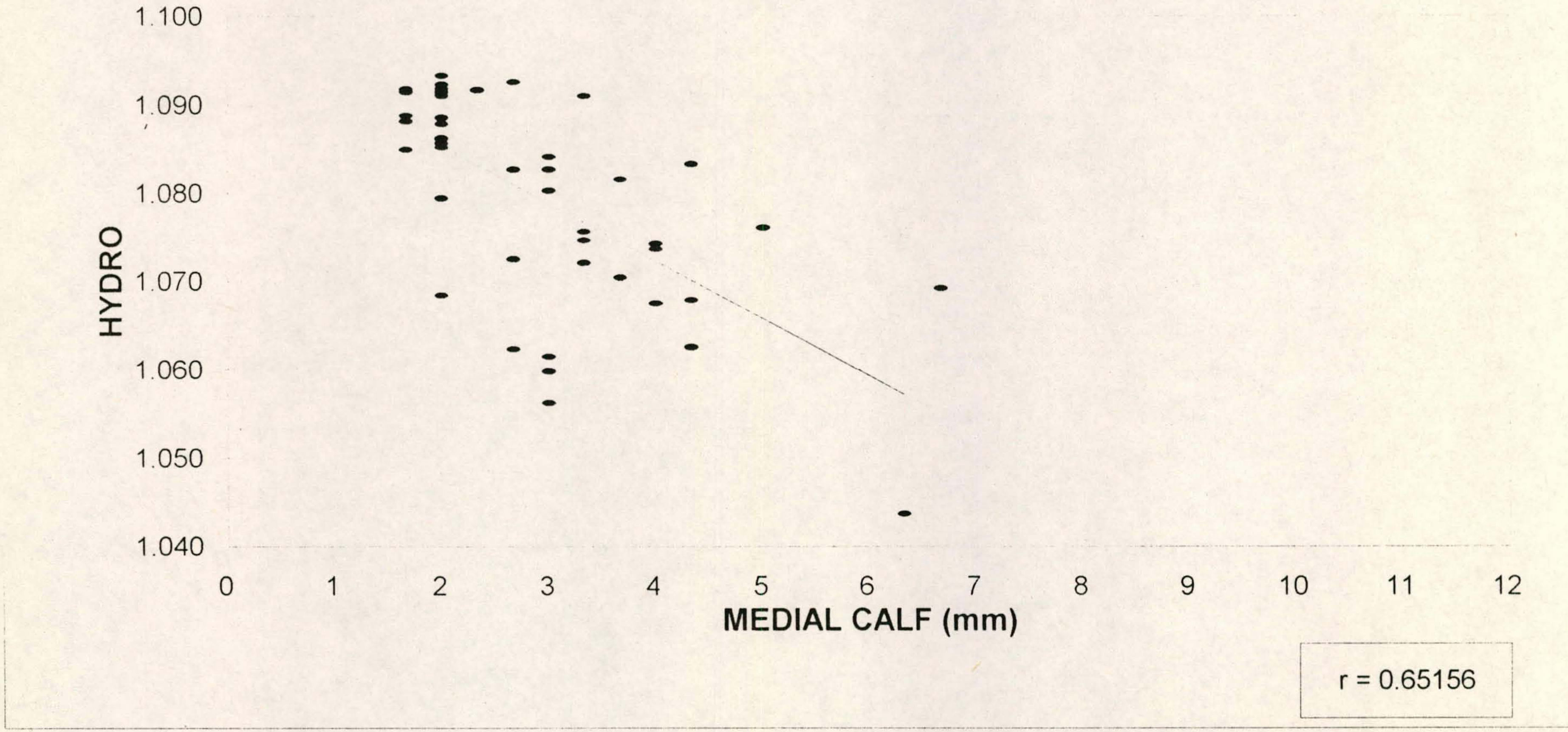

Figure 26l. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

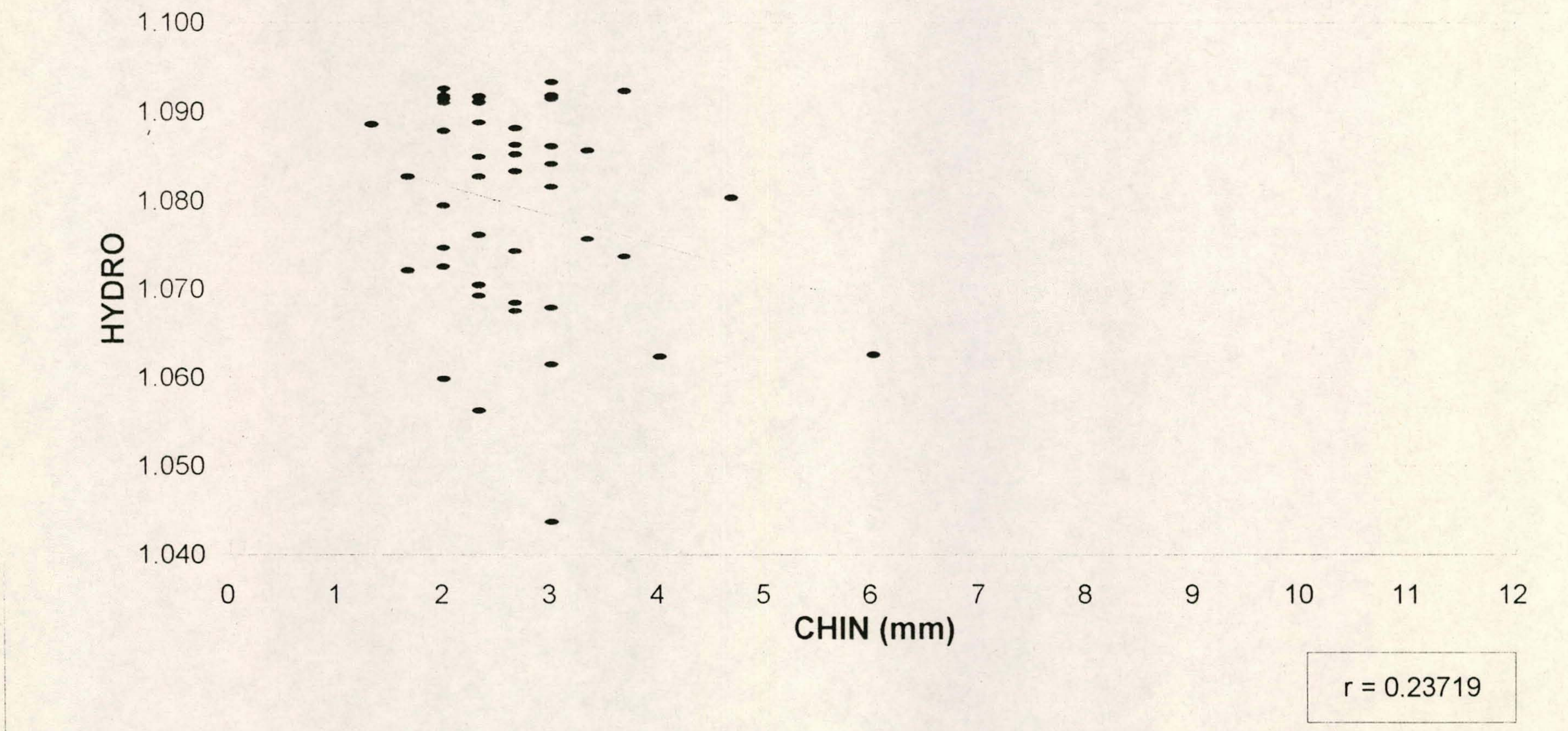

Figure 26m. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

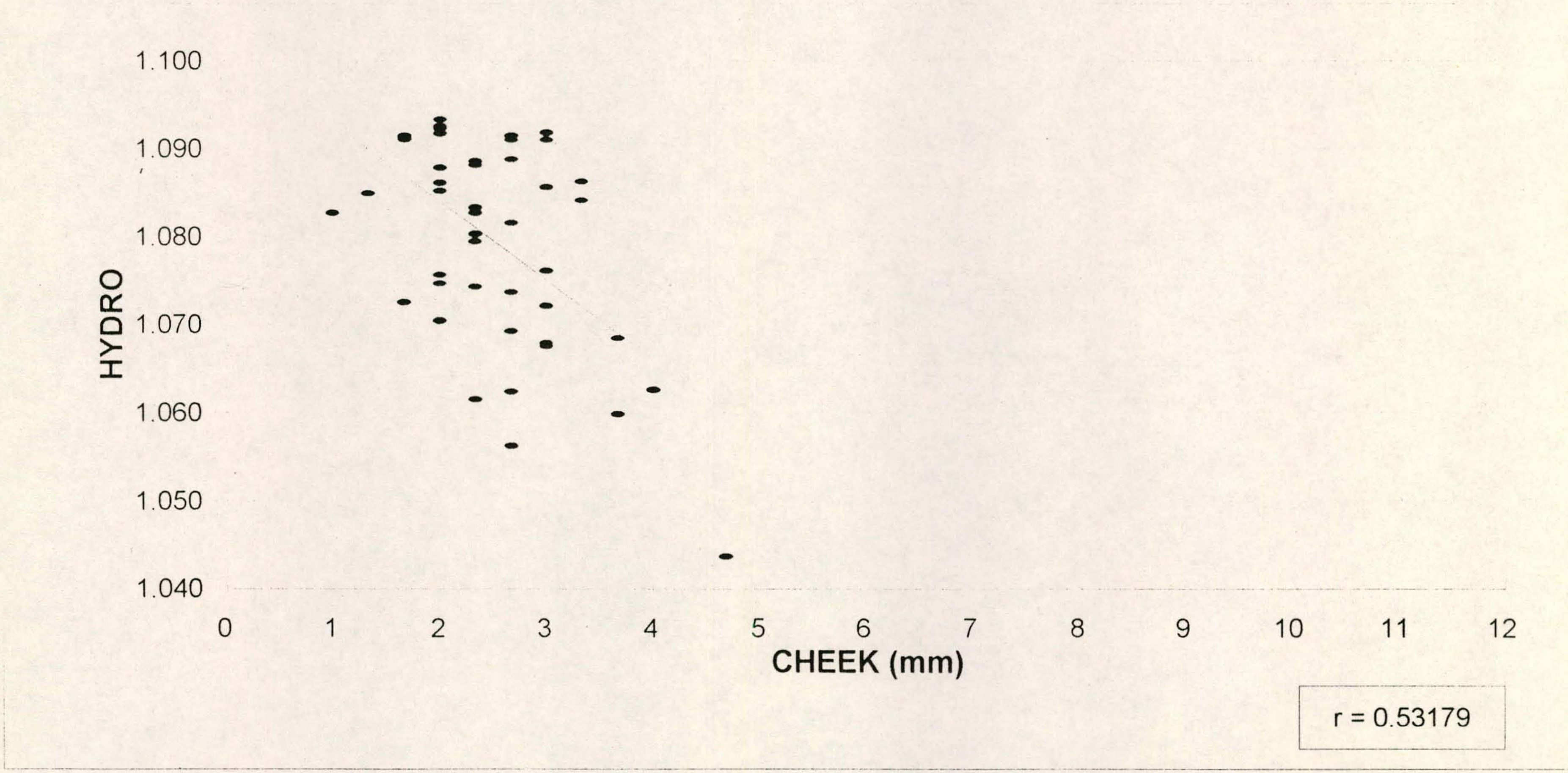

Figure 26n. **CORRELATION OF SONAR (FAT) WITH HYDRODENSITOMETRY**

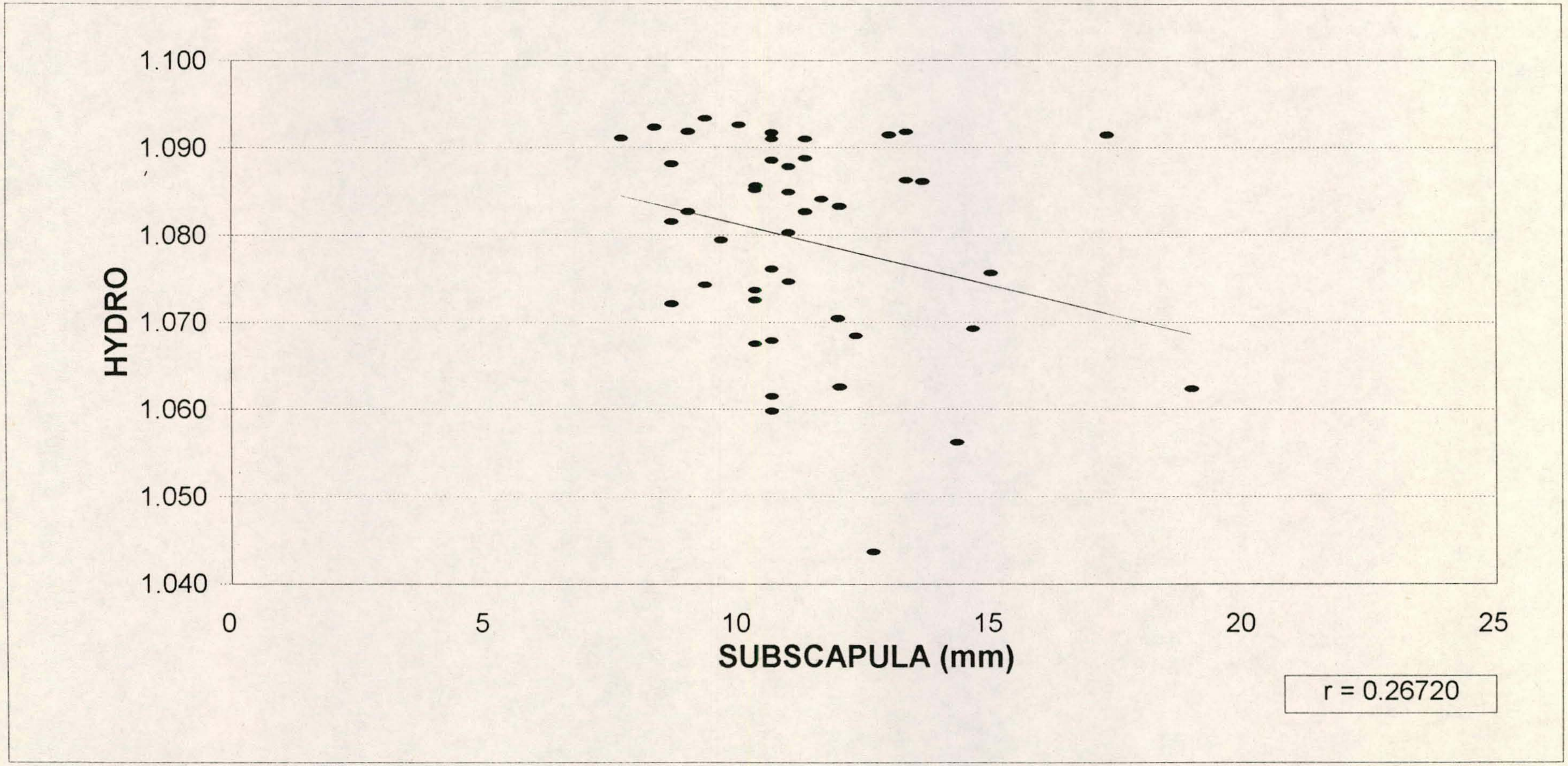

Figure 27a. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

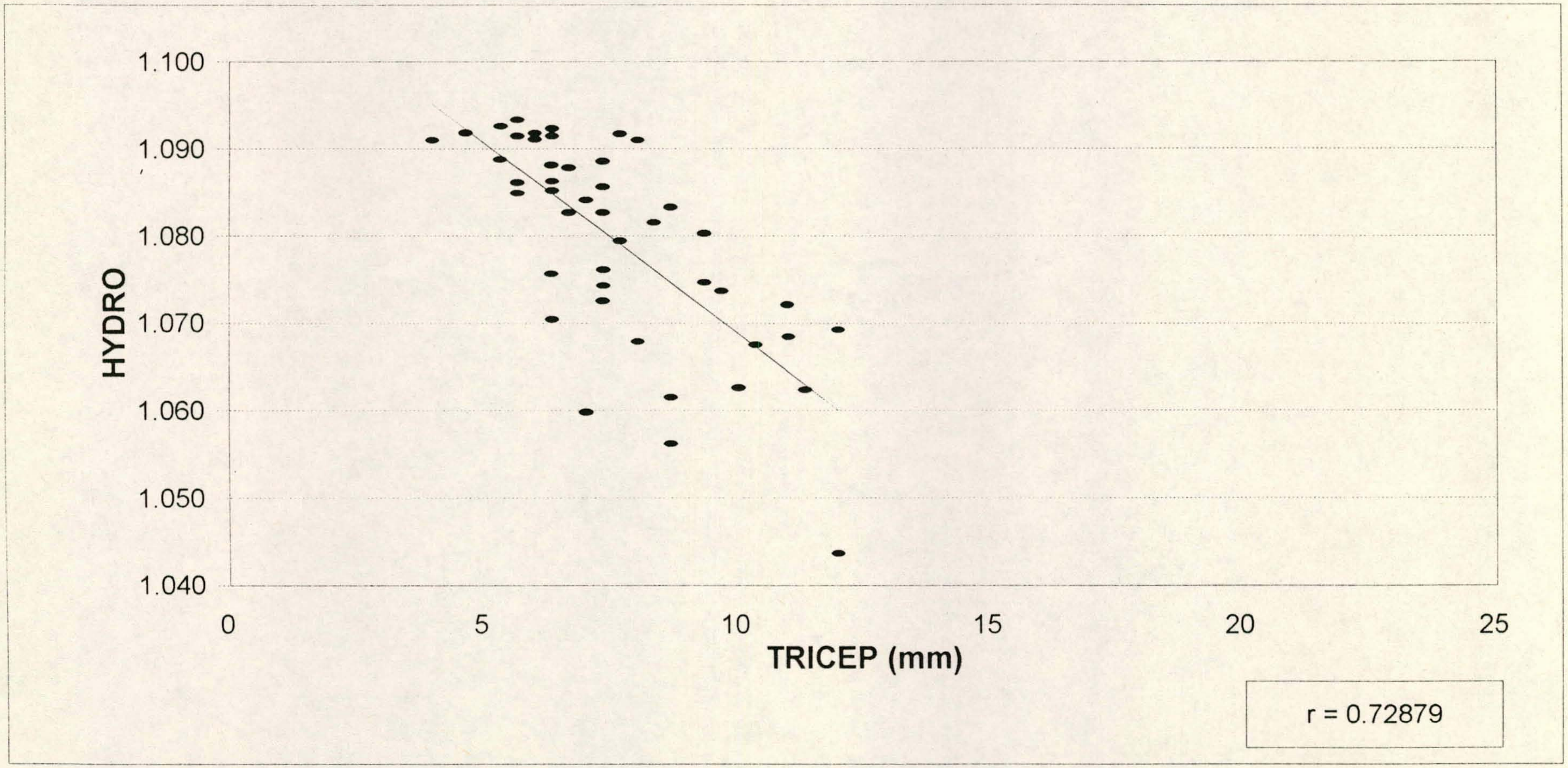

Figure 27b. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

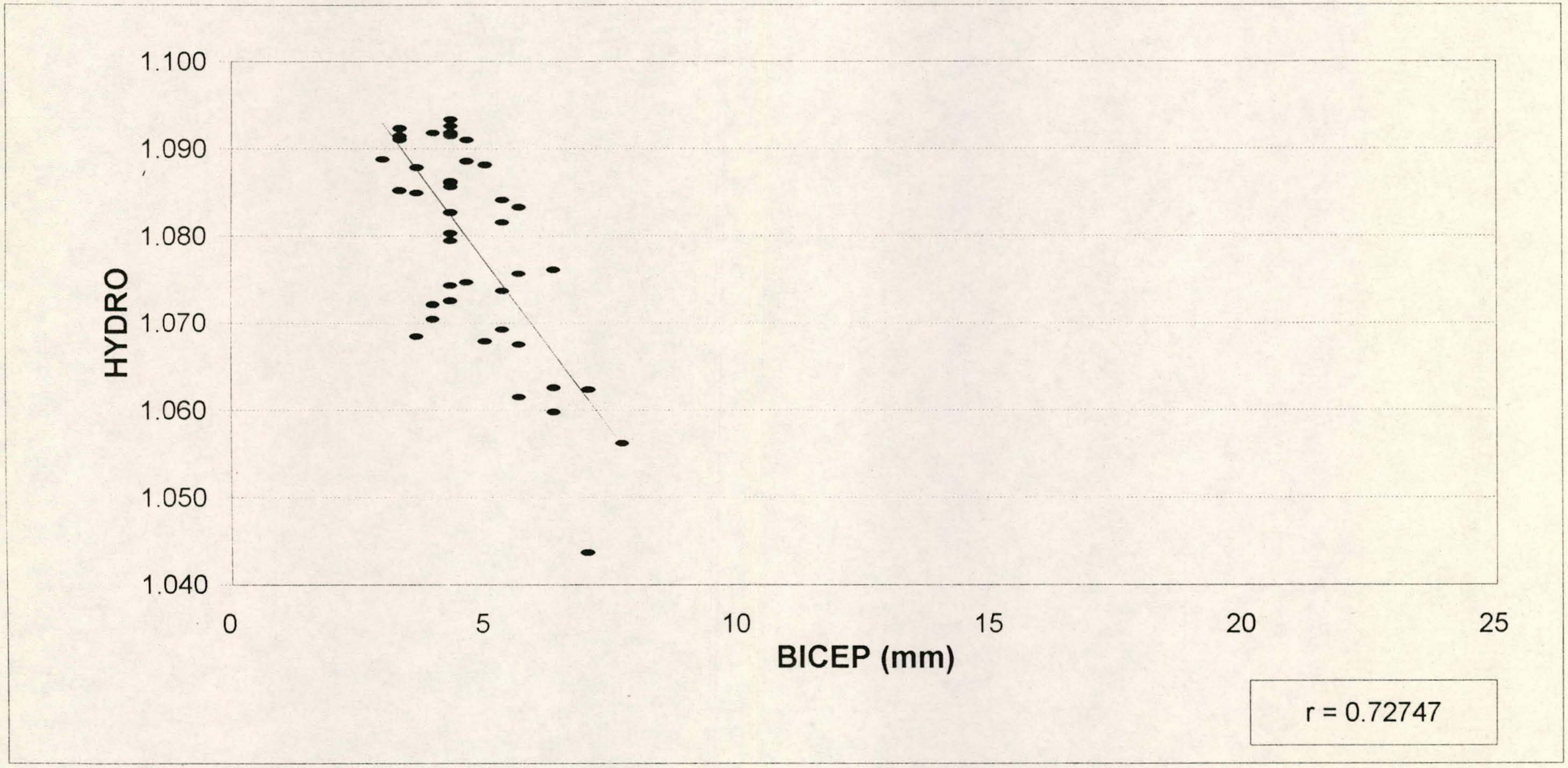

Figure 27c. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

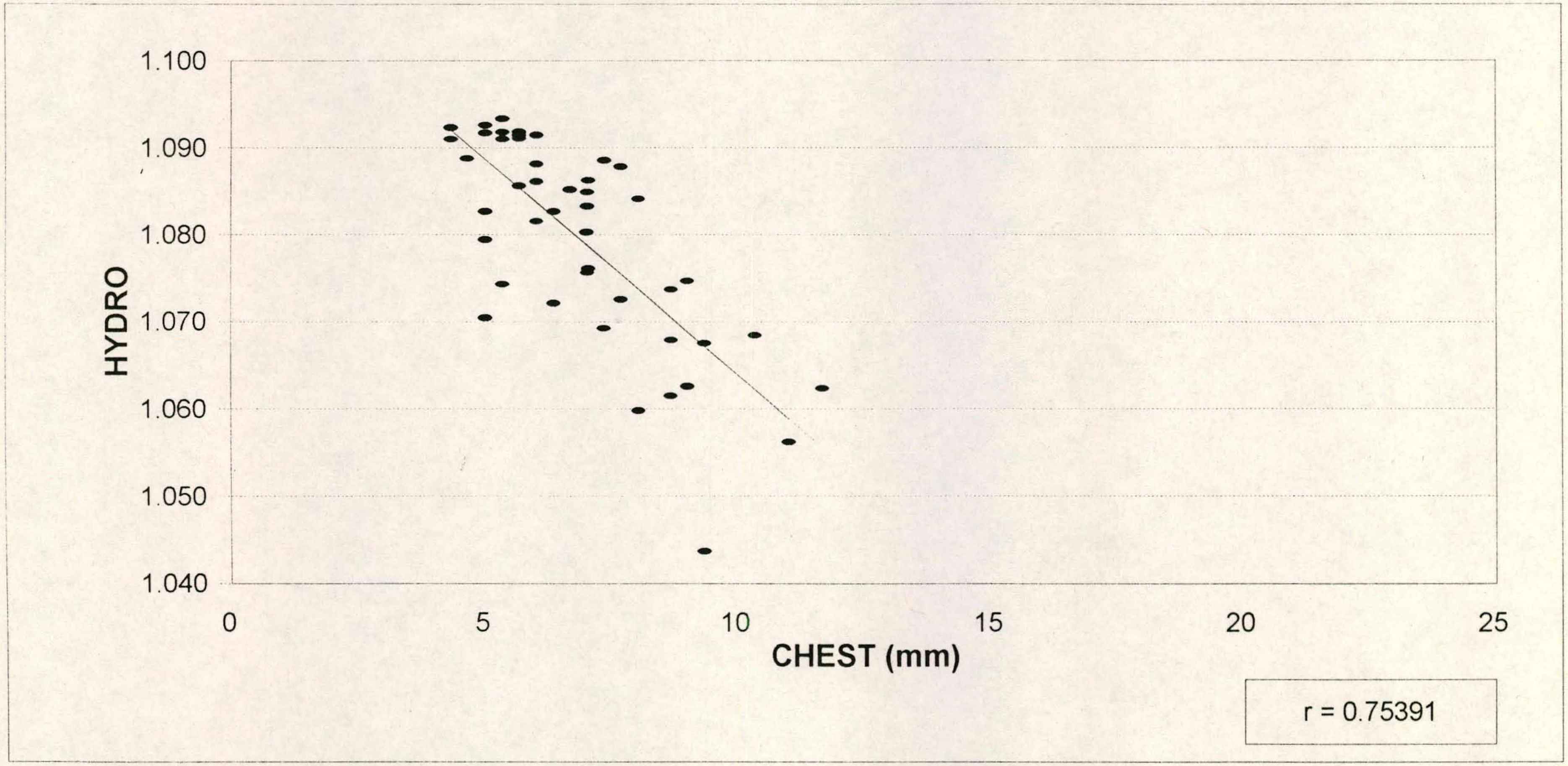

Figure 27d. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

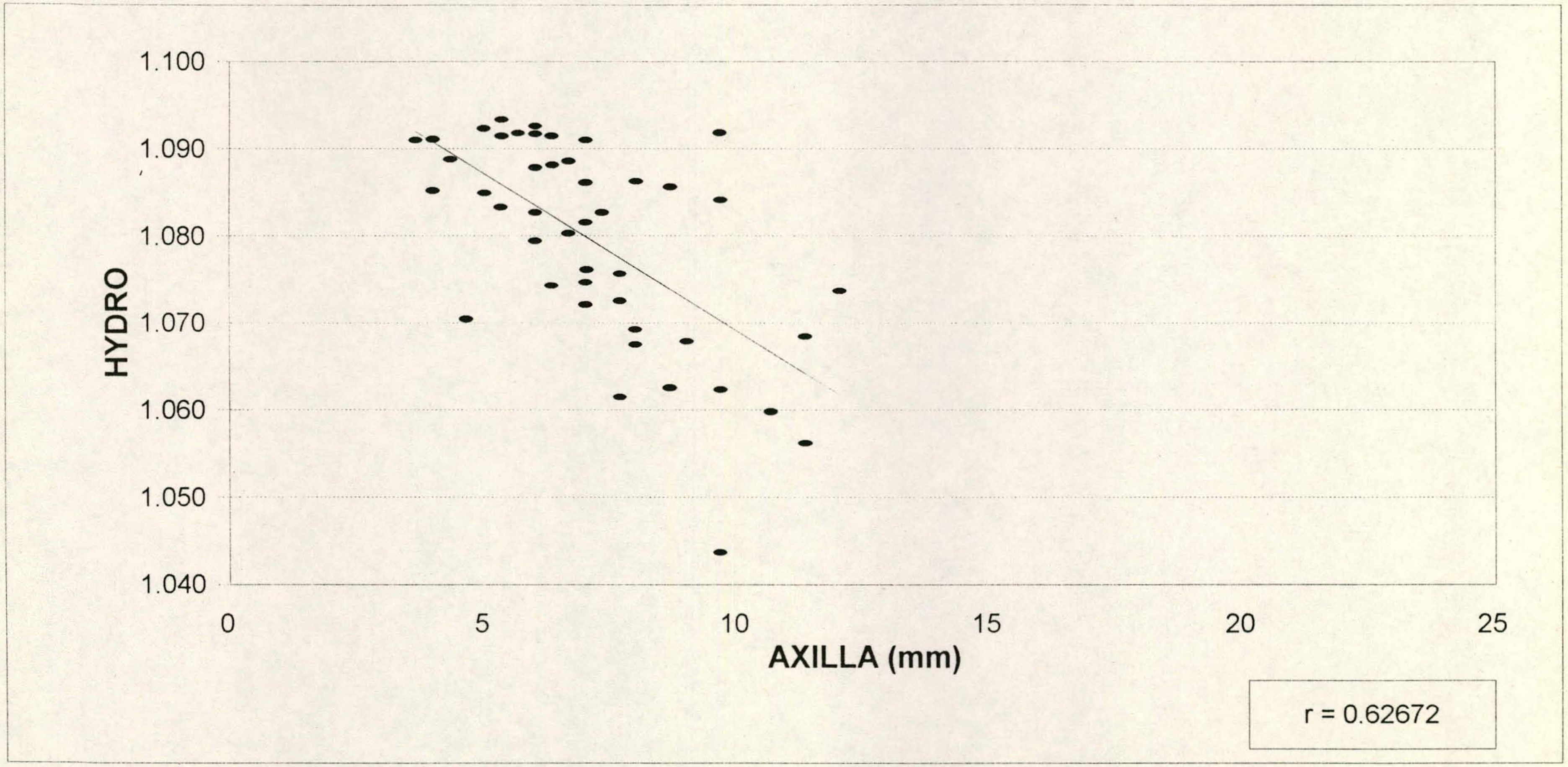

Figure 27e. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

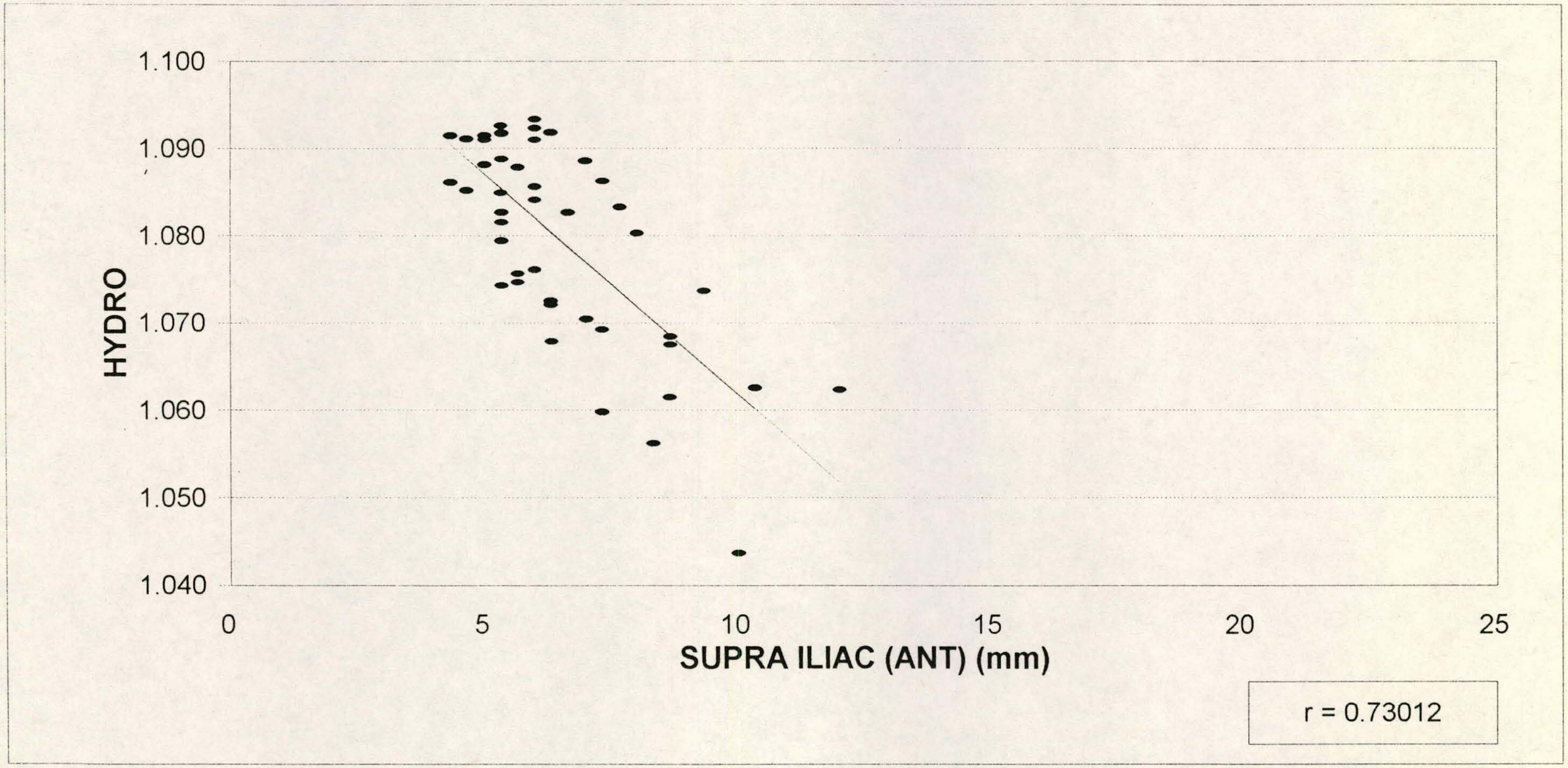

Figure 27f. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

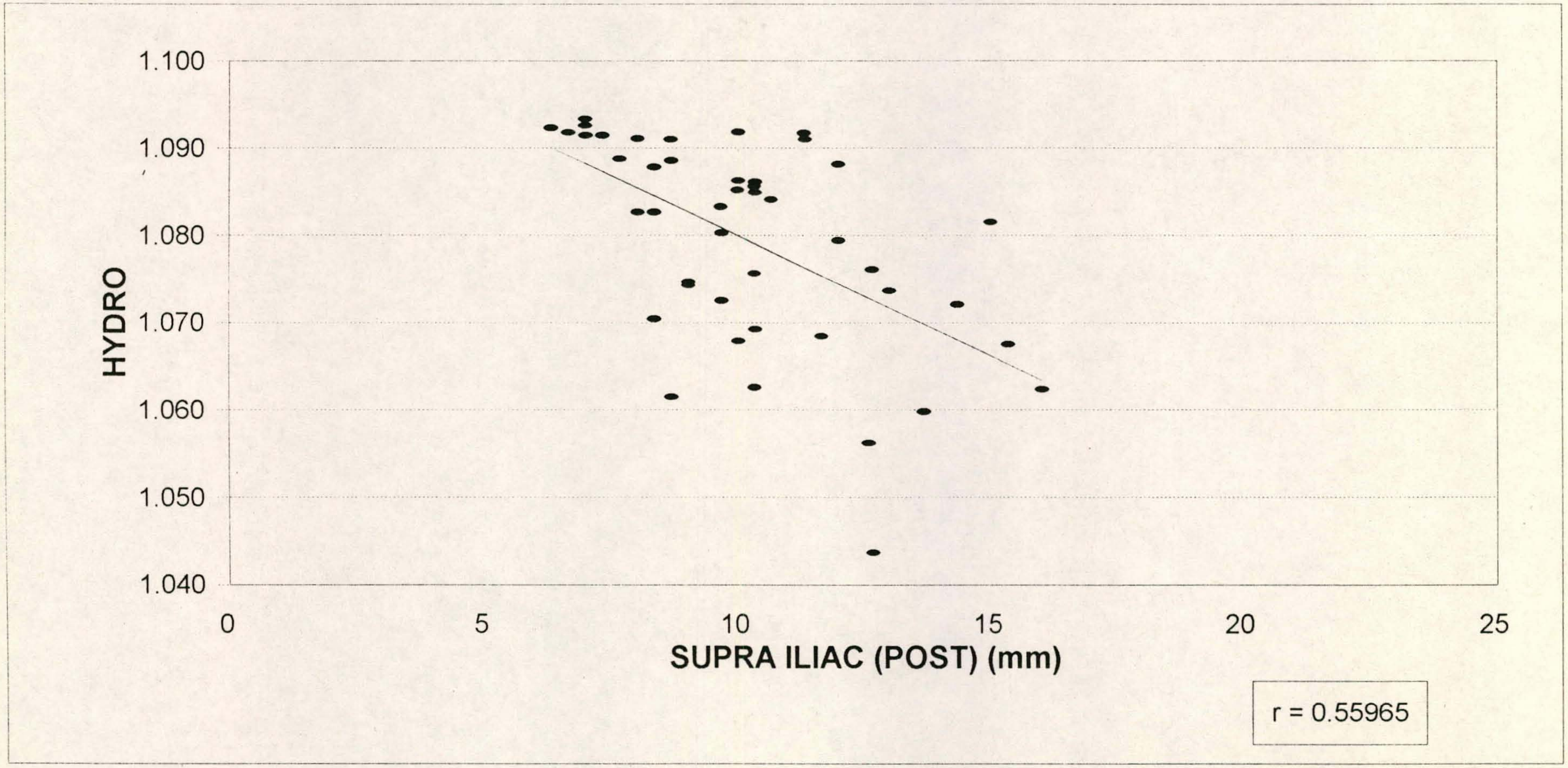

Figure 27g. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

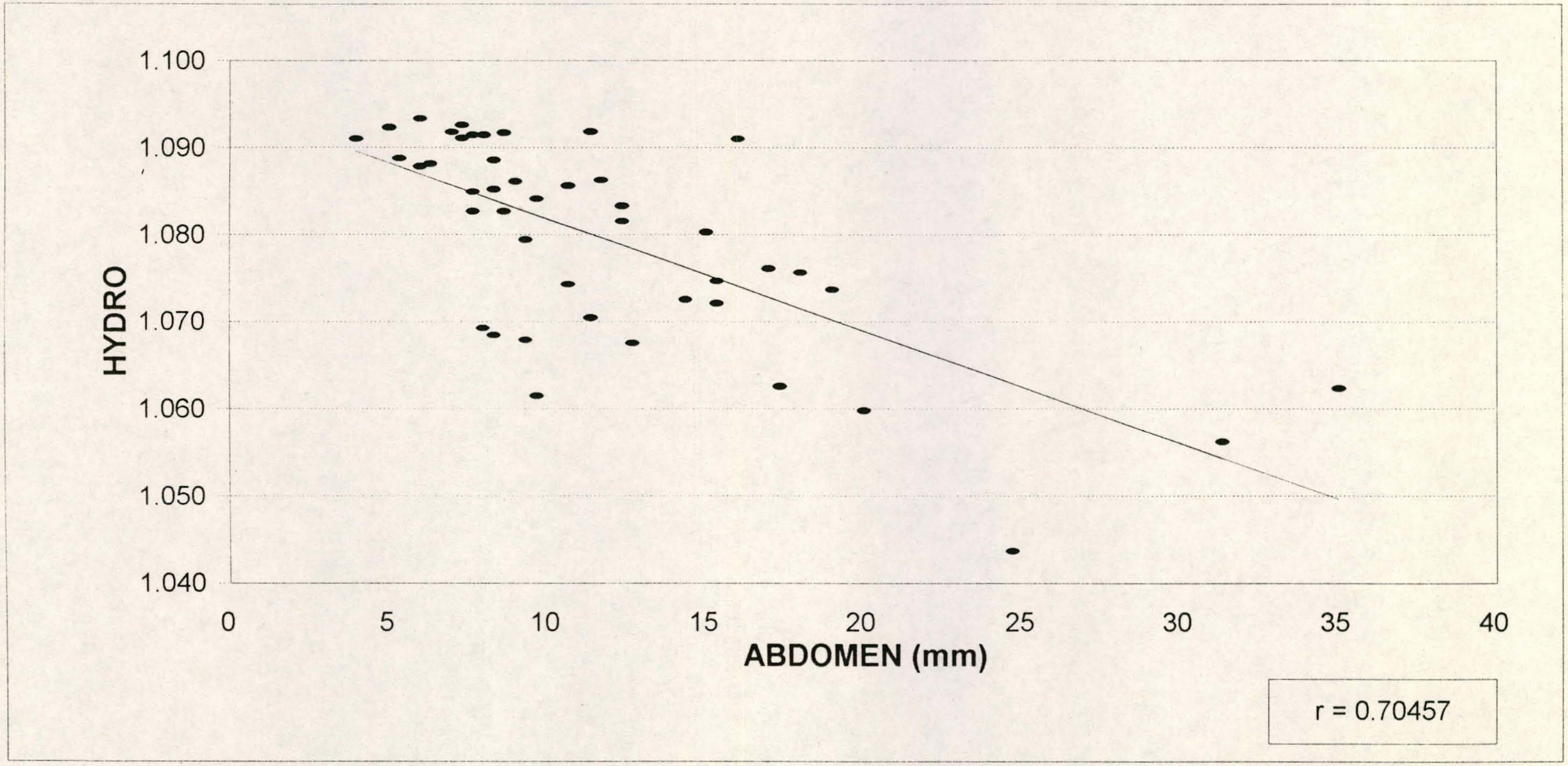

Figure 27h. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

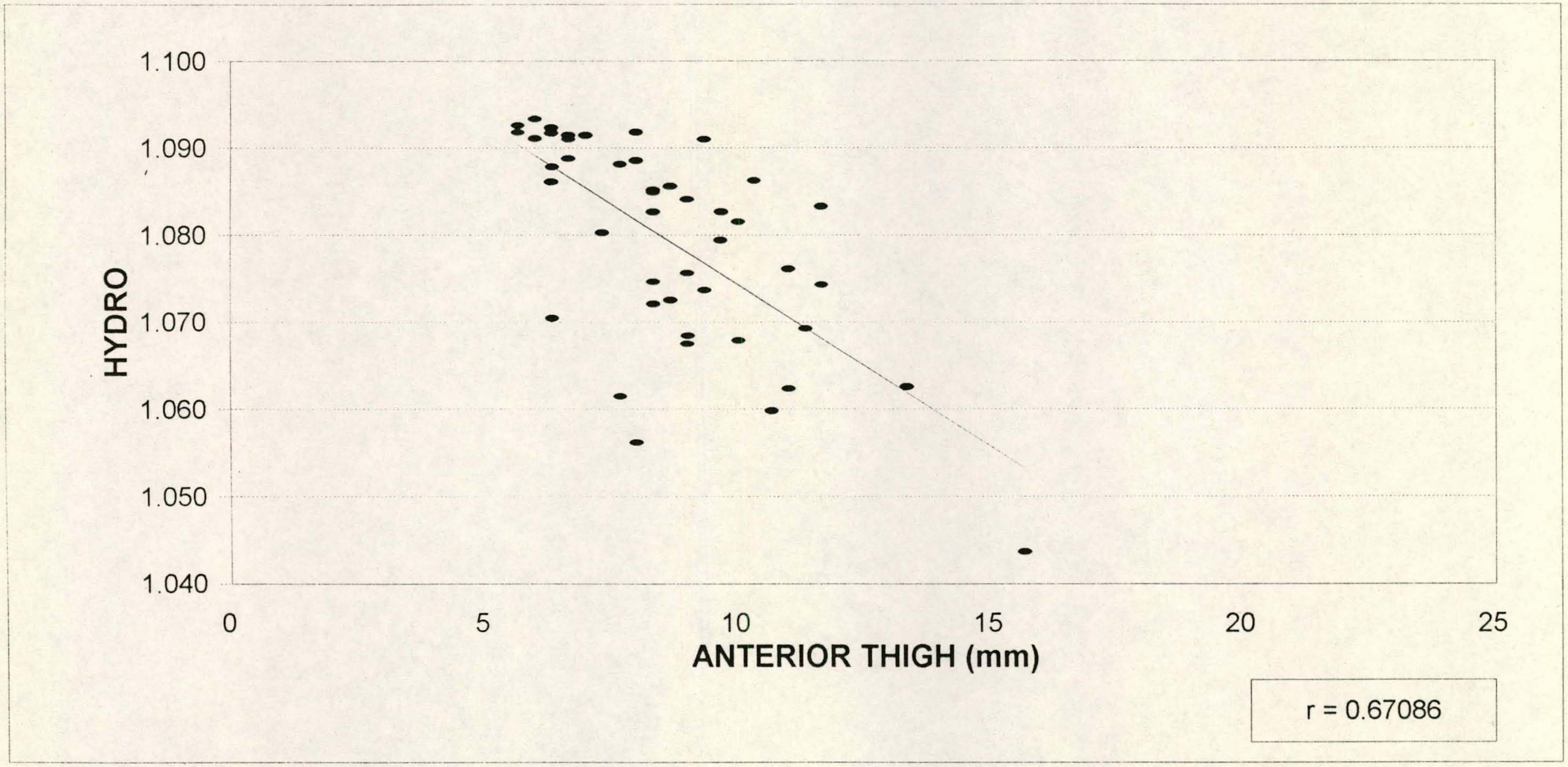

Figure 27i. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

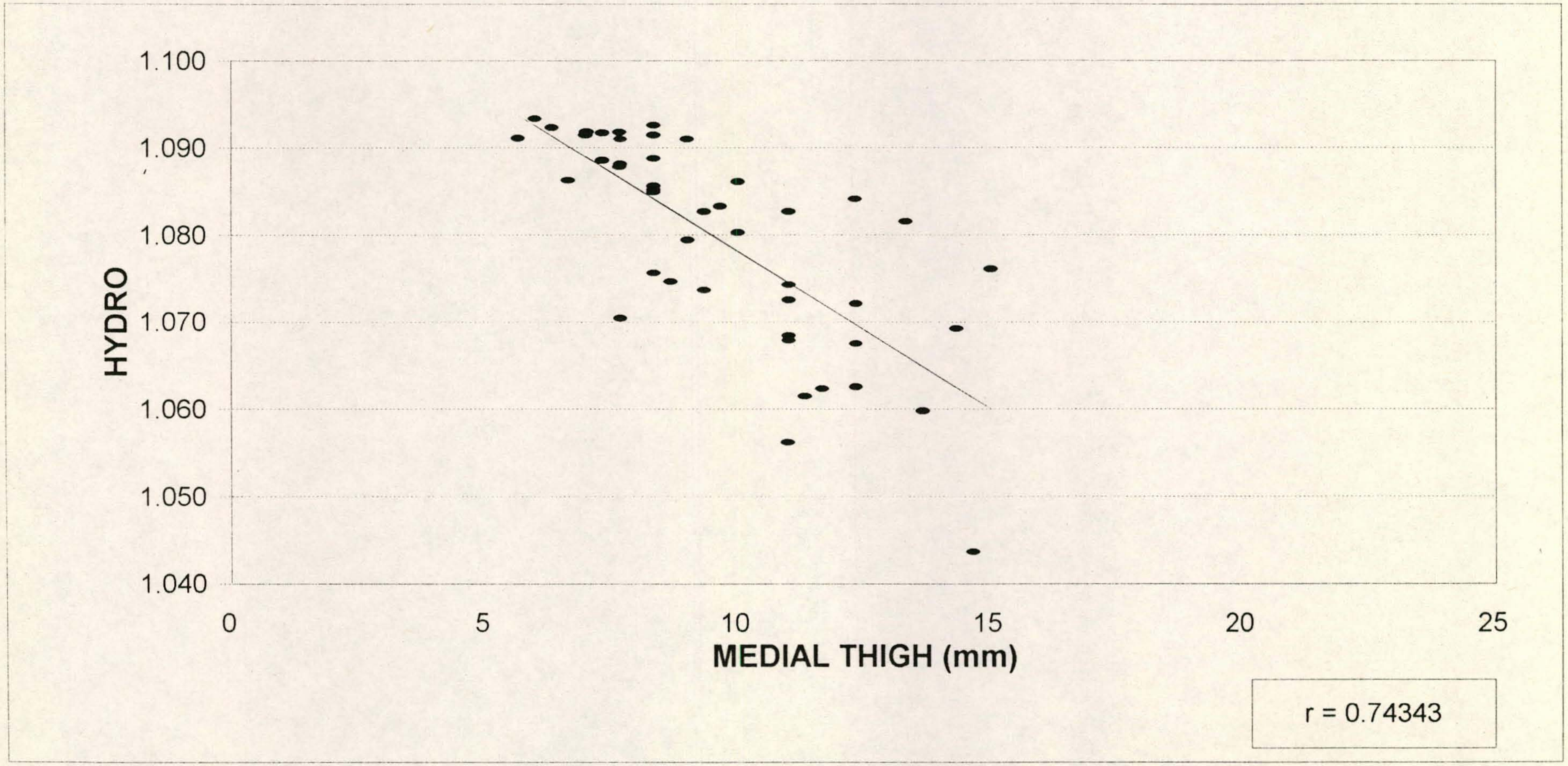

Figure 27j. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

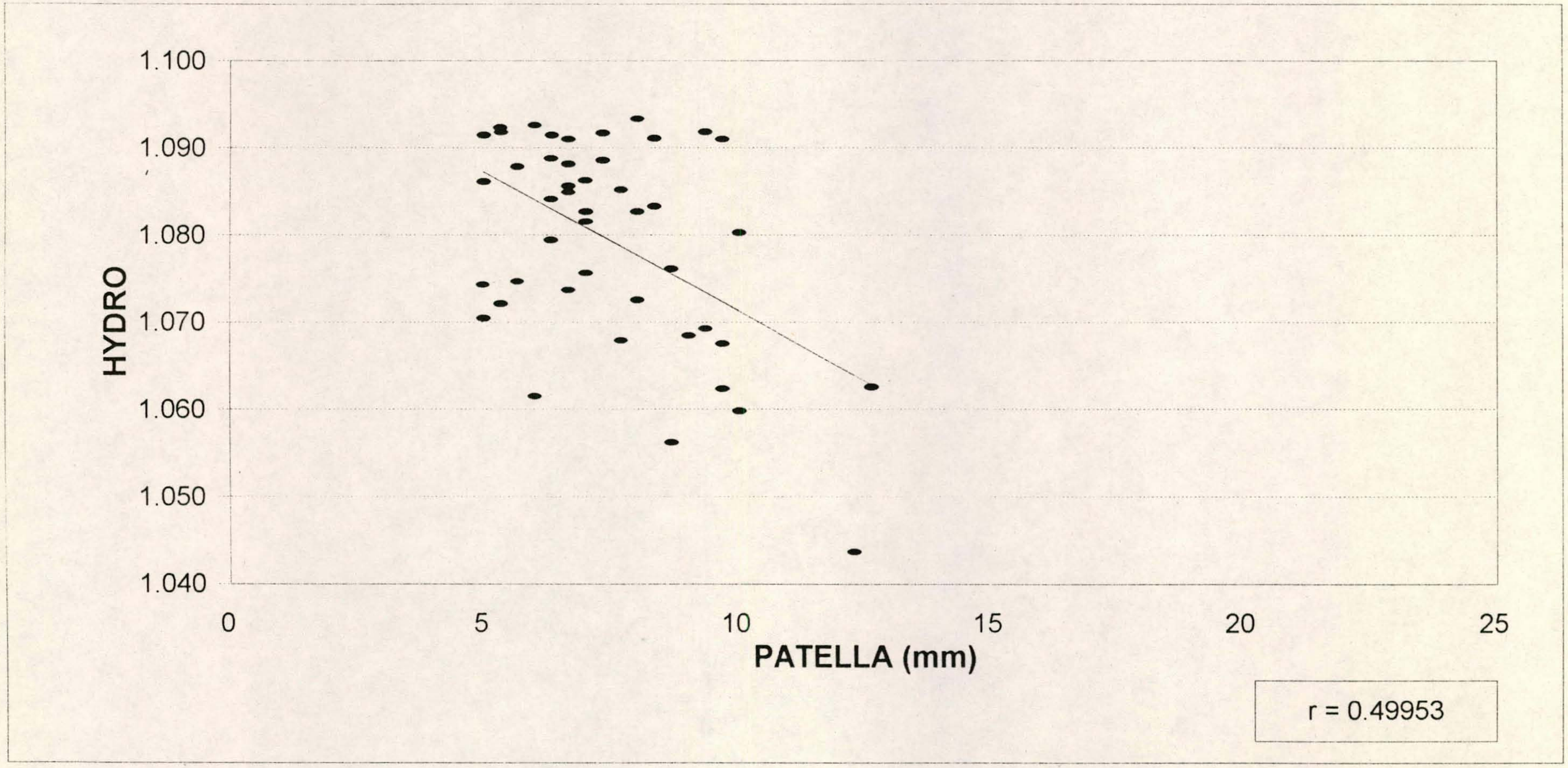

Figure 27k. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

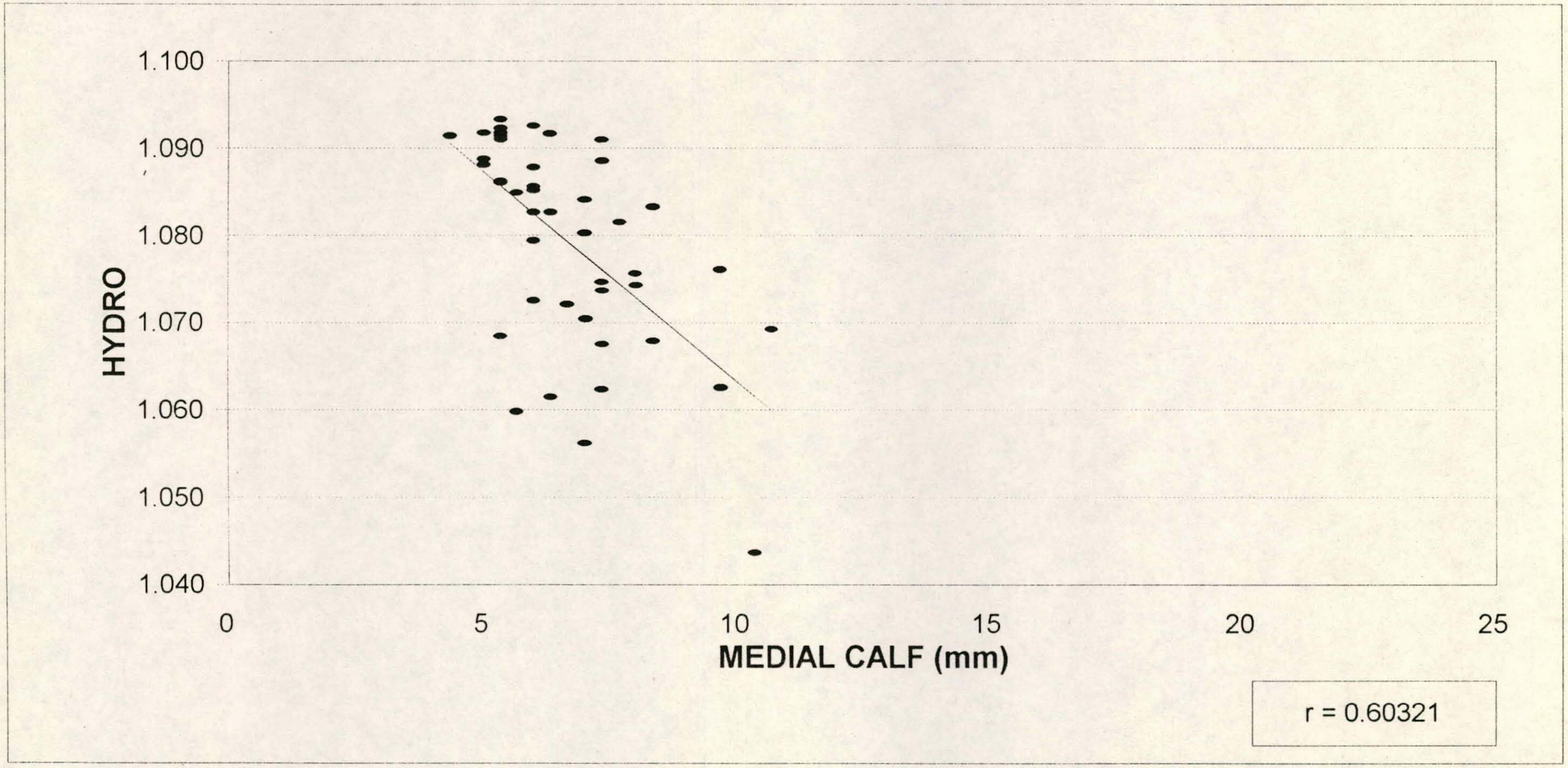

Figure 27l. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

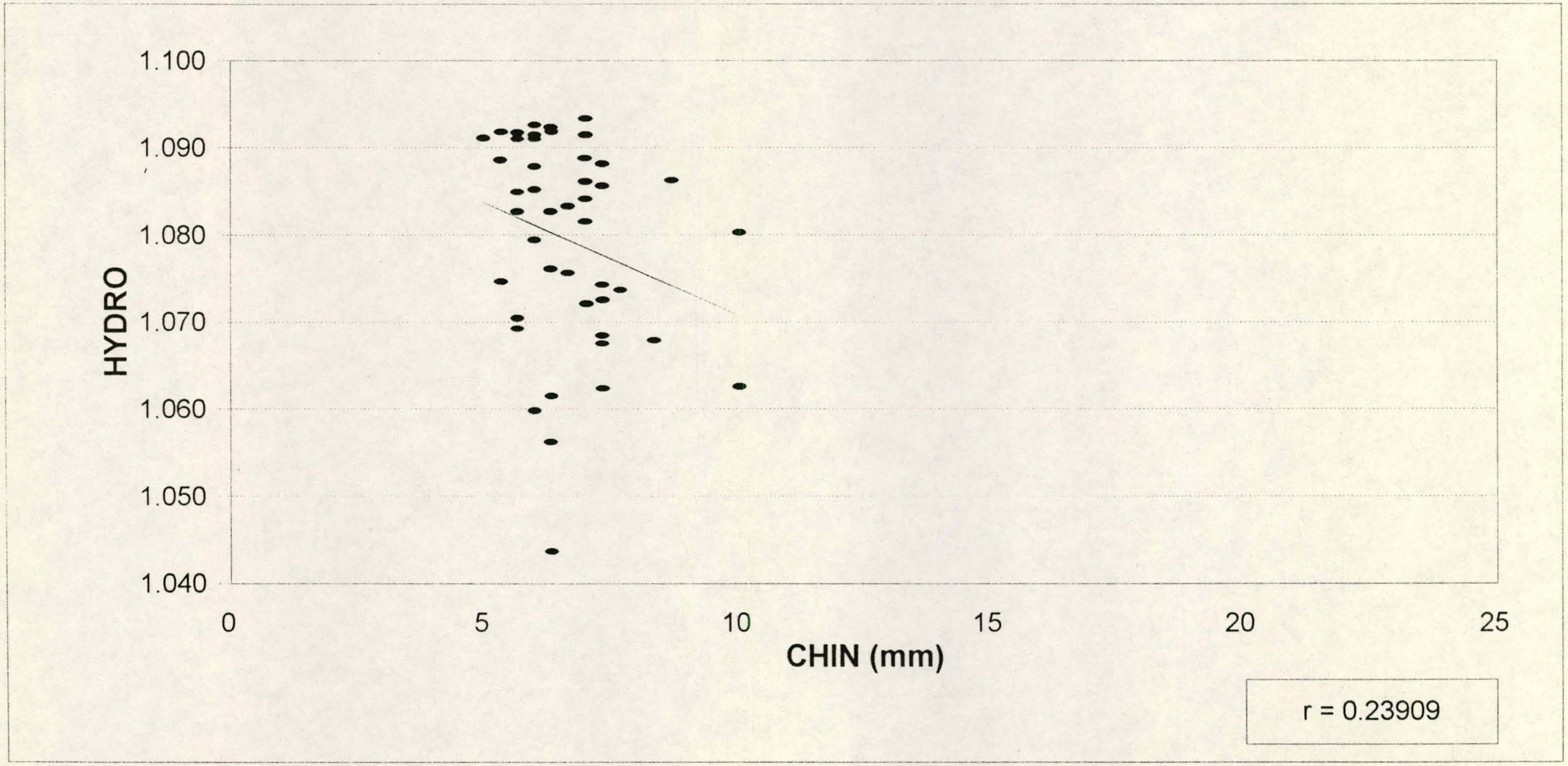

Figure 27m. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

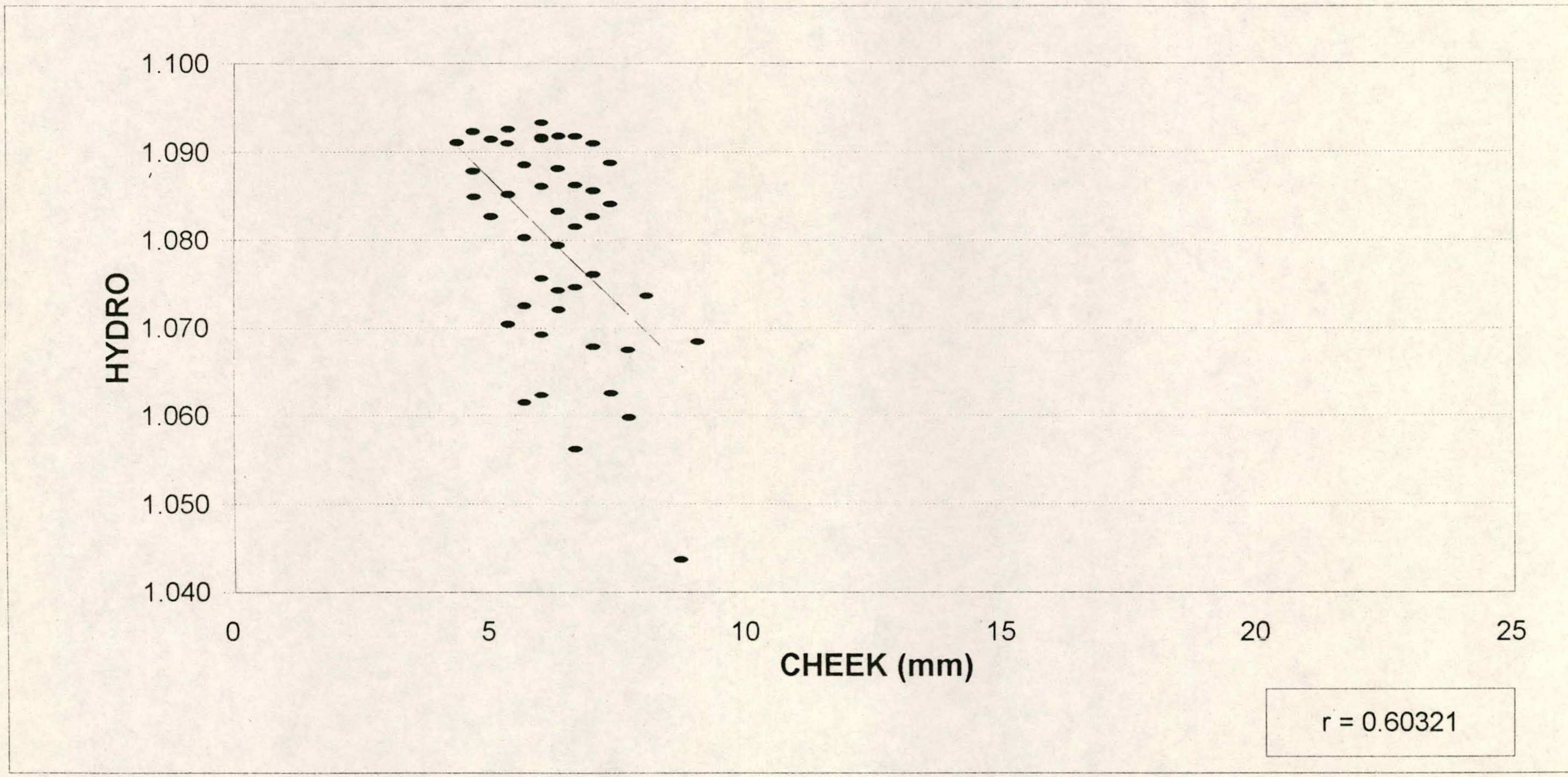

Figure 27n. **CORRELATION OF SONAR (2 x SKIN + FAT) WITH HYDRODENSITOMETRY**

Body Density: [Skinfold(Caliper) - Sonar (2 X Skin)] vs Body Density Fat(Sonar)

The null hypothesis states that the body density, as calculated with the parameters [Skinfold (Caliper) - Sonar (2 X Skin)], is a better predictor than body density, calculated by Fat (Sonar) measurements. This hypothesis can be neglected with 99% confidence. The measure was $t_{(1-\alpha)}$ = 2,42 and the test statistic $t_{(1-0,01)}$ = 2.85, for 43 degrees of freedom and 99% confidence, as determined through linear interpolation. Therefore is body density, calculated with Fat (Sonar), a better predictor than body density, as calculated with [Skinfold (Caliper) - Sonar (2 X Skin)], when applied to the formula of Jackson & Pollock (1978).

By calculating the body density according to the formula of Jackson & Pollock, using the Fat (Sonar) measurements (BD=1,08628), a better correlation with hydrodensitometry (BD=1,07927) were found, than in the case of [Skinfold (Caliper) - Sonar (2 X Skin)] (BD=1,09186). The body density values according to the skinfold may lead to an underestimation of the percentage body fat.

Body Density: Skinfold (Sonar) vs Body Density Skinfold (Caliper): J & P (1978)

The null hypothesis, which states that body density, as calculated with Skinfold (Sonar) i.e 2 x skin + fat thickness measurements, is a better predictor than body density as calculated with Skinfold (Caliper) measurements, can be neglected with 99% confidence. The measure was $t_{(1-\alpha)}$ = 2,42 and the test statistic $t_{(1-0,01)}$ = 3.62, for 43 degrees of freedom and 99% confidence, as determined through linear interpolation. Therefore is body density, calculated with Skinfold (Caliper) measurements, a better predictor than body density, as calculated with Skinfold (Sonar) measurements, when applied to the formula of Jackson & Pollock (1978).

Body Density Sonar (Fat) vs Body Density (Hydrodensitometry)

The null hypothesis, which states that body density, when calculated with Sonar (Fat) measurements and applied to the formula of Jackson & Pollock (1978), overestimates when compared to the body density as determined by hydrodensitometry can be neglected. Therefore it can be said with 99% confidence that an overestimation of body density (Sonar: Fat) results in an underestimation of percentage body fat according to the formula of Siri (1961).

Simultaneously an assumption can be made that , if Sonar (Fat) yielded the correct results, the formula of Jackson & Pollock (1978) may result in an underestimation of the percentage body fat in reality.

DEVELOPMENT OF REGRESSION EQUATIONS

Body Density: Skinfold (Caliper) vs Body Density (Jackson & Pollock)

A linear regression equation to predict body density, using Skinfold (Caliper) measurements of seven body locations, that individually correlated the highest with hydrodensitometry, was developed and correlated with the formula of Jackson & Pollock (1978) (r=0,89121), and reads as follows (see Figure 28):

$$x = \log(TRI + S(A) + CH + BI + MT + ABD + AT)$$

$$BD = 1{,}16011 - 0{,}05689\,(x)$$

where

TRI = Tricep

S(A) = Supra iliac Anterior

CH = Chest

BI = Bicep

MT = Medial Thigh

ABD = Abdomen

AT = Anterior Thigh

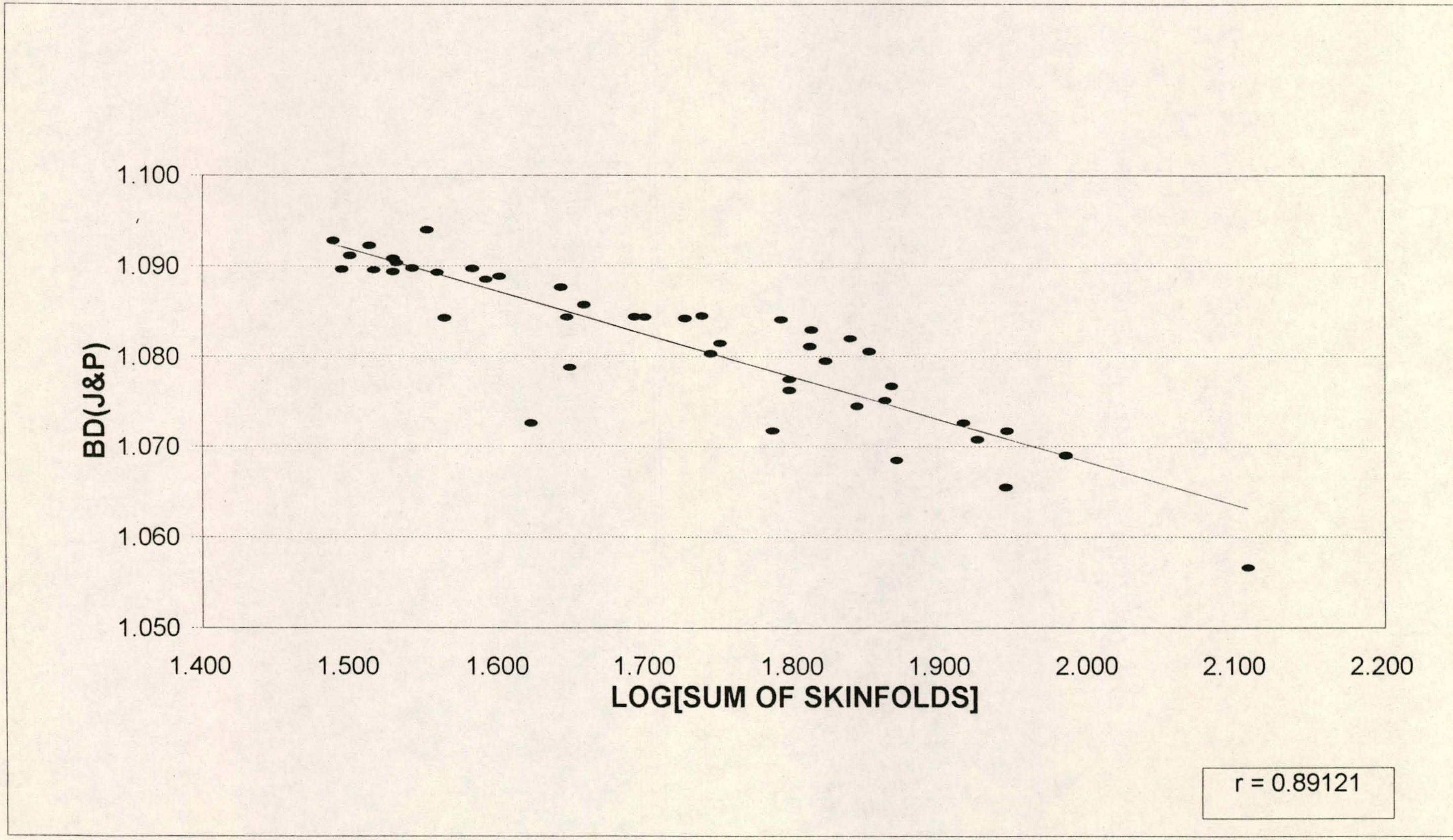

Figure 28. **LINEAR REGRESSION: BODY DENSITY (SKINFOLDS) VS BODY DENSITY (JACKSON & POLLOCK: 1978)**

Body Density: Sonar (Fat) vs Hydrodensitometry

A linear regression equation to predict body density, using Sonar (Fat) measurements of seven body locations, was developed and correlated with the hydrostatic weighing method (r=0,86784), and reads as follows (see Figure 29):

Sonar (Fat)

$$x = \log(TRI + S(A) + CH + BI + MT + ABD + AT)$$

$$BD = 1{,}16011 - 0{,}05689\,(x)$$

This regression equation to predict body density by Sonar (Fat) revealed a high correlation and can be used as an alternative non invasive method. A more detailed discussion about the application of this equation will follow in the next chapter.

Body Density: Skinfold (Caliper) vs Hydrodensitometry

A linear regression equation to predict body density, using Skinfold (Caliper) measurements of seven body locations, that individually correlated the highest with hydrodensitometry, was developed and correlated with the hydrostatic weighing method (r=0,86936), and reads as follows (see Figure 30):

Skinfold (Caliper):

$$x = \log(TRI + S(A) + CH + BI + MT + ABD + AT)$$

$$BD = 1{,}19109 - 0{,}065086\,(x)$$

This regression equation yielded a high correlation with hydrodensitometry and may provide an alternative to the formula of Jackson & Pollock.

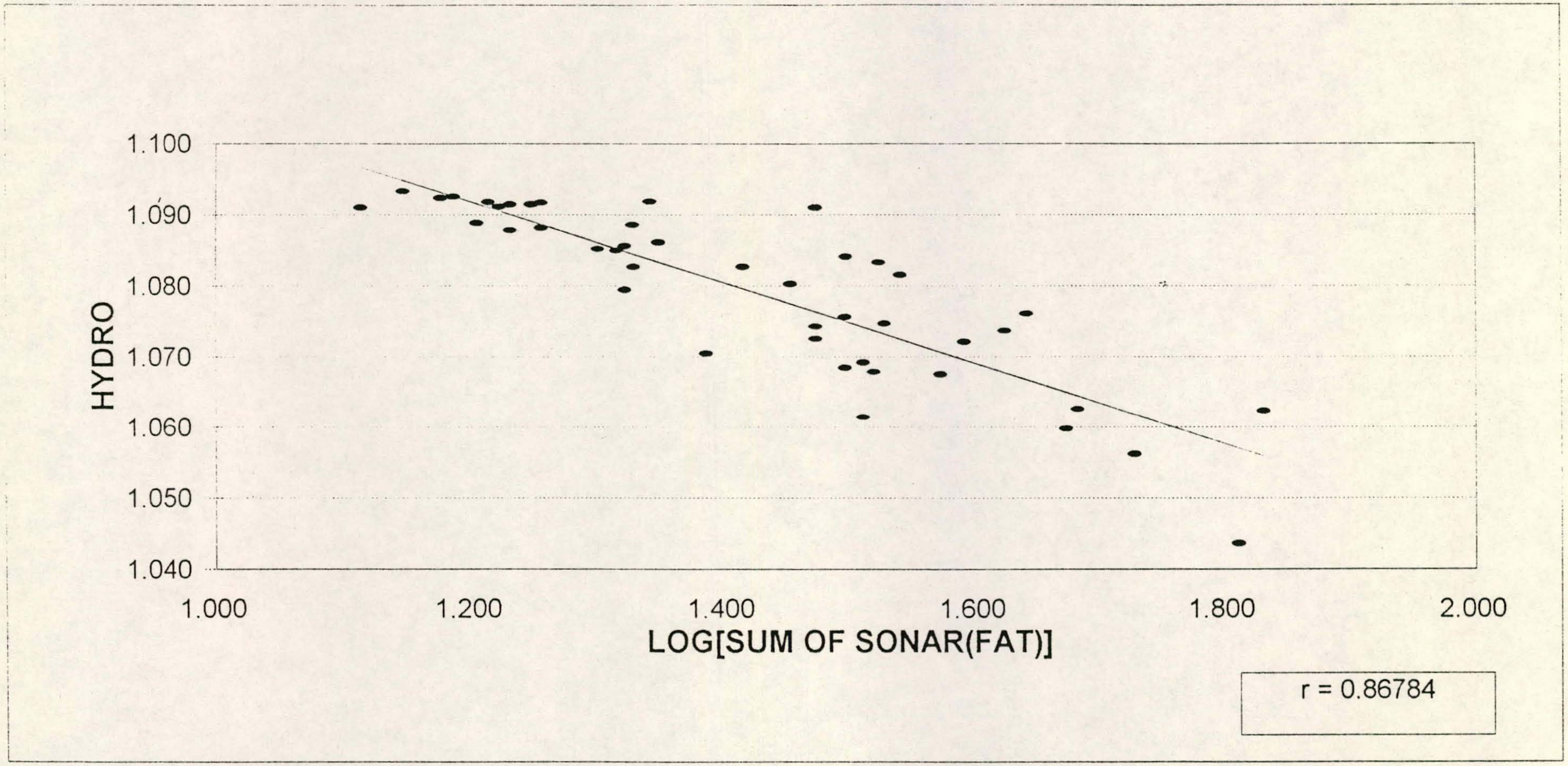

Figure 29. LINEAR REGRESSION: BODY DENSITY WITH FAT THICKNESS (SONAR)

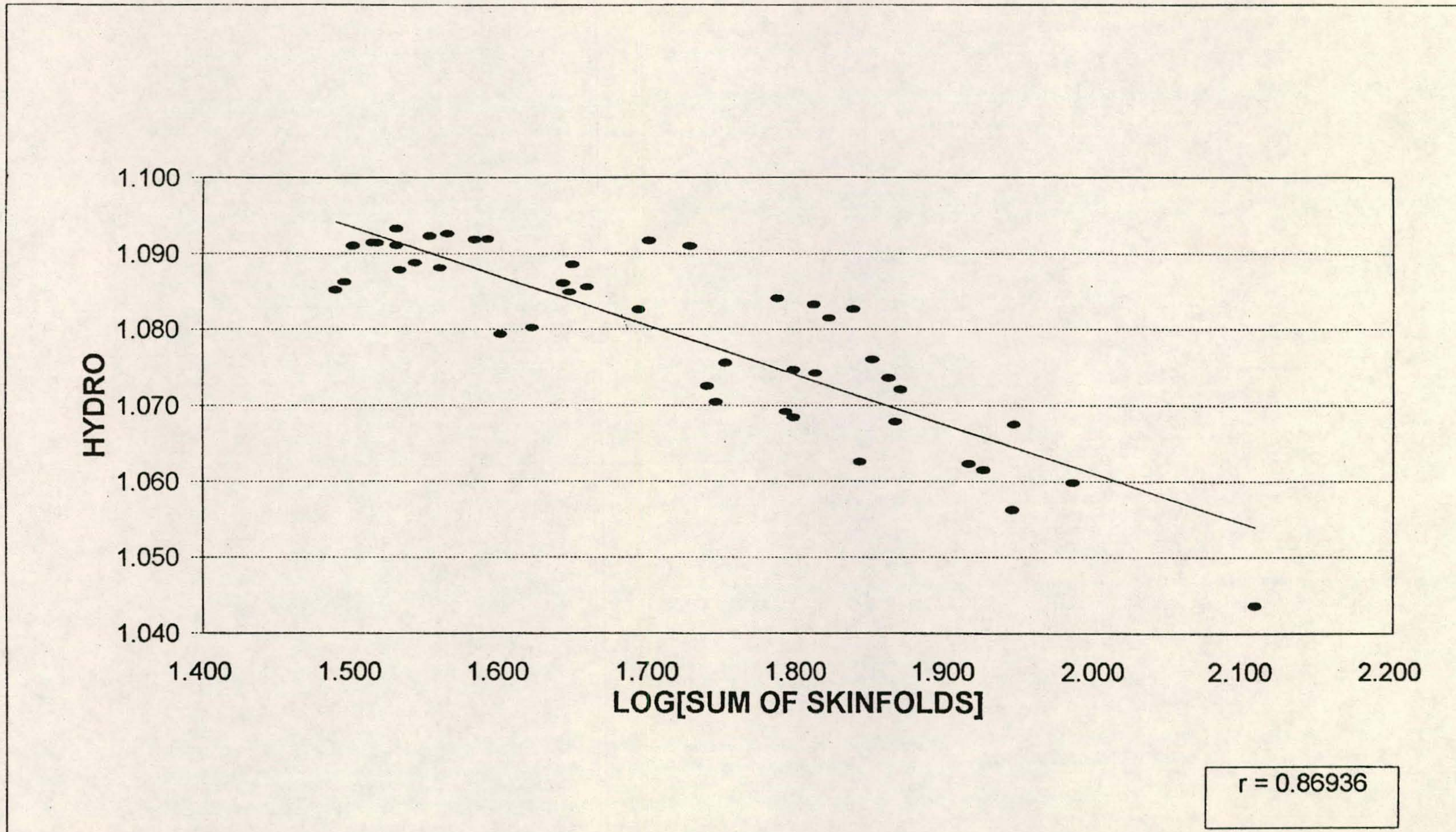

Figure 30. **LINEAR REGRESSION: BODY DENSITY WITH SKINFOLDS**

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The *in vivo* determination of the human body composition has been a challenge to researchers since the beginning of time. The purpose of this study was to investigate whether the skin thickness has an influence on the determination of the body density, as calculated by skinfold methods and formulae.

Although there are many ways to determine skin thickness, most of these methods are invasive, costly in terms of money and time, require skilled personnel to perform the tests and are confined to research and laboratory settings. Since many of these methods involve the determination of the adipose tissue *in vivo*, most techniques rely on external body measurements through the skin.

The value of ultrasound scans in a clinical setting was investigated to provide an alternative method of measuring the different layers such as skin and the subcutaneous adipose tissue individually.

CONCLUSIONS

Ultrasound or sonar scans proved to be a fairly non invasive and inexpensive, not too time consuming, yet accurate method to determine the skin and subcutaneous fat layer separately in human beings. Since there are no ultrasound formulae available to compare this population group who participated in this study, a new regression equation, using seven sonar fat values, was developed to indirectly estimate the body density. A further regression equation was developed, using the sum of seven skinfolds, as measured by caliper, to predict body density. This investigation set out to establish a platform from which further research projects should be launched.

This study provides the health professional with alternatives where a choice between sonar and skinfold measurements can be made, depending on the preference of the patient and clinician or the time and apparatus available. Either method of measurement and accompanying formula yielded good results when compared to hydrodensitometry providing that the subject qualifies for the 18 to 30 year old endo-mesomorphic category.

RECOMMENDATIONS

Since the application and relevance of these formulae are restricted to a specific population in the sports world, but most of the athletes excelling in the world arena of sport and competition fall into this category, an extended study of this kind on elite sportsmen is suggested. It has been proven that the skin does have a significant influence on the determination of the percentage fat, but this influence could not be quantified due to the small representation of a specific population in the universum.

Another follow up study, expanding the age group to at least 60 years, including both genders and other somatotypes, as well as other ethnic groups, could be undertaken. Although they have definite time and expense advantages, the use of the skinfold caliper and its accompanying formulae, have for too long been the "easiest way out" and the inaccuracies along with them too readily accepted.

The suitability of the method and formula using the sonar fat values should be investigated and adapted for women, if needed be. There may be a huge market in the field of gynaecology for an appropriate formula using sonar fat measurements since almost all of these specialists have ultrasound apparatus used for diagnostic purposes in women, pregnant or not. This method could be applied to monitor a female's accumulation of fat during pregnancy, without the effect of the changes that occur in the body and skin of a woman in this medical and physical condition.

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