Biomechanics and Medicine in Swimming VII

EDITED BY

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Preface

Swimming faster is the objective of every applied sport scientist and the ultimate target of the investigator's research. While research findings in and of themselves can not result in faster swimming, the interpretation of the results however, can help the practitioner understand how fast swimming will happen. The opportunity to interpret these results takes place at International Meetings as investigators from around the world come together for the sole purpose of discussing and debating how individual study result can contribute to our overall knowledge of faster swimming. In this edition, we have selected the most practical and thought provoking papers from over 80 studies presented at the VIIth Biomechanics and Medicine in Swimming World Congress.

Although these papers can not convey the enthusiastic discussions that took place during the conference, the editors would encourage the reader to take these findings and host your own discussions with colleagues at home. Hopefully, your discussions will lead to additional questions, additional study and new information in all of our quests to better understand how to swim faster.

Finally, special thanks must be given to key people that made the conference organization possible including Cindy Hayes, Conference Secretariat, Carol Zaleski, President of United States Swimming, Ray Essick, Executive Director of United States Swimming, Jan Clarys and Peter Hollander for ISB and Swimming Subcommittee support.

To those who were not able to join us at this conference, it is our hope that reading this proceedings will stimulate you to participate in future swimming conferences.

John P. Troup, Ph.D.
Mystic, Connecticut USA
1995

Foreword

THE HISTORICAL PERSPECTIVE OF SWIMMING SCIENCE

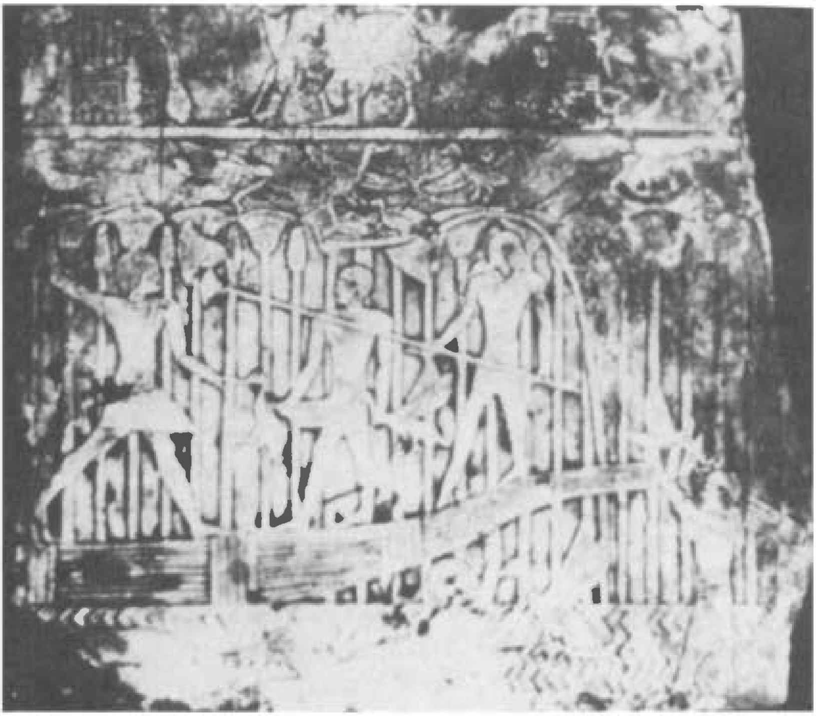
J.P. CLARYS
Experimental Anatomy, Vrije Universiteit Brussels, Belgium

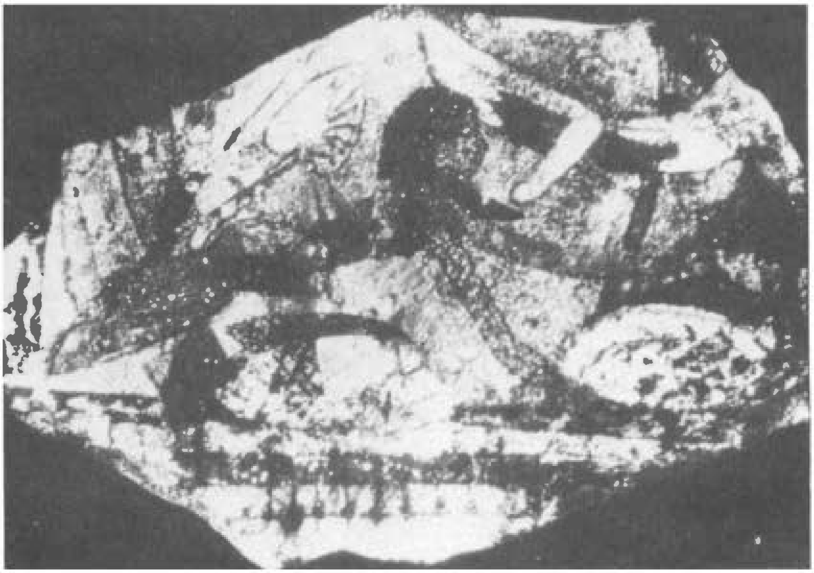
"...Only a part of what was observed in the past was remembered by those who observed it ;.. only a part of what was recorded has survived. ;.. only a part of what has survived has come to the peoples attention ;... only a part of what has come to their attention is credible ;... only a part of what is credible has been grasped ; ... and only part of what has been grasped can be expounded or narrated".

This "reality of the historian" in combination with climatological and geographical differences amongst civilisations, the little practical use of swimming and the individual interpretation of visual historical remainders make it very difficult to tell "the" correct story. Nevertheless it is assumed in riverside cultures that swimming became part of life out of (i) necessity for finding and picking up food (Fig. 1) because of (ii) military reasons e.g. crossing rivers (Fig. 2) due to (iii) religion and self protecting (life saving) influence (Fig. 3) - e.g. the spirit of the death will not find rest if the body was drowned ; and surely out of (iiii) recreational and/or status reasons (Fig. 4) (1) (2) (3) (4) (5).

We are interested in swimming out of other perspectives. We want to look at movement and at performance. We want to appreciate the kinesiology. Observing the two oldest remainders representing swimming (Fig. 5 and 6) and looking at the best known hieroglyphic illustration of a swiming man (or woman)... "the NEBU" (Fig. 7), we do recognize a kind of double backstroke, breastroke (Fig. 5), side stroke or frontcrawl (Fig. 6 and 7). Amazing because we are 5000 and 2100 years BC, (6) (2) (7) and these illustrations are made with a "movement analyses" spirit.

The culturo-historical road to swimming science is long, very long, but the start may be assumed in the field of swimming medicine. We already appreciated a "kind of" reanimation 1250 year BC during the battle of Quadesh, but 3000 BC the "Kahein papyrus" mentioned already blood in urine and described a penis bamboo protection for bathing and swimming in the Nile (Fig. 8). It was suggested that "something"in the Nile waters was penetrating into the body





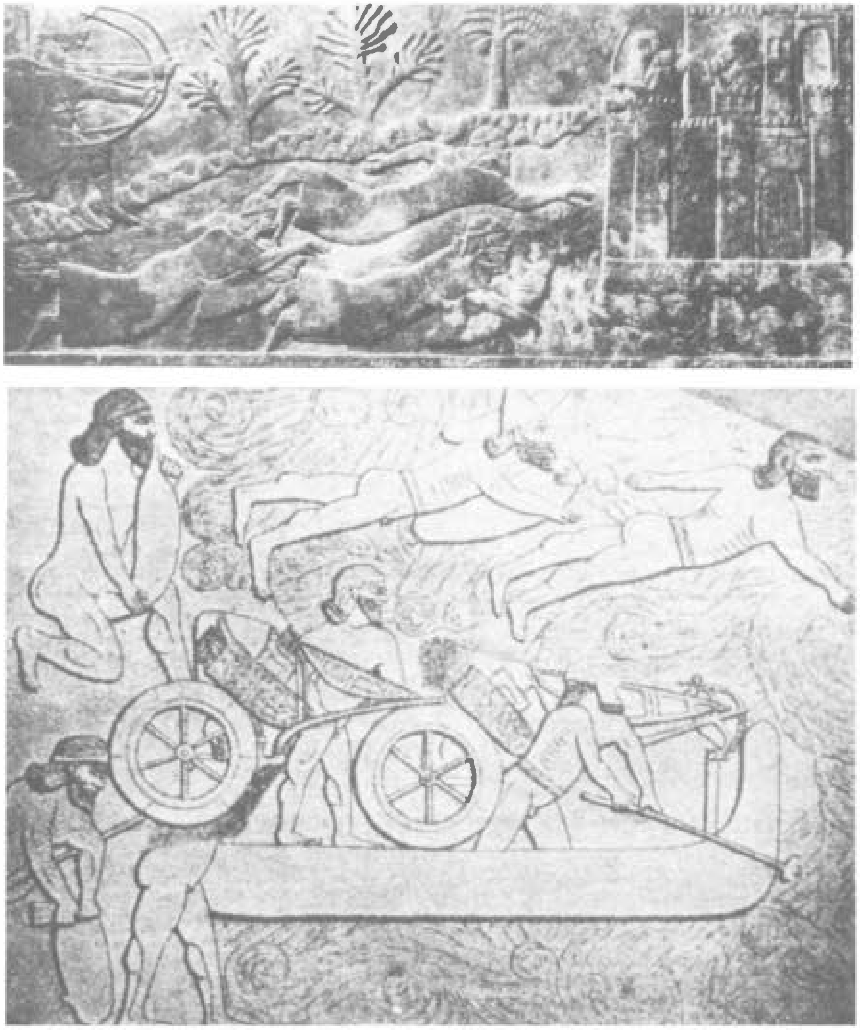


Fig. 2 Assyrian battle illustration (sculpturs and reliefs)
Swimming was essential for crossing waters with or without support (900-600 B.C.) (4)

◄

Fig. 1. Egyptian swimming slave catching birds (1200-1100 B.C. - Egizio Museum Torino) (5)

Fig. 3 Life saving, swimming and reanimation during the battle of Quadesh(1250 B.C. - relief) (5)

Fig. 4 Swimming in Greece : recreation or status ? (vases - 600-500 B.C.) (1)

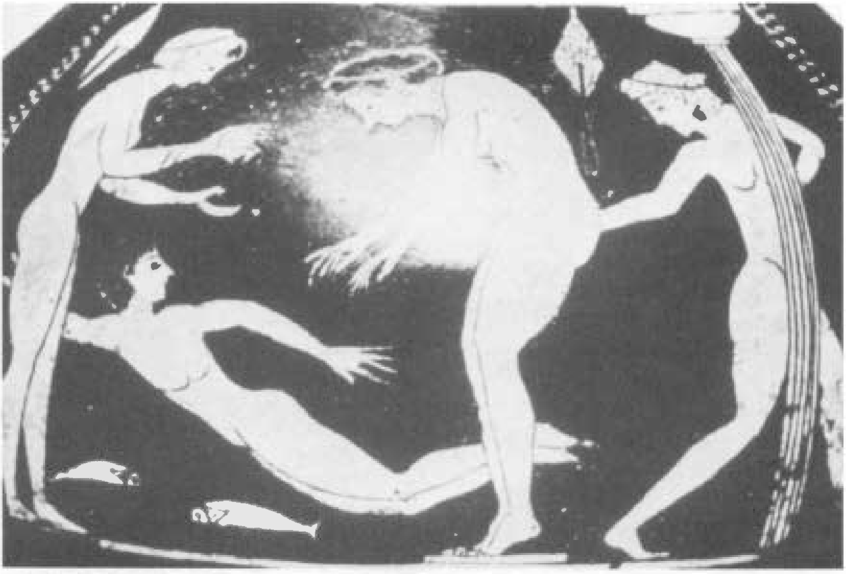


Fig. 5 In1933 the Frobenius expedition found different swimming figures (paintings and carvings) in Nagoda, the bay of Kebir in Lybia (5000 B.C.) (2) A backstroke and a breaststroke are not imaginary.

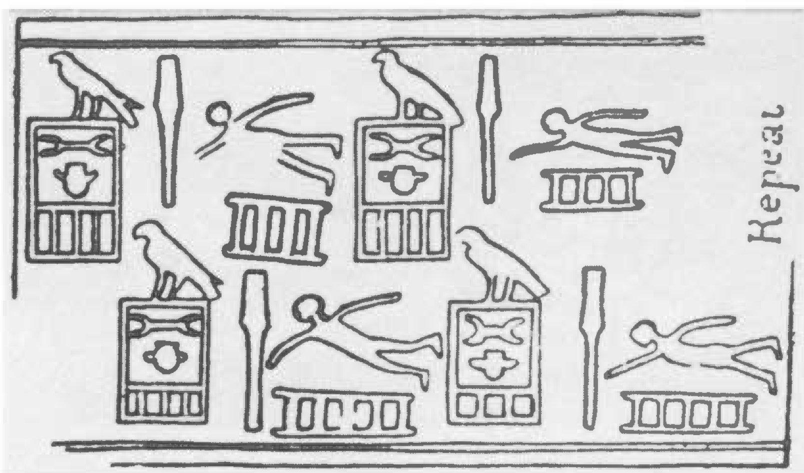


Fig. 6 Amongst the oldest hieroglyphes of the 2nd Egyptian dynasty a side stroke or a crawl swimmer is represented several times (5000 B.C.)(6).

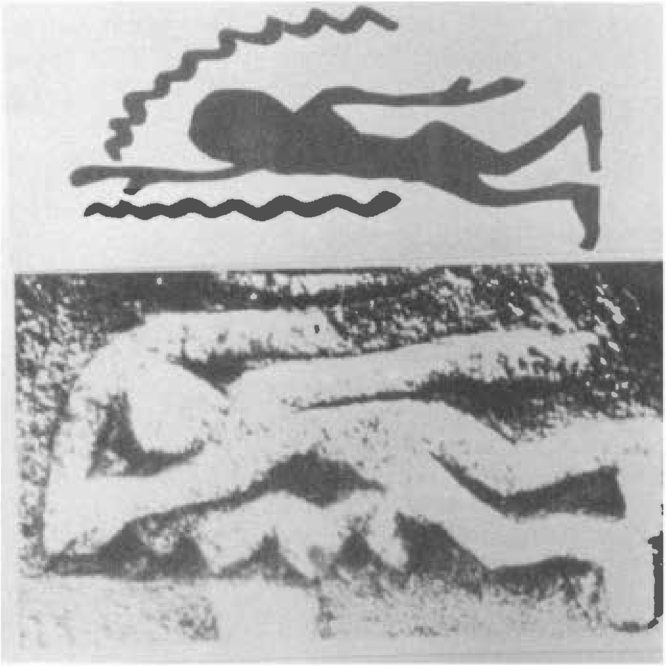


Fig. 7 The swimming man - the NEB or NEBU (2400 B.C.) a hieroglyph... of the 6th Egyptian Dynasty (2)(7).

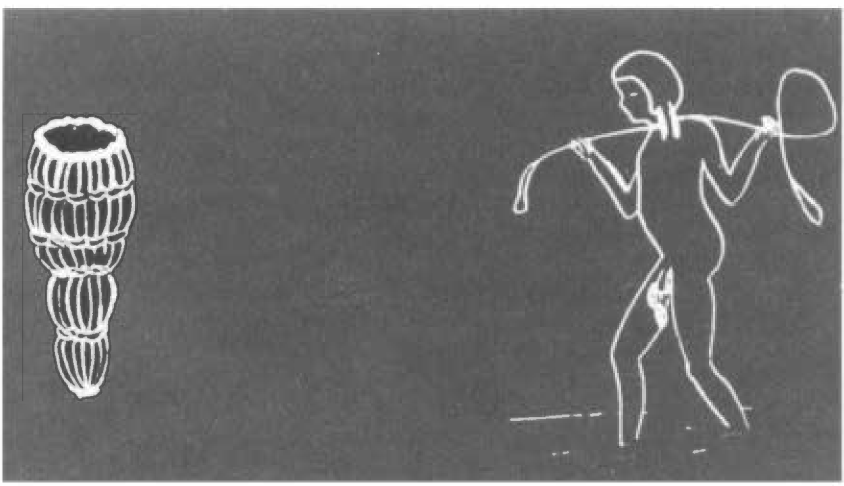


Fig. 8 Preventive Medicine... protecting the penis... avoiding schistosomiasis (3000 B.C. and 1200 B.C.) (8).

(via the penis) creating gastrointestinal problems. The assumed problem was Schistosomiasis.

Schistosomisias is a worm (1 to 2 cm) that develops from (cercarian) parasites who live on snales in subtropical and tropical waters.
These parasites can penetrate the skin in a few minuts, go to the liver via the arterial system where they develop to worms who go and live and lay thousand of eggs in the colon, the ilium and the urinary bladder.
It is estimated that 200 million people have schistosomiasis (8).
Schistosoma eggs were found in mummies of 1200 BC.

We can assume that the associated gastro-intestinal problem explain why the several remainders of Egyptian swimming slaves were female.

Over the years and in comparison to other sports swimming has very little traumatic and/or clinical problems (9), but if problems there are, it are dominant shoulder problems.
According to Kennedy and Hawkins (1974) (10) shoulder pain appeared in Canadian swimmers for 3% only, while in American and European groups very different percentages were found (Richardson et al. 1980 (11) - 42%; Dominguez 1979 (12) - 50%; McMasters 1986 (13) - 68%). It is hard to believe that this variation is due to different swimming techniques. It is not known whether these groups had different training regimes. We do know that it occurs most in the frontcrawl, the backcrawl and the Dolphin. Its frequence is equal between males and females and it is mostly decribed as tendinitis, impingement syndrome and/or shoulder instability.

Shoulder instability can result from the joint and/or can be muscular in origin. Often the major complaint of the swimmer is : "My arm feels death... I have no strength in my arm..." this same complaint is often heard in patients with a thoracic outlet syndrome. In other words, a complaint that could find its origin in a compression of neuro-vascular structures also.

A cadaver study and in paralel an in vivo echographic study on 1321 military and sports men (N=1179) and women (N=142) confirmed the presence of the axillary Arch of Langer in 8.5% (male 8.39 and female 9.15%) (14).
This muscular arch of the axilla can be described as a little muscle coming from the M. latisssimus dorsi and joining the M. pectoralis major to insert on the lateral border of the sulcus intertubercularis of the humerus, thus passing medially to and in front of the Mm. biceps and coracobrachialis and the A. axillaris with the surrounding veins and nerves (Nn.medianus, ulnaris, radialis, cutaneus antebrachii medialis and cutaneus brachii medialis).

The axillary Arch of Langer (Fig. 9) will create a very specific compression of all nerves, veines and arterics entering the sulcus bicipitalis mediales resulting in a loss of strength during movements of the arm over 90° abduction ; 2/3 of the arm movement in all swimming strokes (except the breaststroke) is situated in that range of motion.

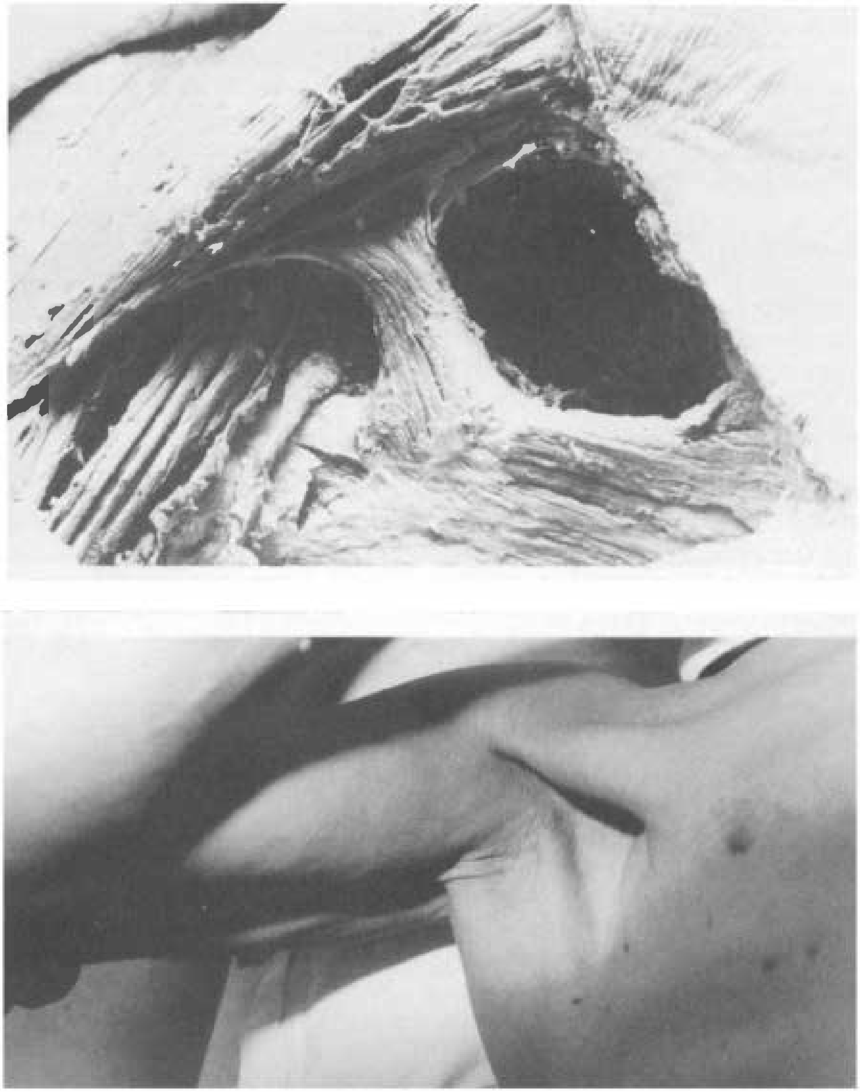


Fig. 9 The axillary Arch of Langer on cadaver and in vivo (14).

But there is more than swimming history, swimming culture and swimming medicine that leads to the science of swimming. Lewillie (1983)(15) stated : "Swimming as it is conceived today is a fairly new activity in the history of human kind". He herewith made allusion to swimming in the modern Olympic Games, but also to the pioneers of the science in swimming and interdisciplinary research such as DuBois-Reymond, 1905, 1927 (16) (17) ; Houssay, 1912(18) ; Liljestrand and Stenström, 1919 (19) ; Amar, 1920 (20) ; Hill, 1924 (21) ; Cureton, 1930 (22) ; Karpovich, 1933 (23)... and on. He was right : "...it is no older than one century".

During this century, a great deal of attention has been given to the presupposed relationship between body shape dimensions and hydrodynamic resistance (24)(20)(25)(26)(27)(28)(29)(30)(31)(23)(32)(19)(33)(34)(35)(36)(37)(38)(39)(40). However, only Clarys (25)(26) related drag for actively swimming subjects (active drag) to anthropometric variables. Contrary to expectations, Clarys (25)(26) found only few correlations between active drag and anthropometric variables, which forced him to conclude that the shape of the human body has hardly any influence on active drag and that other factors are therefore more important (41).

Given the fact that some argue that drag force is directly proportional to the product of velocity squared and a constant of proportionality, which among other things is dependent on the (projected) area of the body exposed to flow (42), one would expect at least some relationship between this variable and drag. The development of a new method of determining active drag (MAD system)(63) warranted a reevaluation of this relationship (41).

Hence what is needed in a interdisciplinary approach which combines hydrodynamic principles with anthropometric and morphologic knowledge in order to generate sufficient information to permit the study of drag created by the body form to propulsive drag in water which is created by human movement in water.

Assuming that active drag is one of the major components determining swimming performance, the hypohetical relation between body form and active drag should confirm (or reject) the idea that human body configuration is an accepted criterion for top swimmer selection or as influencing factors for performance ?

The question remains today : If the MAD hydrodynamic data of the eighties are correct ?! If the recalculations and renewed extrapolation of the Marine station data of the seventies indicate an over estimation !?... How will we explain that passive drag (Dp) and active drag (Ds) become not significantly different... with Dp and Ds having a very different turbulence.

Another question remains today : How do we relate a two dimentional antropometric depth, length, width, skinfolds value and their calculated ratio's with three dimentional but continuous changing and de facto unquantifyable body shapes during intensive swimming movement ?!

What are we doing ; do we need this ; do we not risk a proliferation of unproven or half proven facts...?

An example of similar and related nature : - In the literature, over 1000 articles can be found dealing directly or indirectly with skinfold measurements both in applied - including swimming - and fundamental research. Altogether more than 100 equations to predict "body fat" from skinfolds have been produced. The interest in skinfolds, given the easy accessibility of the subcutaneous layer and given its non invasive approach, has led to a proliferation of the commercialization and use of the skinfold caliper (43).

The available data have clearly demonstrated that skinfold compressibility is by no means constant. Adipose tissue patterning by assessment of skinfold thickness using calipers and incision confirms significant sex differences but emphasizes the neglected importance of skin thickness. It appears that the best adipose tissue predictors are different from those used in general. Also the problem of estimating body fat content by skinfold is compounded by the fact that two identical thicknesses of adipose tissue may contain significantly different concentrations of fat. Skinfolds are significantly related to external (subcutaneous) adipose tissue. However, the relation to internal tissue is less evident and the relation with intramuscular adiposity is unknown (44).

The relation of subcutaneous adipose tissue with the internal (intrathoracical - intraabdominal - intracranial) tissue is almost perfect in women and non significant in male (Fig. 10). In view of all this one of the miracles of contemporary science is how the linear distance between pressure plates of

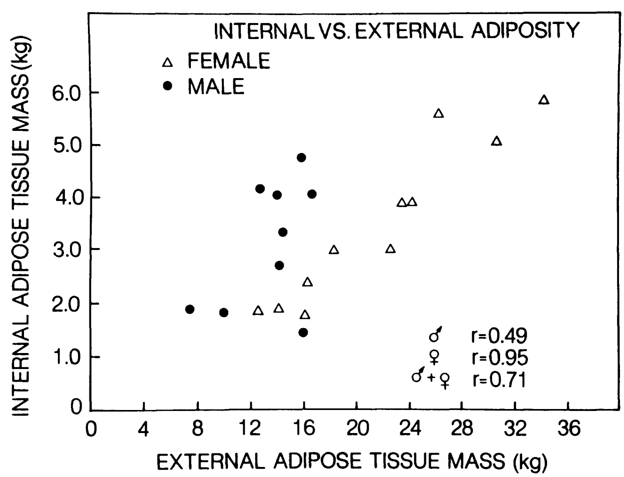


Fig. 10 The relation between external (= subcutaneous) and internal human adipose tissue .

skinfold calipers is transformed into fat. In fact, when using skinfold calipers, what we are really measuring is the thickness of a double fold of skin and compressed external adipose tissue. To infer from this the mass of 'chemical' fat in the body requires a whole series of assumptions which cannot be supported by anatomical evidence.

Let us go back to the historical perspective and back to some of the physiology pioneers of the beginning of the century. In 1905 Du Bois-Reymond (16) and in 1919 Liljestrand and Stenström (19) studied cardiovascular and metabolic aspects of swimming. 1923, Alexander Hill (21) (the same Hill who received the nobelprize Medicine and Physiology in 1922) states that maximal performance in swimming is related to VO_2 max (21) and describes the role of lactic acid in the muscle after exercise. Up to the sixties it was difficult to determine lactic acid in blood, untill an easy enzymatic micromethod was found to assess the concentration of lactic acid which induced a spectacular proliferation of studies using arterial lactic acid to define the performance capacity. Most of these studies did not consider the basic principles of lactic acid metabolims and led therefore to a lot of controversies and contradictions. .. But advantaged too.

spiro-ergometry	**lactic acid**
- complex and cumbersome equipment and measurement	**- free sport practice (eg. no mask)** **- easy handling**
- low resolution of precision - ± 0.8l/min = ± 1.4ml/kg/min equivalence = ± 1.5s/100m	**- high resolution of precision** - equivalence = ± .2mmol/l = ± 0.25s/100m
- maximal effort is necessary motivation is determining	**- maximal effort is not necessary independent of motivation**

Lactic acid concentration in arterial blood is used to determine the physical capacity ; to define and adapt training intensities.

However it is imperative to avoid direct interpretation of lactic acid and one must look at the dynamics behind the lactic acid concentration, because we do not want a Rolls Royce to be equal to a Lada (...both have wheels, but...)

One lactic acid concentration at a given speed can be the result of many combinations of aerobic and anaerobic metabolic capacities.

Relations between speed and lactic acid depends on the form of exercise (e.g. modification of the exercise form induces another localisation of the "individual" aerobic threshold).

It is of crucial importance to know the exact aerobic and anaerobic metabolic capacity according to measure the lactic acid in order to ensure the validity of the assessment of the physical performance capacity of the swimmer and to determine his or her training intensity, quantity and form of exercise (45)(46).

Swimming Medicine, Swimming Hydrodynamics, Swimming Biomechanics, Swimming Physiology, Swimming Biochemistry... the step to Swimming Electromyography becomes easy. Strangely enough the pioneers of muscle electricity are amongst the oldest known scientists ever... the pioneers of swimming EMG are amongs the youngest

The pioneers of clinical and kinesiological electromyography are known to be Galvani 1792 (47), von Humboldt 1797 (42) and Duchenne (de Boulogne) 1855, 1862, 1867, 1872 (49)(50). A bibliometric survey of historical - if possible - original manuscripts have given a lot of informations on the works of different scientists related to Electrology or localizd electrization which became electromyography last century.

Among most scientists Galvani is considered the oldest source in electromyography (muscular irritation) but many original sources and correspondence indicate that many of his peers wereworking on the same topic before the major Galvani publication 1792 (47). In Belgium and Holland many anatomists and movement scientists know Swammerdam and Boerhaave (e.g. Kardel)(51) but very few know that Swammerdam discovered muscular electricity some 130 years before Galvani, who received the credit for it) (52).

Therefore it is very important at this point to acknowledge the work of Ikai and its coworkers 1964 (53) and of Lewillie 1967 (54) because they gave an unprecedented stimulus aswell. They measured EMG in water.No other sport has taken advantage of EMG since (Table1)(55).

Table 1 : Quantification (number of studies) of sport specific EMG research interest

swimming :	33	soccer :	3	Badmington :	1
cycling :	22	rowing :	3	Basketball :	1
running :	17	Judo :	3	Bowling:	1
skiing :	13	windsurfing :	2	cricket :	1
tennis :	8	archery :	2	FIN swimming :	1
gymnastics :	7	voleyball :	2	Handball :	1
Triple-hight-long jump :	5	baseball :	2	rifle shooting :	1
golf :	5	waterpolo :	2	sailing :	1
weight lifting :	5	Javelin :	2	skiff :	1
speed skating :	4	Kayak :	2	softball :	1
				synchro swimming :	1
				shot put :	1
				wrestling :	1

It remains very unfortunate however that some EMG studies cannot be used for comparison because of no or because of wrong normalisation techniques. The MVC is not the best choice as a reference (55).

Nevertheless EMG has become an important tool for obtaining muscle activity information, neccessary for the improvement of classical and alternative training methods (56)(55).

Let us summarize some of the most important findings.

- the trunk muscles during frontcrawl swimming have a significantly higher muscular intensity (IEMG) than any other muscle of the upper and lower limb. These trunk muscles make the difference between the elite and the good swimmers considering equal trainingsintensities.

Clearly and too often the importance of these back and abdominal muscles is underestimated. Additional and localized strength training is advisable.

- Dryland training devices - with or without accomodating resistance - are promoted (still) for their "movement specific workouts and strength increasing qualities". RMEMG and IEMG comparison with the "water" conditions have, however indicated that :

(a) there were overall time differences between dry land and "wet" arm cycle executions ;

(b) the muscle potential amplitudes were different in all five devices studied (expander, roller board, call craft, isokinetic swimbench and latissimus pull)

(c) most muscles showed fewer EMG peaks on dry land ;

(d) there were marked discrepanches for all comparisons (devices - muscles - functional groups - cycle phase separately) ;

(e) the dry land co-ordination creates a different pattern of movement.

It is generally observed that, whenever a swimmer acts against a mechanical resistance (especially in a different environment) important pattern deviation are noted. Specific training cannot be accomplished with dry land devices due to mechanical and environmental differences ((56)(57) In this case imitation does not mean specific.

Strength training effects are negligable or non existant because the intensities (IEMG) in dry land are inferior to those in water. Another study however, demonstrated similar relationship between stroke rate and VO2 max. in sprint swimming and during simulated all out swims on a isokinetc (or biokinetic) swimbench (58).

- Most commercial handpaddles produce specific activity, similar of "normal" swimming, but with higher intensities (IEMG). They are strengthening but place extra load on the shoulder also (59)(57)(60)(55).

Handpalm shaped paddles disturb the muscle pattern and have to be avoided.

- Tethered swimming is a recommended training method because of its highly specific muscular pattern at all velocities up to exhaustion (61). Semi tethered (with an allowed displacement of 8 m) is advisable for longer distance swimmers because at sprint speed the patterns are disturbed.

On the bases of IEMG values a strength training effect is suggested but not obvious.

- As to swimming (training) on the M.A.D. system (63) and in swimming Flume's - training De Luxe" - we know that different arm trajectories are inherent to both systems. In the MAD system because of pushing of on pads and in a Flume because of the laminar counter flow of the water. In both cases however the EMG patterns arrive at an acceptable level of specificity. The strength training efect again, maybe suggested but needs more study. Both the MAD system and the Flume however, are very valuable research instruments (62)((63)(64).

Strength training has become an important part of swimming training... but it is not sure that all trainers know what strength training is... or what can be done with it !?!?!!!!...
Strengh training... is more than increasing overall and local strength
* it is... agonist - antagonist ; concentric - eccentric ; constant - variable ; left - right... training
* it is monitoring and increasing muscular equilibrium.

In the past decade the development of dynamic muscle testing devices has increased our knowledge of the human neuromuscular system and its relation to performance, dramatically. The introduction of the isokinetic dynamometers based on the accomodating resistance principle allowing training and measurement of forces at a controlable constant speed throughout the range of motion. It gave a new impuls to the importance of strength training (65).

The dynamic (isostonic) methods for strength training can fall into three categories : 1) constant, 2) variable, and 3) accomodating resistance (66). Numerous strength training machines have been developped as alternative to the traditional barbels and dumbbells, providing a more compact, convenient, and safer form of exernal loading. Their increasing application in all sports and swimming in particular has raised the inevitable question whether they are superior with respect to strength gain, and if they are, in what respect for each of the categories (67).

In the constant resistance concept the load is always the same, i.e. a constant resistance through the total range of motion. Therefore, loading occurs at the weakest point in the system while the rest of the system is working at a lower capacity. To overcome this shortcoming, the variable resistance devices use pulley and cam systems and attempt to vary the resistance as the muscle lengthens or shortens. The reviewed litterature on strength training (65) indicates that both resistance exercise have seldom been compared, but when they have been studied neither method has shown overall superiority. Nevertheless, variable resistance devices may produce position-dependent increases which point to a specific training effect at the joint angle at which peak loading is induced by the device.

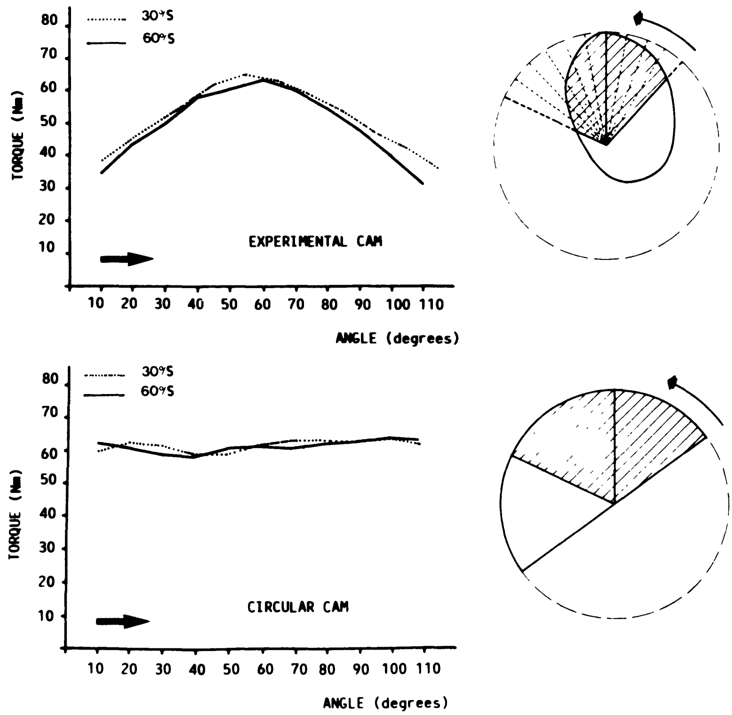


Fig. 11 The experimental cam for the variable resistance training and the circular cam design for the constant resistance training and their corresponding torque-angle curve patterns.

Pipes 1978 (66), De Witte et al.1988 (67) compared the effects of constant resistance training using a circular cam system versus variable resistance training, using an experimental cam design (Fig. 11), on the force angle relationship.

Without going into the detail of the concentric and eccentric work it is clear that both, constant and variable resistance training, increase strength significantly. The variable resistance mode, however, being the most profitable for both male and female, up to a very significant gain in female (Fig. 12) within a short (6 to 7 weeks) period of time.

The historical perspective of Swimming Science is like a very big house with many doors. We have used a few only, the house is big, very big, and very rich. Seven Int. Symposia on Biomechanics & Medicine in Swimming (WCSB)* plus ten World Congresses of Medical and Scientific aspects of aquatic sports (FINA)*

WCSB = World Commission of Sport Biomechanics ; FINA = Fédération International de Natation Amateur

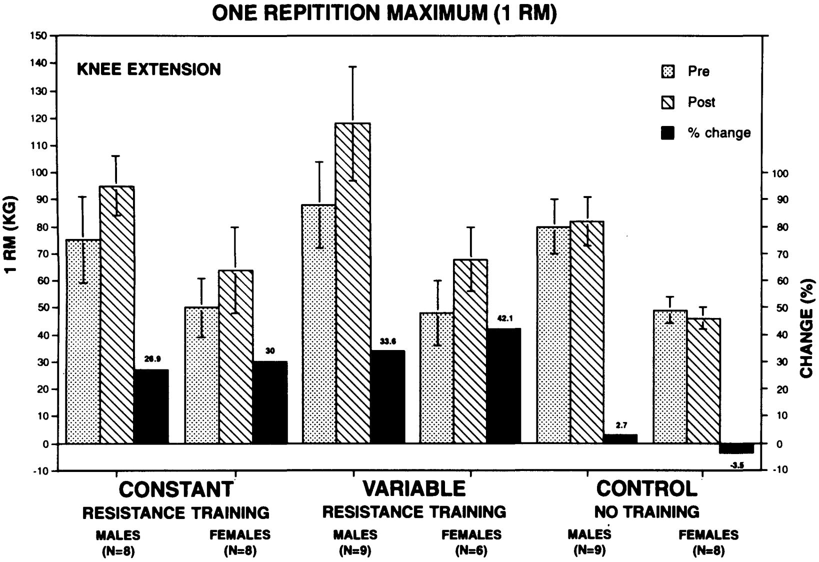


Fig. 12 Comparison of force scores, before and after variable & constant resistance extension at 60°/S and 30°/S for males and females.

has given us a wealth of research unique and unprecendented in the world of sports.

World FINA Medical Congresses

I	II	III	IV	V	VI
London	Dublin	Barcelona	Stockholm	Amsterdam	Dunedin
1969	1971	1974	1977	1982 with WCSB	1985

VII	VIII	IX	X	XI
Orlando	London	Rio Di Janeiro	Kyotô	Athene
1987	1989	1991	1993	1995

Biomechanics (& Medicine) in Swimming

1970	1974	1978	1982	1986	1990	1994
Brussels	Brussels	Edmonton	Amsterdam	Bielefelt	Liverpool	Atlanta

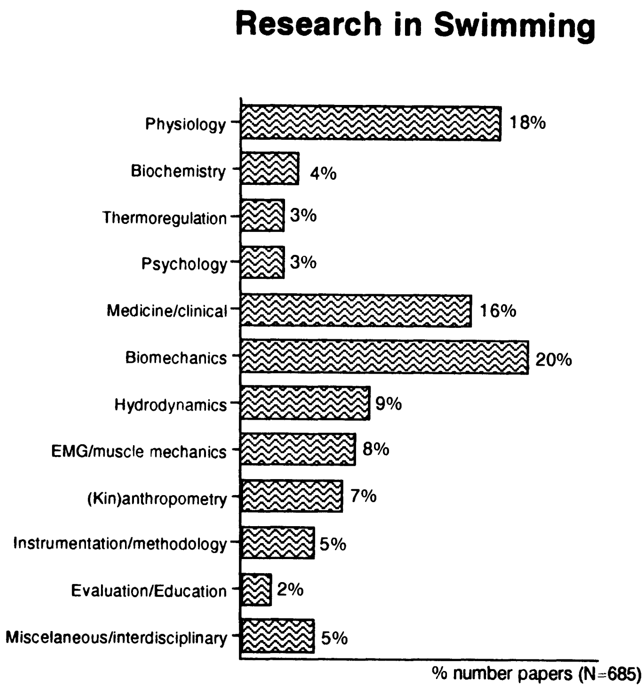


Fig. 13 Research topics in swimming expressed as percentage of peer reviewed papers.

In addition and on the bases of peer reviewed papers swimming physiology and biomechanics seem to have attracted the researcher most (Fig. 13) and within these and other fields the front crawl received almost all attention. The NEBU (Fig. 7) 2400 B.C. has shown the way.

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