CHAPTER 1

INTRODUCTION AND STATEMENT OF THE PROBLEM

1.1 MAN`S UPRIGHT POSTURE

1.1.1 Posture and human structure

Posture is the essence and substance of this study. It is as far as the author can ascertain, uniquely human, since it is only used in the upright human context. In animals terms such as body shape, form and outline are used to describe the "posture" of an animal.

Posture cannot be considered without reference to the element of structure. Most people think that these two words are synonymous, but according to Rolf (1977) they are not. Etymologically, the term *"posture"* contains an element of placement, since the root of the word is the Latin *positūra,* position, from *pōnere* (past participle *positus*) which means *"to place."* Applied to the human, therefore, posture implies that something has been placed into a space where it should belong (Rolf, 1977). From this it follows that posture is the consequence of structure, and that if posture is modified, from a physical point of view, it is structure that needs to be considered. For the purposes of the present study, therefore, posture will be viewed from this perspective.

In any plane, structure/body structure and therefore posture, implies a relationship. This relationship may be between structures within the individual human body or the relationship of an individual in terms of his environment. Placement of one specific body part in relation to the others may alter the total posture, function and structure of the individual, or one or more of his body parts. This placement may have a considerable effect on the individual, but on the environment the effect is small and usually restricted to the immediate environment of the individual. Posture may, for example, affect the way the individual moves or balances himself, how the clothing fits, the wear and tear on shoes, the design of furniture and how the individual is perceived by others (Barker, 1981; Lowen, 1971; Mandal, 1984; Wikler, 1980). The opposite, however, is not the case. Environmental factors such as gravity, furniture, clothing, may affect posture and the human structure to a large extent (Barlow, 1990; Mandal, 1984; Rolf, 1977). Such is the influence of environmental pressure or constraints on man, that it may in all probability have given rise to the development of the permanent upright posture in the human.

1.1.2 The attainment of human uprightness

The attainment of human uprightness has long excited the attention of those interested in this unique aspect of humanness. Man's permanent upright posture and its anatomical basis are the most striking characteristics that distinguish the human from the rest of the animal kingdom. It was also one of the earliest distinctively human features to emerge, for the hominids have, according to current scientific knowledge, been walking upright for at least 3,5 to 4 million years (Coffing, Feibel, Leakey & Walker, 1994; Tobias, 1982). Human uprightness has helped man to solve a number of problems, but contributed, on the other hand, to what Keith (1923) called the ills of uprightness. These ills include flat feet, low back pain, and malposture (Dart, 1947; Plowman, 1992; Tobias, 1982).

The upright posture has freed man`s hands from the locomotive function, and enabled them to be used for grabbing, hanging and the making of tools (Pilbeam, 1990; Tobias, 1982). The upright posture led to a smaller base of support, a greater susceptibility to fall (Dart, 1947) and costly mechanical problems such as the present nemesis of medicine - low back pain (Pope, Andersson, Frymoyer & Chaffin, 1991a).

Man's constant upright posture places him in a class of his own in the Animal

Man's constant upright posture places him in a class of his own in the Animal Kingdom. It was the first characteristic of humanness to emerge and this, according to Tobias (1982) put him on the road to full humanity.

Despite its uniqueness, the human bipedal-erect stance is not enjoying the attention it deserves from the scientific community. In physical anthropology, interest in these aspects originates mainly from the uncertainty of the date and geographical placement of the origin of the advent of man`s uprightness, which is now thought to be closely related to the origin of man (as human being) and eclipsing the big brain theory completely (Gorman, 1995; Gould, 1987; Leakey & Lewin, 1992; Lemonick, 1994; Shreeve, 1996).

Initially the scientific world placed the beginnings of mankind in Asia, and then a discovery in 1924 by Dart moved man's origins to Africa (Dart, 1925; Tobias, 1982). The discovery was that of a skull of a fossil child near Taung in the Northern Cape Province. Lately the oldest hominid fossils are being discovered in East Africa and South Africa, such as the *Australopithecus anamensis* discovered by Meave Leakey in Kenya in 1995 which was older than the *Australopithecus afarensis* found in Ethiopia 20 years earlier (Shreeve, 1996). From this famous fossil skeleton, known as Lucy, and discovered in 1974, it became clear that bipedalism came first and a large brain later, as Lucy stood upright, but had an apelike skull (Lemonick, 1994).

Bipedalism could not have taken place without influencing the rest of the physical body as well as all future development of the physical body (Dart, 1970). That significant social and intellectual changes followed bipedalism, is widely accepted and closely scrutinized (Morris, 1969), yet the nagging question remains of whether bipedalism was the cause or effect of major social changes (Leakey & Lewin, 1992). This seminal question can be applied to the whole of the posture issue up to the present state of affairs: Which was the cause and which the effect? Does structure affect function or is function the cause of structure? (Barlow, 1990).

Posture is an intensely personal feature of an individual, probably the most recognisable and stable of his characteristics (Lawson-Wood & Lawson-Wood, 1977; Lowen, 1971; Rolf, 1977). Yet this ever present attribute, attached to an ability developed more than 4 million years ago, still poses many questions, conjectures and surmises such as the optimal posture and the maintenance thereof, as well as the effect of its malfunctioning (Barker, 1985; Barlow, 1990). Because of the omnipotence of the concept of posture, a vast number of approaches and/or areas of investigation are possible, of which some are listed below:

1. A physical approach may lead to the question of whether a person's structure and the use thereof (mechanism) influences his function and his physical health (Barlow, 1990; Goldthwait, Brown, Swaim & Kuhns, 1952; Phelps, Kiphuth & Goff, 1956),

2. A psychological approach may, amongst other things, pose the question of whether a person's character lies in his posture or vice versa and can a change in one influence the other (Cailliet, 1995; Feldenkrais, 1985; Lowen, 1969; 1971; Painter, 1986; Reich, 1999)?

Due to the fact that posture is taken for granted, it is often overlooked in therapies, not noticed at all in daily life, and it does rise and fall in popularity. In the West it is mainly given attention to in activities such as ballet (Tobias, 1982) and horse riding (Albrecht, 1993; De la Guérinière, 1994). In the world of athletics its value has been realized by some (Gelb, 1981; Martin & Coe, 1991; Watson, 1995). Of particular interest is the correct posture in static Eastern practices such as Yoga (Iyengar, 1968) and in dynamic exercises, for example, Tai Chi Chuan (Pang & Hock, 1984). Posture is a subject with infinite possibilities and merits. In the present era a holistic approach is seen to be the most effective way of dealing with most types of body, mind or soul problems (Lowen, 1969; Lowen & Lowen, 1977; Painter, 1986). An overview of all aspects of posture may help to indicate the contribution of postural aspects such as muscle balance, and body alignment, in an attempt to approach total well-being from a holistic point of view. This is a way of developing the potential of the human body, and hopefully will provide an indication of the abilities and limitations of the human being.

The subject and the study of posture is regularly, but not often, dealt with in literature - scientific and otherwise. Unfortunately most of this is often done in a vague and fragmentary fashion. Publications usually highlight only individual aspects of the subject. Consequently, no integrated point of view of this subject could be found, and as a result many aspects of posture are poorly understood, and many questions are not dealt with properly.

1.2 AIMS AND PURPOSE OF THE PRESENT STUDY

The primary purpose of this study is an attempt to formulate an integrated approach to this field of study. In order to achieve this aim, posture and all its ramifications, will be approached from both a physical and a psychological perspective. With this purpose in mind the study will be subdivided into the following sections:

1.2.1 Posture from a physical perspective

In this part of the study, literature dealing with the various physical aspects of posture will be analysed. The aim of this part of the study is to gather facts in the literature relevant to posture. The premise here is, that in order to reach a full understanding of the subject, one needs to build it up from its earliest beginnings, hence the inclusion of chapters on human *phylogeny* and *ontogeny* - enabling a better comprehension of the structural and physiological adaptations to the upright posture in the human, such as neuromusculo-skeletal function, involved in upright posture and bipedalism. This will not only lead to a better appreciation of the anatomical-, physiological- and biomechanical factors pertaining to posture, but also to improvements in firstly, the approach to the treatment of defects of the fully developed posture, and secondly in the ability to recognise aberrations of, or regressions in posture, and thirdly to the improvement in physical performance (Alexander, 1932; Feldenkrais, 1985; Martin & Coe, 1991). Every step along the way of human development may have an influence on the end product; one needs to know where one has been, and to know where one is going to.

Apart from human *phylogeny* and *ontogeny,* an in-depth analysis of the physical aspects of human posture such as the "ideal" posture, postural aberrations and their consequences will be considered.

The first section will be divided into a number of chapters, each dealing with a specific issue:

☐ The erect, standing posture has specific characteristics and measurable qualities. These are reviewed in the second chapter. The term *"posture"* and others relevant to it will also be defined in view of these attributes,

☐ In Chapter 3 posture will be approached from **a paleo-anthropological point of view,** starting with a superficial overview of the course of development of a single cellular biological organism into the complex multicellular, multidimensional organism which is man today. The purpose of this is to place man in time and space in the Animal Kingdom. This will be followed by a discussion of the development of the upright bipedal posture in man. This discussion will include the following:

  The factors that may have been responsible for the change from the quadrupedal state to upright human bipedalism, The functional and structural changes associated with these changes,

An overview of the comparative anatomy of the human in relation to other primates in order to formulate an explanation of the contribution of the musculo-skeletal adaptations to the attainment of man's permanent upright posture,

The functional consequences and impact of the attainment of the upright posture to neuromusculo-skeletal control in modern man.

☐ The fourth chapter briefly touches on human anatomical development from foetal life to adulthood. Here, changes which take place in the human structure during the course of the different stages of individual development, will be highlighted. Human ontogenetic and phylogenetic development will also be compared,

☐ In the fifth chapter the problem of malposture will be investigated. Additionally the normal musculo-skeletal functions and defects in each body segment, and the effects thereof on the total body or on other segments will be investigated,

☐ The sixth chapter investigates the neural mechanisms responsible for the control of the upright position in the human and its implications for exercise science and postural rehabilitation.

1.2.2 Posture from a psychological perspective

The primary purpose of this part of the study is to examine the relationships between the physical and the psychological from a postural perspective.

☐ In the seventh chapter the work and ideas of founder members of today's body therapies are reviewed, as well as the principles of their methods. This chapter will also investigate a number of physical and psychological approaches to postural and motor rehabilitation.

1.2.3 Quantitative an qualitative studies on posture in South African subjects

The third section will address some quantitative and qualitative studies done on some selected groups of the South African population.

☐ In the eighth chapter postural evaluations conducted on samples of adult middle aged senior executives and primary school boys, will be presented. This will be followed by two studies conducted on small samples, in which the outcomes of postural rehabilitation will be examined.

1.2.4 Conclusion and recommendations

The final chapter attempts a perspective and evaluation of the role and meaning of posture in integrating the physical and psychological spheres of life. Reasons for recommending improved posture are listed, as well as means to achieve this goal. The chapter concludes with suggestions for further postural research.

CHAPTER 2

POSTURE

> *Standing is actually movement upon a stationary base, sway being inseparable from the upright stance* (Hellebrandt, 1938: 473).

> *Standing is a complex phenomenon. Its evaluation is composed of the sum total of many diagnostic signs, changing in an infinite variety of ways* (Hellebrandt, Riddle, Larsen & Fries, 1942: 148).

2.1 POSTURE AND *POISE*

> *Posture has long been thought of in terms of standing and sitting, and correct posture as the erect position assumed when one is under inspection, but posture should really be considered as the sum total of the positions and movements of the body throughout the day and throughout life. It should include not only the fundamental static positions in lying, sitting and standing and the variations of these positions but also the dynamic postures of the body in motion or action, for it is here that posture becomes most important and most effective. Posture has a direct relation to the comfort, mechanical efficiency and physiological functioning of the individual* (Howorth, 1946: 1398).

The above is how Howorth (1946) summed up the whole issue of human posture. Dart (1947: 74) had the following to say on the same subject matter:

> *The human machine certainly meets more differing conditions and performs work of greater diversity than any known*

> *mechanism. These functions are efficiently discharged when the body is in a state of* ***poise.*** *Visceral functions (such as those of digestion, circulation, respiration and excretion) as well as physical activities must continue with the maximum of efficiency and the minimum of interference with their rhythm whether the body is supine or prone, erect or bent, twisted or straight. Integration of these vegetative and voluntary activities of the body occurs, and their rhythm is maximal, when the body enjoys* ***poise****, because it is only when the voluntary (or striated) musculature is working in a balanced way that it is making minimal demands on the vegetative (or unstriated musculature). The striated musculature, which was elaborated for movement of the body as a whole, can only work in a really balanced way when it is responding without impediment to the vestibular organs of balance through the mechanisms elaborated for that purpose by the central nervous system - in other words, when the reflex neuromuscular apparatus of body-balance is integrated with the neuromuscular apparatus of non-reflex, purposeful or intentional movement.*

Others (Alexander, 1932; Barlow, 1990; Feldenkrais, 1985; Goldthwait *et al.*, 1952; Painter, 1986) have all echoed the opinions of Dart and Howorth, yet the condition of malposture is pandemic in urbanised and industrialised communities (Dart, 1947; Sherrington, 1946). Lawson-Wood and Lawson-Wood (1977: 13) were of the same opinion when they observed mankind in totality:

> *The erect position has NOT been attained by the overwhelming majority of mankind. It is true that human beings approximate more or less to the upright stance: it is just this more-or-lessness that conceals from people the fact that their stance and dynamic posture is still inefficient, uneconomical, and wastes a great deal of vital energy.*

Therapeutic procedures have been directed towards reducing or eliminating malposture; many of these were unfortunately based on partial understanding of the true nature of posture, its underlying principles and mechanisms, and therefore have had limited success (Barlow, 1990; Dart, 1947). In Chapter 3 (section 3.4) an attempt will be made to come to a clearer understanding of the origin and mechanics of the upright posture. The lack of understanding of the basic anatomical and biomechanical mechanisms involved in the upright human posture, and its resultant erroneous approaches in the treatment of postural problems such as low back pain will be highlighted. In this and the following chapters the question of posture and all its ramifications will be further pursued, with the eventual aim to apprehend its real nature. Once this is achieved a logical therapeusis for malposture may be elaborated.

In order to come to the essence of posture a few approaches to this issue will be investigated below.

2.1.1 Towards a definition of posture

> *Posture as a* ***state*** *of the body is defined by two relationships which we separate - that of the body to the ground and that of the parts to each other* (Martin, 1977: 25).

Alexander (1932, 1987), Barlow (1990), Feldenkrais (1972, 1985) and Howorth (1946)'s contention was that the individual should accept that posture is a twenty-four hour proposition, **and that only he can correct it, and then only if he knows how, wishes to do it and applies himself to it continuously.** Posture-consciousness, or in a broader sense, consciousness/awareness of the self, should therefore become part of the individual's life in order to form and maintain good posture and body mechanics (Alexander, 1932; Dart, 1947; Feldenkrais, 1985).

In Chapter 1 (section 1.1) it was outlined that the term posture is derived from the Latin root *positūra* which means *"to place"*. This may imply that the term posture denotes the placing of body structures in a fixed position, with the result that posture should be viewed from this point of view. Feldenkrais (1985) also linked position to posture by stating that position describes the location and configuration of the various segments of the body. Posture, on the other hand, according to Feldenkrais (1985: 53):

> *.....describes the use of the entire self in achieving and maintaining this or that change of configuration and position.* ***Posture*** *is therefore describing action, and is a dynamic term.*

Riley, Mann and Hodge (1990: 503), went further and linked the orientation of body segments to balance when they asserted that:

> *Posture, the position and orientation of body segments, and balance, the control of the center of gravity (CG) or center of force (COF) position, are coupled; most postural adjustments change the CG location.*

The control of body segment placement, that is, posture, by the central nervous system is to maintain balance (Riley *et al.*, 1990), an opinion with which Feldenkrais (1985: 53) is in agreement:

> ***Posture*** *relates to the use made of the entire neuromuscular function, or more generally, the cerebrosomatic whole; that is, the way the affect, the motivation, the direction and the execution of the act is organized while it is performed.* ***Posture*** *must, therefore, be used to describe the way the idea of an act is projected and the way the different segments of the body are correlated to achieve a change or to maintain a state.*

The link of posture to balance will be one of the central principles of this study. Balance, as far as this study is concerned, is not only about the placement of body segments, shown in Figure 2.1, but balance within the structures concerned with this the positioning of structures, and their neural control.

2.1.2 The dynamic nature of posture

Research, as well as the work done by those involved in body work, are pointing towards the dynamic and ever-changing element in human posture (Alexander, 1932; Feldenkrais, 1985; Hellebrandt, 1938; Riley *et al.*, 1990; Rolf, 1977; Valk-Fai, 1973) - in fact Howorth, already in 1946, referred to what he called "dynamic posture".

To Howorth (1946: 1401) good dynamic posture implied:

> *···the use of the body or its parts in the simplest and most effective way, using muscle contraction and relaxation, balance, coordination, rhythm and timing, as well as gravity, inertia and momentum to optimum advantage.*

Dart (1947), however, considered Howorth's (1946) dynamic posture to be nothing other than approximate poise or approximate mobile equilibrium, something which may be qualified as good, better or best. *Poise,* on the other hand, Dart (1947) felt, are either present or absent, and posture being something habitual or fixed - must with increasing fixation, ultimately become *malposture.* Alexander (1932) maintained that posture is best judged by the way in which an individual moves and carries himself.

The basic standing position has, according to Barker (1985), Dangerfield (1996), Howorth (1946), Lawson-Wood & Lawson-Wood (1977), Rolf (1977), Safrit (1986) certain ideal characteristics (Figure 2.1), characteristics which are in accordance with the principles of balance outlined in section 2.1.1. Basically the erect body should be **vertical** and essentially straight when seen from the side as well as from the back. Three dimensionally the different segments of the body should be stacked squarely on top of each other (Figure 2.1) - deviation from this ideal being viewed as a postural abnormality (Rolf, 1977). The vertical line should pass through the ear, shoulder, centre of the hip and ankle when seen from the side - the physiological thoracic and lumbar curves should be slight and the pelvis erect rather than tilted forward. The feet and knees should be directed forward, and the arches of the feet should not sag. The chest should be erect but not fully expanded or tense, the abdomen flat and relaxed, neither sagging nor pulled in. The shoulders should rest comfortably on the crest rather than be held rigidly back with the arms turned outward. The position should be held with the spine rather than with the shoulders. The body should achieve its full height in this position, with the head and chin level and not inclined backwards. There should be a feeling of tallness, with the top of the head pulling away from the feet.

All postural tests are constructed around the premise:

> *...that the less the jointed body parts deviate from the vertical, the smaller the rotational stresses demanding equilibration by muscular contraction and the less the energy cost* (Hellebrandt & Franseen, 1943: 225).

Others, however, are of a different opinion, and feel that the above ideal biomechanical posture, in which joint centres are linearly arranged, are not to be expected in healthy populations (Woodhull, Maltrud & Mello, 1985) (Figure 2.1b). Woodhull *et al.* (1985) and others (Barker, 1985; Brunnstrom, 1954; Fox & Young, 1954; Gowitzke & Milner, 1988) stated that the vertical line falls anterior to the ankle joint, where two opposing forces - gravity and the tension of the *soleus* muscles - operate a first class lever system - the axis through the ankle joint lies between the *soleus*, acting from behind and gravity acting in front of the ankle axis (Gowitzke & Milner, 1988; Smith, 1957).

A third approach puts the vertical line behind the ankle joint (Barlow, 1990) (Figure 2.1c).

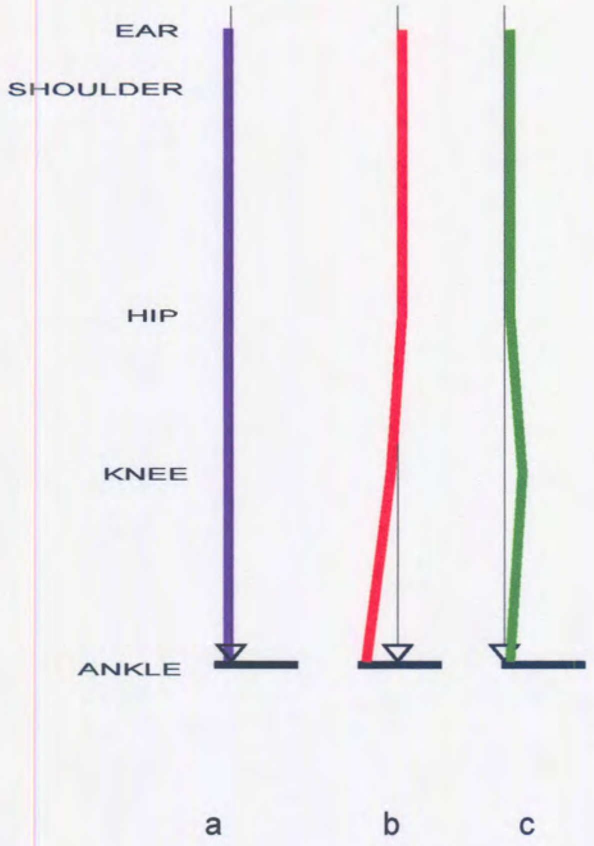

Fig. 2.1 **The biomechanical " ideal" upright standing position according to various opinions (a). Standing with the gravity line (black line) going through the ankle joint (Howorth, 1946; Kendall & McCreary, 1983; Kummer, 1962; Rolf, 1977; Safrit, 1986) (b). Standing with the gravity line in front of the ankle joint (Barker, 1985; Gowitzke & Milner, 1988; Kummer, 1962), and (c) the Alexander approach, with the gravity line behind the ankle joint. The knees are also slightly bent (Barlow, 1990).**

The standing position is generally the way in which posture is evaluated (Kendall & McCreary, 1983; Safrit, 1986). Although apparently static, it should, however, be realised that simple postural analysis such as this may yield abundant information about human structure, in as much as any posture - good or bad - is the outcome of neuromusculo-skeletal (tripartite) control; control which is largely the outcome of what has been learnt in the past (Alexander, 1932; Feldenkrais, 1985; Massion, 1992).

The basic tenet of this study, then, is that posture - dynamic or static:

a) Is the physical and observable consequence of the effect of the environment on the individual and of what has been learnt before,

b) Gives an indication of the arrangement of different structures in relation to each other in an individual's body, and by means of this,

c) Gives an indication of the way in which the body musculature is balanced and controlled.

The above approach is in accordance with that of Dart (1947) in that the aim of learning should be towards **the acquisition of *poise*.** This is, according to those involved in postural rehabilitation, only possible through careful study, observation and increased bodily awareness (Alexander, 1932; Dart, 1946, 1947; Feldenkrais, 1985; Hanna, 1988; Plummer, 1982; Rywerant, 1983). *Poise* - and therefore one of its visible components, posture - will then become a body state of **balance and its maintenance** (Dart, 1947). The individual, accordingly, is either balanced or not, and when this is considered, Dart's (1947: 76) definition of *poise* makes sense:

> ***Poise*** *is a character of repose or rest in the good body whether it is in the relatively static positions of lying, sitting or standing, or is actually in progressive motion during the activities of life's daily routine or of sport.*

Feldenkrais (1985: 110) brought perceptual motor learning and psychological aspects into this definition by stating that:

> *Correct posture is a matter of emotional growth and learning. It is not acquired by simple exercising or by repetition of the desired act or attitude. Learning is not a purely mental occupation, as many people believe, just as the acquisition of*

> *skill is not a purely physical process. Essentially it consists in recognizing in the total situation - environment, mind and body - a relationship in the form of a sensation that in the long run becomes so distinct that we can almost describe it in a sensible language.*

Good posture, Feldenkrais (1985: 54) also felt, is associated with a specific emotional state:

> *The common association of good posture with poise - that is, mental or emotional tranquility - is in fact an excellent criterion of good posture. Neither excessive muscular tension nor emotional intensity is compatible with good posture. Good posture means acting fast but without hurry; hurry means generally heightened activity that results not in faster action, but only in increased muscular contraction. Good posture means using all the power one possesses without enacting any parasitic movements.*

Interesting also is Howorth's (1946) basic "dynamic posture", which is characterized by a slight crouch, with the ankles, knees and hips flexed, the head and trunk inclined forward and the trunk slightly flexed, the arms relaxed and slightly flexed. With the body in this position he found that the muscles were in a midposition with increased tone, balanced and ready for instant and powerful action in any direction (Figure 2.2). In this position the muscles are able to act as springs, absorbing shock and initiating movement. The similarity between this and Alexander's (see Barlow, 1990; Drake, 1991; Jones, 1979) *position of mechanical advantage* is striking - the basic differences being Alexander's emphasis on lengthening in the spine and neck and the release of unnecessary tension in the muscles. If correctly executed, this position will produce a state of plastic tonus throughout the extensor muscle system (Jones, 1979), allowing the position to be maintained with minimal muscular effort, since all the body parts are in dynamic balance. According to Dart (1947) this is a primitive posture approximating that of the Kalahari Bushman - a position he referred to as the *humanoid orthograde posture.*

Fig. 2.2 **The human *orthograde* posture (Dart, 1947), the position of mechanical advantage (Jones, 1979) or dynamic posture (Howorth, 1946). Drawing: M. Langston.**

2.2 THE INFLUENCE OF GRAVITY ON HUMAN STRUCTURES

Even though the human body has evolved over millions of years and is structurally and functionally well adapted to the erect position, the earth's force of gravity is a constant presence that tends to unbalance this balanced structure. Hellebrandt and Braun (1939) wrote about the ever-present collapsing stresses of gravity that must be constantly equilibrated by muscular contraction. The result of this is motion even while standing perfectly still. Today this phenomenon is referred to as *body sway* or *postural sway*. Postural sway is inseparable from the upright stance (Hellebrandt & Franseen, 1943).

The significance of body sway as a diagnostic instrument for the assessment of balance has been recognized, even in the previous century (Vierordt, 1862 quoted by Hellebrandt & Franseen, 1943) and at the beginning of this century 'steadiness of standing' has been used as a criterion for both motor power and neuromuscular control (Hellebrandt & Braun, 1939). The phenomenon of postural sway still holds such a fascination that it has been scrutinized by various investigators for different reasons with a myriad array of techniques, making it difficult to apply observations from one study to the next. Andres and Anderson (1980) wondered who at that time studied postural sway, and for what reason. They observed that scientists from numerous disciplines have studied body sway including neurologists who have utilized postural sway measures in the clinical assessment of motor function as well as otoneurologists who have employed tests of postural sway to assess the vestibular system. Control engineers who study the sensory system, scientists in the field of aviation and aerospace medicine and occupational health and safety scientists all find value in pursuing postural sway studies (Andres & Anderson, 1980).

2.2.1 Definition of postural sway

Standing balance is the dynamic process of maintaining a stable upright position and postural sway has been used as a measure of standing balance (Ekdahl, Jarnlo & Andersson, 1989; Hasselkus & Shambes, 1975). Ratliffe, Alba, Halium and Jewell, (1987: 503) defined postural sway in standing as follows:

> *A dynamic equilibrium in which individual movements of different joints result in oscillations of the body. The frequency and excursion of oscillations vary according to the body's ability to maintain an upright posture against opposing forces.*

2.2.2 The features of postural sway

To fully describe postural dynamics, movements of the 5 body segments should be considered, namely: the head, torso, thigh, calf and foot. The segments in the sagittal plane rotate around 4 joint axes located at the neck, hip, knee and ankle. Postural sway occurs like an inverted pendulum with the mandible having a relatively greater displacement during sway than the hip and knee. In normal individuals the lower extremity is used for postural fixation (Ratliffe *et al.,* 1987, also refer to Chapter 3, section 3.4 for more detail).

Swaying, which normally occurs during the standing at ease position, is not sufficient to alter the relationship of the line of mass of the different segments of the body to the appropriate joints. Intermittent activity thus does not occur in the groups of muscles which resist the extending or flexing force due to gravity (Joseph, 1962). On the basis of electromyographic studies of the upright human posture in which electrical activity in leg, hip and posterior hip muscles were recorded during the standing at ease position, Joseph (1962) concluded that the concept that the erect attitude is maintained by the balance between opposing muscle groups, and that in the maintenance of this and the normal pattern the ligaments play no part, is erroneous. This is so because Joseph (1962) only found continuous variable activity in the calf muscles - mainly the *soleus* - and in the lower thoracic posterior vertebral muscles. As a rule he found no activity in the tibialis anterior, the muscles of the thigh and the hip, and the lumbar and cervical muscles. These observations emphasize the notion outlined in section 3.4.2 that standing posture depends on more than just muscle contraction, but also on other parameters such as muscle tightness, and other passive factors such as elastic tension in tissues such as ligaments, deep fascia, skin and the fibrous framework of muscles (Smith, 1957). Joseph (1962), however, in his study did not determine whether his subjects were *poised* or not - one can therefore only assume that the presence or absence of electrical activity in the muscles studied, was that which supported the habitual upright position of his subjects. In view of the pandemic nature of malposture, which includes poor mechanical alignment of body structures on top of each other (Dart, 1947; Sherrington, 1946; Woodhull *et al.,* 1985; Chapter 8 - this study), the likelihood of malposture in Joseph's (1962) subjects is more likely than not. Activity - and therefore tension - in the *soleus* muscles of Joseph's (1962) subjects is probably explained by the fact that it counteracted the downward-forward moment caused by gravity, and so prevented his subject's bodies from falling forward (Gowitzke & Milner, 1988).

Some relative motion between the body segments also exists, something which necessitates continual balance corrections (Valk-Fai, 1973). Such motion will invariably necessitate muscular contraction to some extent, something which was not observed by Joseph (1962) in his study. The least activity exists at the knee and the motion of the head and the legs is balanced by the motion of the trunk. The motion of the various body segments has a balancing effect, which can be seen in the average position of the body segments relative to each other. Their relative position is such that the centre of gravity always stays at the centre of the body in a stable position (Valk-Fai, 1973).

Upright posture in standing and gait is coordinately controlled by specialized front-back (anterior-posterior) and left-right (lateral) body-movements which govern the body's centre of gravity and, in addition, dynamically regulate movement of visual, tactual and auditory stimuli relative to the sides, base and apex of the body. Differential right-left and forward-back movements act to self-generate equilibrating motions to stabilize the eyes and head relative to the observed horizon, and to stimuli that pass laterally and vertically around the body during motion (Smith & Arndt, 1970).

Anterior-posterior sway is normally greater than lateral sway (Hellebrandt, 1938; Hellebrandt & Franseen, 1943; Yoshida, Iwakura & Inoue 1983). According to Stribley, Albers, Tourtelotte and Cockrell (1974), it is twice as large. However, body sway after disturbance of balance, is large in all age groups and is more pronounced in the lateral direction even when the disturbance is in the anterior-posterior direction (Era & Heikkinen, 1985). In addition, deviation of the direction of oscillation of the body axis seems to be contingent, although Cernacek and Jagr (1972) found deviation of the body axis to the right when the eyes are open. This they contributed to the dominance of the left eye for verticality in healthy subjects.

There is a general agreement that the upright stance is steadied when the eyes are open and focused on a fixed point, and least stable with the eyes closed. Distraction, on the other hand, reduces sway (Hellebrandt & Franseen, 1943).

2.2.3 Effect of age on postural sway

Balance gradually becomes centrally controlled during childhood and many balance behaviours become automatic as a child becomes adult (see Massion, 1992). However, this process reverses itself in late adulthood as balance gradually begins to require greater conscious effort than it had before (Payne & Isaacs, 1991).

The extent of sway changes with age. Sheldon (1963) found that children from 5 to 14 years sway more than adults. Between the ages of 15 to 60 years, the amount of sway is relatively constant. After the age of 60 years, the amount of sway increases with increasing age (Fernie, Gryfe, Holliday, Llewellyn, 1982; Murray, Seireg & Sepic, 1975; Sheldon, 1963; Stribley *et al.,* 1974).

Sheldon (1963) emphasized the difference in control amongst the age groups; the 6 to 14 years group lacks control of random movements, which leads to an increased total area of sway, while the very accurate control of stance onwards to the forties seems to be due entirely to control over these movements. The best controllers are those in their twenties, who are able to control their sway within an area of one-fiftieth of a square inch (2,54 cm) in the space of one minute. Postural equilibrium in children does however improve rapidly and reaches a plateau at 10 to 12 years (Nelson & Zike, 1971).

In elderly persons the reflexive mechanisms were found to be relatively intact. When the posture is under the control of slower, higher level sensory integrative mechanisms, however, elderly persons are at some disadvantage (Stelmach, Teasdale, Di Fabio & Phillips, 1989).

The magnitude of a person's body sway while standing, is often used to indicate balance ability (Payne & Isaacs, 1991). Hellebrandt and Braun (1939) measured postural sway in subjects ranging from 3 to 86 years, and concluded that the mean location of the centre of gravity projection near the centre of the supportive base, was consistent at all ages. However, the magnitude of the sway about the centre of the base, tended to be larger in the very young and very old.

Hellebrandt, Mueller, Summers, Houtz, Heap and Eubanik (1950) stated that the normal adult utilizes 0.66% of the functional base of support in postural sway during upright stance, while Hasselkus and Shambes (1975) put the mean maximal percentages at 0.33%, explaining that the differences were due to greater accuracy in the measuring instruments. On a practical level, Hellebrandt and Franseen (1943) observed that when the feet are together the stance is unsettled, turning the feet out to an angle of 45 degrees or separating the feet, so as to equalise the coronal and sagittal diameters of support, steadies the stance. This approach is in agreement with what was suggested by Drake (1991).

Amplitudes, as well as extent of sway, differ significantly between age groups. Era and Heikkinen (1985) found that both these variables increase about twofold when proceeding from the youngest to the oldest age groups. The differences between the age groups were more pronounced in anterior-posterior sway than in lateral sway.

Standing balance is thus proven to be influenced by age, with impaired capacity for balance in the older subjects (Ekdahl *et al.*, 1989), probably caused by physiological decline of *poise*/posture with age (Overstall, Exton-Smith, Imms & Johnson, 1977). The result of balance loss in the elderly leads to an increase in falls. The average speed of sway was significantly greater for those who were inclined to fall when compared to those who did not fall (Fernie *et al.*, 1982). Apparently many accidental falls were caused by impaired balance with the problem being that the elderly are unable to correct their balance once they have stumbled, compared to the young who regain their balance rapidly and avoid an actual fall (Overstall *et al.*, 1977).

2.2.4 Gender differences

Men and women of all ages reveal different traits in postural sway and balance. Hanock (1894, quoted by Sheldon, 1963) found that in early childhood boys swayed more than girls, thus suggesting that the two sexes mature at a different rate in their control of stance. This might also suggest that they differ in their rates of deterioration in old age. Girls in the 7 to 13 year old age group are slightly better at maintaining balance than boys of the same age - girls averaging 10% steadier. For subjects more than 15 years old, there is no difference between the sexes (Stribley *et al.*, 1974). Yet Overstall *et al.* (1977), found that at all ages women sway more than men, and attributed this to a probable function of body mass/muscle mass ratio. Without attributing it to anything, Yoshida *et al.* (1983) confirmed the finding that the grade of sway in quiet standing was greater in women than in men. However, he also mentioned that the centre of force of the male was located more anteriorly than that of the female and the mass of the female group had a greater tendency to shift backward than did that of the males. Men also utilize a greater percentage of their base of support in sway (Hellebrandt & Braun, 1939). Ekdahl *et al.* (1989), however, insisted that overall, women show better standing balance compared to men.

Swaying can be considered as a homeostatic system of the body, according to Barlow (1955). This is a system which returns to a resting state of equilibrium when it is disturbed.

> *...postural adjustment is a homoeostatic mechanism which is largely under voluntary control, provided that the right amount of information about errors finds its way back from the muscle to the cortex* (Barlow, 1955: 659).

Barlow (1955) found that there is always a slight sway around a resting mid-point, never excessive, **except in neurotics who show a much larger sway.**

Andres and Anderson (1980) warned that body sway is a psychophysical as well as a physiological response.

> *Though kaleidoscopic at first sight, when carefully made, postural sway patterns are characteristic for each person and highly reproducible* (Hellebrandt & Franseen, 1943: 227).

2.3 MEASUREMENT OF POSTURE

> *The spirit of Plato dies hard. We have been unable to escape the philosophical tradition that what we can see and measure in the world is merely the superficial and imperfect representation of an underlying reality* (Gould, 1987: 239).

With this statement Gould (1987) tried to emphasise the fact that with the correct measuring tools the researcher will, if he persists, eventually be able to come to the true nature of things. In this section the attempts by researchers to measure and understand the underlying reality of posture will be discussed, and whether we have indeed been able to put Plato's spirit to rest. This will then be contrasted to the holistic approach of those who became pioneers in the field of posture.

The erect, standing posture has specific characteristics and measurable qualities. Although the human body is always balanced on the feet when standing, and the segments follow the same sequence, that is, head, neck, shoulders, thorax, abdomen, pelvis, legs and feet, the alignment of the segments and angle of the body as a whole towards the surface, shows great discrepancies (Barlow, 1990; Burt, 1950; Hanna, 1988; Rolf, 1977; Woodhull *et al.,* 1985). For purposes of comparison on a personal, general and developmental level reliable tools and reproducible results may deliver valuable information on a scientific level. These tools will be discussed on the following pages. It must be understood, however, that the outcomes of measurement with the help of these tools are only valid in specific contexts, and that some underlying reality will not necessarily be revealed (Capra, 1983). In posture this problem may be attributed to its many facets.

Both subjective and objective observations of posture are notoriously unreliable, being influenced by various external and internal factors such as prevalent tastes in aesthetic appreciation and the level of sensitivity or awareness of the subject (Gelb, 1981). For scientific purposes of evaluation, comparison or cataloguing, it is necessary to find reliable measuring tools and methods. Accuracy alone, however, does not make assessment of postural control valid, sensitive or useful. An understanding of the biomechanical, and neurophysiological bases for postural control and dyscontrol is the most valuable measurement tool available to the therapist involved in postural evaluation and rehabilitation (Horak, 1987).

In 1943 a review paper by Hellebrandt and Franseen appeared on the physiology of the vertical stance of man and in which they also covered tests and measurements of posture dating from 1909 to the then present. During the same year Massey (1943) published a critical study of methods for measuring posture. From both these extensive works, it becomes clear that in the first part of the century, posture and the measurement thereof was very important in both the physical educational and medical fields. They were pursuing a criterion for a good and healthy posture, as practitioners in both the medical and physical educational fields became aware of the detrimental effects of the industrialised society and sedentary lifestyle on posture (Barlow, 1990; Dart, 1947; Sherrington, 1946). That bad posture had an adverse effect on the general health of an individual came to be suspected at this stage and many efforts were made to prove and rectify this. Foremost in this respect was the work done by Goldthwait *et al.* (1952).

Hellebrandt and Franseen (1943) observed that since 1900, few physiologists have interested themselves in the problems of body alignment. The validity of this statement appears to apply up to the present. They did not seem to have been impressed by either the methods or reasons for measurement, criticizing the fact that posture tests then in use were based almost exclusively on an untenable static concept of standing. Lee and Brown (1923) were of the opinion that the subjective rating of a physician who sees the body in use, may give a fairer evaluation of stance mechanics than that attainable from a single instantaneous objective observation. Alexander (1932) was a staunch supporter of this concept. This view was also held by observers in the latter part of the century (Gelb, 1981).

Problems with measuring methods do not necessarily lie with the method, but with the measurer. In the first half of the century efforts to measure posture have been made largely by lay observers (Hellebrandt & Franseen, 1943), yet posture evaluation in the hands of experts have considerable practical value and is useful for research purposes (Andres & Anderson, 1980; Massey, 1943; Winter & Hall, 1978). There is also a disparity about the nomenclature. Subjective methods could be seen as self evaluation in today's terms, whereas Massey (1943) saw them as rating by inspection, a qualitative test with no quantitative record and open to differences in interpretation. The same method of mass examinations by observation is considered to be objective, though unreliable, by Hellebrandt & Franseen (1943).

The literature contains a series of increasingly complex ways of testing and measuring posture in order to obtain a permanent record. These include the Vertical Line test and Triple Line test (1914), the schematograph (1915), the silhouetteograph (1923), Crampton's Total Ptosis test (1925) as well as the X-ray, pantograph, lithograph, centre of mass apparatus (1909) and photography. Co-ordinates were later included in the photographs to assist in evaluating the verticality of alignment (1934) and biplane stereoscopic photographs obtained a three-dimensional concept of body position with the use of mirrors. Variations in the depth of the antero-posterior curvatures of the spine have been scrutinized by the use of the lead tape, the conformature (1909), the comparagraph and by the application of light aluminium pointers to project skeletal parts which are invisible in profile view photography (1937) (Hellebrandt & Franseen, 1943). Early in the century photography gave satisfactory results but was viewed as an expensive method with the disadvantage of identifying the subject (Hellebrandt & Franseen, 1943; Massey, 1943).

Today photographs are a valuable method of documenting body alignment and spinal deformity (Barker, 1985; Winter & Hall, 1978).

2.3.1 Body sway

Body sway seems to be a phenomenon which has intrigued and drawn many investigators for many years. According to Andres and Anderson (1980) many techniques for body sway registration exist. The reason for this lies in the complexity of the control of posture (multi level reflexes, central motor programmes and psychological components) as well as methodological factors.

Romberg (1853, cited by Andres & Anderson, 1980) recognized and appreciated the diagnostic value of postural sway and subsequently attempts were made to quantify sway. At first the subject was placed in front of a grid pattern while the observer sat 10 feet away with one eye closed, writing down the maximum amplitude of observed sway. By 1887 graphic tracings were obtained by placing the subject, with a piece of smoked paper placed on the top of his head, under a stationary stylus. This ataxiagraph was used and modified for several years until the ataxiameter was developed around 1922 (Andres & Anderson, 1980).

Ataxiameters consisted of a helmet worn by the subject which had silk threads attached which were strung over pulleys, thus total movement in all directions could be measured. The disadvantages of both the ataxiagraph and ataxiameter were the mechanical loading of the subject and the fact that only head movements were measured and recorded (Andres & Anderson, 1980).

2.3.2 Unstable- and force platforms

During the 1930s unstable platforms projecting the subject's centre of gravity onto the base of support as a function of time, were constructed. At the same time the force platform, using bonded strain gauges, was being developed for studies of human locomotion. Since then and up to the present, many investigators have used different models of the force platform as tools to analyse postural sway. Andres and Anderson (1980) questioned the validity of the results of force platform measurements, citing the limitations of the assumption of an inverted pendulum body model, and the wide range of foot positions and relative body link positions that make comparisons difficult. Unstable- and force platforms mainly yield information on the control of postural steadiness and stability (Murray *et al.*, 1975), but do not give any information on the vertical alignment of the body, the shape and position of the different body segments (refer to computer and photographic techniques below).

2.3.3 Computer analysis of posture

Since the 1970s TV cameras combined with a computer analysis scheme have been in use (Dangerfield, 1996; Jones, 1979). Some of these require the use of photography as a basic tool (Dangerfield, 1996). Examples of these are Moiré photography and grating projection techniques. Moiré photography employs optical interference patterns to record the three-dimensional shape of a surface. This technique is useful in the evaluation of problems such as pelvic rotation and trunk deformity (Willner, 1979). At present it is also possible to produce three-dimensional reconstructions of the trunk by means of grating projection techniques (Dangerfield, 1996). Computer assistance also allows automatic calculation of parameters similar to those gathered by means of goniometers or flexicurves (Dangerfield, 1996).

Jones (1965, 1979) and Jones and O'Connell (1958) found multiple-image photography to be an ideal way of demonstrating posture in movement, a technique developed by the French physiologist Etienne Marey in the 1880s to enable him to analyse human and animal movement. This was the precursor of the motion picture and consists of leaving the camera shutter open and interrupting the light at fixed intervals with a perforated disc (Marey wheel) rotated in front of the camera. A movement could then be recorded as a succession of discrete images whose time relations were known. Marey called his refined method for human movement studies "geometric chronophotography". This consisted of dressing the subject in black, attaching metal reflectors at various places on the head, trunk and limbs and then taking the photograph in strong light against a dark background. The image of the subject disappeared, leaving only a black-and-white pattern showing the successive positions of the markers (Jones, 1979). Jones and O'Connell (1958) refined the method by attaching strips of reflecting tape to the subject and recording the moving image by repetitive strobe rates of 5, 10 and 20 flashes per second. The stroboscopic method is highly flexible and allows the subject a maximum of freedom to move. Patterns obtained in this way are sharp and clear-cut and contain a vast amount of information that can be quantified. Besides giving a gestalt of the movement, the method provides a large number of quantitative indices from the various trajectories. Patterns recorded in this way provide data that can be analysed graphically and statistically (Jones,1965; Jones,1979; Jones, Gray, Hanson & O'Connell, 1959).

In an attempt to evaluate the posture of public school students, grades 4 through 12, the New York State Education Department developed the New York State Posture Rating Test in 1966. The rating chart is used to assess 13 areas of the body, following the assumption that posture is the alignment of the body and its segments. This measurement method requires only a screen, rating chart and plumb line (Safrit, 1986).

Viewing the body posteriorly, 6 areas are observed and evaluated according to an illustrated rating chart provided for this purpose. The rating chart identifies the correct position, a slight deviation and a pronounced deviation from the correct position of the various body segments. A score is then allocated to each area according to the position: 5 points for the correct position, 3 points for a slight deviation and 1 point for a pronounced deviation.

Some of the identifiable defects which may be assessed by this procedure are the following (Safrit, 1986):

Head twisted or turned to one side; one shoulder higher than the other; lateral curvature of spine; one hip higher than the other; feet pointed out with ankles sagging and feet with lowered arches. Neck forward and chin out; chest depressed; shoulders forward; rounded upper back; rear inclination of the trunk; protruding abdomen and hollow lower back.

This often-used procedure is mechanistically oriented in its approach and only evaluates the arrangement and placement of different body segments, but makes no attempt to investigate aspects such as muscular use/integration.

2.3.4 Photography

Widely accepted and still the most valuable and suitable method of documenting postural information are photographs (Barlow, 1990; Safrit, 1986; Winter & Hall, 1978). Although unsuitable for quantitative analysis of certain aspects of posture such as trunk deformity and pelvic rotation, it is still a useful approach to use in the study of certain aspects of posture. These are:

> Accurate determinations of aspects such as the shape of the spine, pelvic tilt, vertical alignment of the body and its segments,or position of one body compartment relative to the other (Barlow, 1990; Rolf, 1977; Safrit, 1986; Woodhull *et al.*, 1985). Photographical records may yield similar results to that obtained with the New York State Posture Rating Test, discussed in section 2.3.3.

The basic underlying neuromuscular mechanisms involved in the maintenance of the standing position. Although qualitative, assessment of muscle tension in general and different body areas, may serve as a useful tool for future reassessment and correction (Barlow, 1990).

Photography is a valuable method of documenting body deformities and imbalances. A series of photographs of different views of the body taken at one session and compared with subsequent photographic sessions show the degree of improvement and effectiveness of the therapy or treatment. The static and visual nature of this measuring tool allows for repeated perusals of the subject matter. A series of photographs is ideal for deformities such as scoliosis or kyphosis where an ideal series consists of frontal and posterior views, posterior oblique, right and left lateral upright and lateral forward bending views (Winter & Hall, 1978). Postural alignment can be measured with relative rating scales or with goniometers and rulers from photographs by referencing anatomical landmarks to a rectangular grid or plumb line (Horak, 1987).

2.3.4.1 Photographic methods

Moire photography uses optical interference patterns to record the three-dimensional shape of a surface. It has been used to evaluate pelvic and trunk rotation and trunk deformity (Willner, 1979).

Stereophotogrammetry (Dangerfield, 1996) uses two cameras to take overlapping pairs of photographs. These can be analysed to produce a three-dimensional contour map of the subject. The technique has been adopted in the evaluation of structural deformity of the trunk and for posture measurement but has limited application in the study of scoliosis.

An extension of the above technique is stereoradiography where two x-ray images are used instead of photographs (Dangerfield, 1996). This technique is invasive and potentially hazardous due to the use of ionizing radiation. It has found only limited application.

Non-invasive methods of postural assessment employ either scanning light beams or projection of structural light patterns onto the subject. Such methods are accurate and offer the potential of fast acquisition and analysis of results, particularly with the recent advent of high speed image processing boards within computer systems (Dangerfield, 1996).

2.4 REFLECTIONS ON POSTURAL RESEARCH

A review of the literature on the subject of posture measurement tools, emphasises the uncertainties about what should be measured and the significance of the outcome of the measurements.

It is easy to conclude with Horak (1987: 1884) in that:

> *Simple, quantitative measures with stopwatches, scales, video recorders, photographs, wall grids and plumb lines can become powerful tools when they are applied with a basic understanding of what these measures indicate in terms of the central nervous system's control of posture.*

This underlines the experience of many researchers that observations and measurements by an untrained observer cannot always be relied on. A thorough understanding of the human nervous system, muscles and movement, is the most valuable asset when evaluating posture. In this respect researchers such as Barlow (1990), Dart (1947) and Jones (1979) made valuable contributions.

The trained and knowledgeable mind will discern muscle weaknesses, -over contraction and -imbalances when viewing the individual as a whole. The enlightened scientist or therapist is able to make an informed guess as to the cause of the imbalance, be its origin muscular, nervous, psychological or misuse. By asking the right questions as to the cause of the discerned problem, or by comparing relevant photographs, the trained worker is likely to come to the right conclusion concerning the course to take in rectifying the problem and to be able to suggest a relevant exercise or therapy.

A scientific investigation of posture is easier to theorise about than to implement. The main obstacle in the present study was a lack of funds. Fortunately the above-mentioned training and experience could compensate to a large extent for the shortage of equipment. The present study has made liberal use of the experience of leaders in the field of posture. These include great names such as Raymond Dart, Phillip Tobias, Frederick Matthias Alexander, Frank Pierce Jones, Wilfred Barlow, Ida Rolf, Moshe Feldenkrais, Wilhelm Reich and Alexander Lowen. These personalities were all, each in his or her own way, a mixture of a philosopher, a scientist, a psychologist and a therapist. The main categories of interest in this group were: muscles pertaining to posture, posture and the skeleton (Alexander, 1932, 1941, 1987, 1996; Barlow, 1990; Dart, 1946, 1947; Feldenkrais, 1972; 1985; Jones, 1979; Tobias, 1982), posture and psychology (Lowen, 1969, 1971, 1975, 1994; Reich, 1999), fascia and posture (Rolf, 1977).

With the exception of Alexander, all the above-mentioned names were highly regarded conventional scientists and academics, yet their most inspired and significant achievements on posture were the results of experience rather than experiment. They came from different parts of the world, yet each in his/her different and individual way reached the conclusion that improving the posture improves the person as a whole. The contribution of these individuals to the field of posture will be discussed in the chapters to follow. Special attention will be given to their contribution to the understanding of the mind-body implications of posture in Chapter 7.

CHAPTER 3

THE DEVELOPMENT OF UNIQUE HUMAN CHARACTERISTICS: A PALEO-ANTHROPOLOGICAL PERSPECTIVE

The past is the key to our future
(Louis Leakey, quoted by Leaky & Lewin, 1993: xv).

But how successfully man will use his emerging power to steer the course of the future may depend on how well he understands the steps by which nature formed him in the first place
(Leonard, 1973: 100).

.....all things move spirally and all growth is helical
(Dart, 1950: 265).

For me, the fundamental distinction between us and our closest relatives is not language, not our culture, not our technology. It is that we stand upright, with our lower limbs for support and locomotion and our upper limbs free from those functions
(Leakey & Lewin, 1993: 81).

The uniqueness of modern man is seen as the result of a technical-social life which tripled the size of the brain, reduced the face, and modified many other structures of the body
(Washburn & Howell, 1960: 52-53).

God never wrought miracles to convince atheism, because his ordinary works convince it
Sir Francis Bacon.

For You have made him a little lower than the angels,
And You have crowned him with glory and honour
Psalm 8:5 (New King James Version).

3.1 INTRODUCTION

Man is an erect terrestrial biped (Tobias, 1982). The origin of the upright posture in man is some of paleo-anthropology's most persistent mysteries (Gebo, 1996). The morphological changes associated with this development are unique and extreme, developments which clearly gave impetus to the common idea that man is indeed the crown of creation (Psalm 8:5). The upright posture is not genetically determined, but a case of imitation of the previous generation (Morton, 1926). It did, however, take millions of years of evolvement to shape him to the current stage of structure and function (Leonard, 1973), in a process which, according to Joubert (1997), was part of a Great Thought [for a full discussion of this issue see Pelikan (1960) and Schroeder (1997)].

3.2 FROM A SINGLE CELL TO AN UPRIGHT MULTICELLULAR CREATURE

It took an estimated 3,000 million years of trial and selection for the first multi-celled creatures to acquire an inside and outside, front and back and mirror imaged right and left sides and thus became invertebrates (Leonard, 1973).

The invertebrates then gave rise to the vertebrates. Most important was the establishment of the spinal column, 500 million years ago, followed by the skull, teeth and jaws. The process of evolving limbs began some 400 million years ago. Fins made way for land going limbs. Platelike bones of the pelvis and shoulder developed to provide bases for muscles as did the fulcrums between limbs and spine. The transition from an aquatic habitat to a terrestrial environment caused body mass to become a factor to be reckoned with (Leonard, 1973; Morton, 1926; Phelps *et al.*, 1956).

The earliest limbs were stubby, projected sideways and caused a waddling gait. Not being underneath the body, they could not carry weight efficiently, nor move very far with each step. The feet were complicated, with 5 sets of articulated bones forming the toes (Leonard, 1973; Moody, 1953; Phelps *et al.*, 1956; Romer, 1964).

By 225 million years ago, mammal-like reptiles had evolved and were equipped for walking and running. Their limbs were nearly underneath the body and could swivel more freely at both ends. Movement of the limbs was backwards and forwards, parallel to the body. Feet were turned to point forward (Leonard, 1973; also see Dart's double spiral arrangement of body musculature in 2.3.2.8).

The first true mammals (± 150 million years ago) eventually gave rise to the primate line (between 80 and 50 million years ago) that culminated in man (Morris, 1969).

3.3 THE DEVELOPMENT OF HUMAN CHARACTERISTICS

Man is the only primate with the ability to stand fully erect for long periods of time, with full extension at the knee joint and minimal expenditure of muscular energy. This kind of uprightness is singular to the human species among all living primates. His striding gait is his other unique feature (Tobias, 1982; Wolpoff, 1996).

Non-human primates are also capable of standing or walking on their two hind feet but the functional relations between hip-bones and thigh muscles are such that the hip joint is then subjected to stress and must be bent. The forward displacement of the centre of gravity causes instability and to compensate for this, the knees must be bent. When the ape stands or walks bipedally, it assumes a bent-hip, bent-knee stance or gait (Tobias, 1982).

Whether terrestrial or arboreal life (Leonard, 1973; Phelps *et al.*, 1956) immediately preceded evolvement in a *humanoid*[1] direction is still a debated

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[1] Humanoids are members of the Superfamily: *Hominoidia* which includes the Family *Hylobatidae* (gibbons and siamangs) and the Family *Pongidae* which includes the Subfamily

issue (Gebo, 1996). Many of the exclusively human features are legacies of agile arboreal and/or terrestrial travelling ancestors, who freed their hands from the burden of support. Thus carrying became one of the key elements in the development of efficient bipedalism (Gebo, 1996). Other developments included the coming forward of the eyes to the front of the face together with the achievement of stereoscopic vision and also amazingly dextrous hands (Leonard, 1973; Phelps *et al.*, 1956).

3.3.1 The transformation from a quadrupedal to an upright bipedal posture

How the first upright hominoids developed from the quadrupeds is still not clear. A few of the theories put forth in the twentieth century and most pertinent to the development of the upright posture will be discussed below.

The purpose of this discussion is to draw attention to the emergence of several physical characteristics, some of which the human shares with other primates, and some which became uniquely his - characteristics which should, as will later be pointed out in more detail in section 2.3.2, continuously be attended to in the growing child and adolescent as well as the adult, in order to cultivate and maintain human well-being in all age groups (see Chapters 4 & 7).

About 25 million years ago some monkey-like creatures became bigger and heavier, their tails became obsolete and instead of scampering and leaping, they became climbing and/or brachiating[2] (Gebo, 1996; Keith, 1923; Morris, 1969). According to Dart (1970: 20):

Anthropithecinae to which man, their closest relatives, the chimpanzees, as well as the gorillas belong (Wolpoff, 1996).

[2] Brachiation implies life in trees, and is a form of under branch, hand-over-hand locomotion which uses the forearms for support and power and the pendulum characteristics of the swinging body for forward momentum (Gebo, 1996; Wolpoff, 1996).

> *He has been clambering along and swinging by his hands from branches and rearing himself up on his hind legs during only the past 10 million years or less.*

Scientists believed, with little proof, that the transformation to an upright stance probably occurred between 4 and 6 million years ago. A fossil find by Meave Leakey and her team in 1995 led them to announce that a species of hominid strode upright at least 4 million years ago (Gorman, 1995). Other finds date hominids to be older than the finds of Leakey (Shreeve, 1996). During the past century fossil finds led to different approaches in how man developed the upright posture. Some of these approaches will be discussed briefly with the aim to highlight those physical attributes which make up man, and basic reasons why they should still be considered in our daily lives. In this respect two issues are important; of which the first is the sequence and circumstances in which the present humanoid characteristics developed. The second issue is the importance of these changes to human physical activity at present, and the design of physical activity programmes, in so far as their purpose and content are concerned.

3.3.1.1 The historical precursors of hominid bipedalism and the upright posture

Keith (1923) proposed four sequential phases in human evolution: a pronograde[3] catarrhine monkey-like ancestor, a small bodied, orthograde[4], brachiating gibbon-like ancestor (the hylobatians), a large-bodied, orthograde arboreal ape-like ancestor (the troglodytians - eg chimpanzees) and a hominid[5] (human) phase of

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[3] Pronograde indicates standing and /or walking on four feet (Dart, 1947).

[4] Orthograde denotes a vertically upright posture (Dart, 1947; McDonough, 1994).

[5] Hominids are characterized by four uniquely morphological complexes (Wolpoff, 1996):

- The development of bipedal locomotion;
- Locomotor-related pelvic changes that altered the process of giving birth so as to make it more difficult;
- The development of language and culture;
- Alterations in masticatory function that combine some dental and craniofacial adaptations for very powerful grinding.

upright plantigrade[6] progression. The great anthropoid apes practised frequent brachiation, and this upright position probably preceded bipedalism in the early hominids (Keith, 1923). Morton (1926) also inferred that an arboreal (tree living), vertically suspended posture was the inevitable source of a terrestrial vertically supported posture. This was widely accepted and it seems as though the adaptations made for arboreal life, later imminently suited the varied life styles of a terrestrial biped (Jones, 1979; Lawson-Wood & Lawson-Wood, 1977; Morton, 1926; Phelps *et al.*, 1956; Tobias, 1982). The "brachiationist" theory later fell into disfavour (Gebo, 1996), even with Keith (1940) abandoning his own explanation.

The idea that dominated paleo-anthropology for a century, however, was that upright bipedalism developed in early hominids who lived in the Savanna. The upright position would then allow these early hominids to see over tall grass, escape predators, or walk more efficiently over long distances (Shreeve, 1996). Recently the discovery of new hominid fossils from Africa pointed in a new direction, in that upright bipedalism developed in a forest environment (Shreeve, 1996).

Kinematic studies have shown little similarity between human and primate bipedalism, but surprisingly a connection between human bipedalism and vertical climbing was found, despite a different arrangement of hip musculature (Prost, 1980) (also refer to 3.3.2.2). Today the vertical-climbing hypothesis is the most generally accepted explanation for the development of the upright posture (Fleagle, Stern, Jungers, Susman, Vangor & Wells, 1981) - an approach which suggests that climbing is the biomechanical link between brachiation and bipedalism (Fleagle *et al.,* 1981).

The discovery of the skeleton known as "Lucy" (*Austalopithecus afarensis)* in the Afar Triangle of Ethiopia in 1974 was a milestone in that it preserved enough

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[6] Plantigrade is locomotion with the entire sole and heel of the foot on the ground (Wolpoff, 1996).

detail to analyse early hominoid posture and locomotion (Lovejoy, 1988). "Lucy" walked upright, had a rather straight spine; a feature also observed in the later *Homo erectus* (Phelps *et al.,* 1956; Swanson, 1973). Of interest in "Lucy" was her long arms and curved fingers which hinted at tree climbing (Shreeve, 1996).

Phelps *et al.* (1956) and Gebo (1996), argued that climbing and its morphological associations only represent primitive hominoid adaptations, while Wolpoff (1996) added that these adaptations led to subsequent pongid skeletal adaptations for brachiation and arm hanging. Although primitive, these adaptations to vertical climbing and a brachiating type of body plan brought about significant changes in the thorax, shoulder girdle and upper extremity structure and function (see section 3.3.2.2). Gebo (1996) felt that this alone could not explain the mass bearing adaptations retained in the hands and feet of hominids. Quadrupedalism was a necessary element in travel, and it was here that ancestral African apes developed a foot morphology associated with heel-strike plantigrade footfalls, a mass bearing wrist and perhaps knuckle-walking fingers as functional-adaptive complexes for terrestrial quadrupedal travel (Gebo, 1996; Wolpoff, 1996). Hominid bipedalism continued the trend of terrestrial travelling, but now with freed hands for carrying articles while travelling (Gebo, 1996).

In 1924 Raymond Dart discovered the skull of a fossil child near Taung in the Northern Cape Province (Dart, 1925). His analysis of this skull forced the world of paleo-anthropology to appreciate that there had indeed been, at one time in Africa, ***small-brained*** but upright walking members of the family of man. He also compelled the realization that not all parts of the putative human ancestors' bodies had become hominized at the same rate or at the same time (Tobias, 1982).

Thus the development of the major characteristics of the human body form and stature **preceded the humanoid expansion of the cranium and brain and the ultimate refinement of facial characteristics**, observations already made early in this century by Dart (1925) and Morton (1927), observations which were later verified by subsequent research (Tobias, 1982).

Two aspects of the uprightness of man make the study of human posture important *viz*: 1) erectness of the trunk and 2) the bipedal stance or gait (see Tobias, 1982). Since the time of Darwin, most scientists in the field have tended to concentrate on bipedalism only when speaking of uprightness (Tobias 1982). Some workers concluded that this freed the hands for cultural activities and made handling of tools possible (Washburn & Howell, 1960). Vevers and Weiner (1963) suggested that the bipedal stance, although not essential for the emergence of tool-using activities, must have been crucial for the change from tool-using to tool-making. Washburn and Howell (1960) supported this idea, although they modified their own view by conjecturing that tool use is both the cause and effect of hominid bipedalism. According to the latter viewpoint, Washburn and Howell (1960) came to the conclusion that evolution of erect posture occurred simultaneously with the earliest use of tools. Tobias (1965; 1982), however, eloquently argued that a habitual upright posture and bipedal gait were not a necessary prerequisite either to effective tool-using or to rudimentary tool-making. He went further and stated that most of the implemental activities of man are carried out in the sitting position (Tobias, 1965). Sitting leads to greater trunk stability, and stability is a most important structural and functional consideration in the development of manual skills. Tobias (1965, 1982) deducted that trunk uprightness probably long preceded that of the fully *orthograde* (standing or walking erect) posture and might have been present some 50 to 60 million years ago and added that:

> *Perhaps students of human evolution have been inclined to take truncal erectness too much for granted and scarcely to include it in their thinking on the upright posture. Yet it was a fundamental and most ancient phase in the evolution of bipedalism* (Tobias, 1982: 12).

In the transition from the quadrupedal to brachiating habits, the functions of the spine changed somewhat. Whereas it acted as a bridge between the fore and hind limbs of the quadruped as well as a base for the suspension of the abdominal viscera, it then became the direct means of suspension of the pelvis and legs and the abdominal viscera within the bowl-like pelvis (Phelps *et al.*, 1956).

From the above it is clear that man has a rich structural and functional heritage, which eventually found expression in man's present physical characteristics and -abilities. These adaptations imply that man is designed and ideally equipped for a certain set of physical functions - functions which have anatomical, physiological and psychological implications. Small wonder then, that sedentary Modern Man is now becoming more and more aware of the value and importance of his heritage of movement, and the fact that his total well-being depends largely on it (Kraus & Raab, 1961; National Institutes of Health, 1997; Pate, Pratt, Blair, Haskell, Macera, Bouchard, Buchner, Ettinger, Heath, King, Kriska, Leon, Marcus, Morris, Paffenbarger, Patrick, Pollock, Rippe, Sallis & Wilmore, 1995).

The author is of the opinion that movements related to this heritage and human uniqueness are those that ought to be developed and implemented in all societies that have fallen prey to the modern sedentary lifestyle. Participation in **all** our ancestral physical patterns is not only a fundamental requirement in the development and maintenance of a number of essential items such as posture, muscular coordination, agility, balance - in short *poise*, but also may help maintain our functional ability throughout life. These exercises/activities should, as far as posture is concerned, serve to maintain the integrity and stability of the arms, shoulder and pelvic girdle, back thorax and lower limbs. The baby, for example, has to go through a number of apprenticeships such as crawling in order to master the upright bipedal position (Feldenkrais, 1985). Even in adults it makes good sense to return to our ancestral quadrupedal patterns such as crawling, climbing, hanging on branches, swinging whilst hanging (like gibbons) and walking (for example, our early ancestors and some present nomadic tribes), since movement in which fundamental and ancestral neural patterns are used, serves many purposes in growing children and adolescents, adults, and in those with neuromuscular dysfunction and common problems such as learning disabilities (Dart, 1947; Dennison, 1980; Feldenkrais, 1972, 1985; Gelb, 1981; Hannaford, 1995; Wikler, 1980). If the correct emphasis is placed on the proper use (employment) of all the body structures, the above type of exercises do not only serve to strengthen and maintain structures and functions in the human body, but also form part of all of which is required for total well-being.

The purpose and functional suitability of the exercises prescribed in gymnasia and physical education mainly cater for the improvement of so-called fitness parameters, posture and motor skills, by mainly concentrating on muscles **responsible for movement**, and subsequently do not address functions of those muscles primarily concerned with aspects such as neuromuscular coordination and the correct use/employment of various human structures (Armstrong, 1993; Baechle, 1994; Christaldi & Mueller, 1963; Fenton, 1973; Schrecker, 1971; Yessis, 1992). Armstrong (1993) blamed this on Christian thought in the Middle Ages which sought to mortify the body as a way to serve the spirit. Thinkers during the later Enlightenment ignored the body and located the source of a person's identity securely in the mind (Armstrong, 1993). René Descartes (1596-1650), the great French philosopher, wrote that there is nothing included in the concept of the body that belongs to the mind, and nothing in the mind that belongs to the body. To the mind Descartes ascribed spiritual things, while the body was merely a machine like a clock which worked according to mechanical and mathematical laws (Brom & Jaros, 1990). Armstrong (1993: 78) is strongly of the opinion that attitudes like these made intellectual *"'Mr Duffy's' of us all"*. Armstrong (1993: 78) added:

> *Intellectual activity came to be identified almost exclusively with logical-mathematical and linguistic abilities. Physical activity was assigned a lower-class status and restricted to the bedroom, the shipyard, and the playing field. Even today, with many Americans experiencing a kind of Renaissance in physical fitness, bodily culture is associated more often with Nautilus machines, weight training programs, and racquetball courts than with anything having to do with the mind. Athletes are all too*

> *often seen as "dumb jocks", and working with the hands in manual arts is assigned a second class status in comparison to the "higher" world of the humanities and sciences.*

The rapid changes mankind had to contend with since becoming "civilised" also took its toll (Alexander, 1987: 1-2):

> *The effect of these rapid changes upon a creature, who heretofore had experienced only slow and gradual changes of environment and was still subconsciously guided and controlled, could hardly fail to be harmful, inasmuch as many of his instincts, in consequence of these changes, came to survive their usefulness, whilst many of those new instincts which were developed during his* ***quick*** *attempts to meet the new demands of civilization proved to be unreliable. This degree of unreliability increased as time went on, until an observant minority became aware of a gradual but most serious deterioration, a deterioration, however, which unfortunately they recognized as a physical deterioration only, and which, at what must be considered as a psychological moment in human development, they attempted to set right by the adoption of "physical exercises."*

By regarding purposeful physical activity as an intelligence in its own right, however, this rift between body and mind may be healed (Armstrong, 1993). Recently an upsurge occurred in the use of exercises concerned with the development, integration of the nervous system, and the use of key postural muscles and the mind, exercises such as those developed by teachers of the Alexander Technique (Brennan, 1992; Drake, 1991), Dart, (Dart, 1946; 1947), Dennison (1980), Feldenkrais, (1972; 1985), Hanna, (1988), Hannaford (1995) and Pilates (Pilates & Miller, 1998; Robinson & Fisher, 1998; Robinson & Thomson, 1997; 1999). In Chapter 7 some activities/exercises, particularly designed for the improvement of *poise*, and more particularly posture will be discussed.

3.3.2 The effect of the advent of the upright bipedal posture on human structure and function

The way in which the body had to adjust its structure and biomechanics to the upright bipedal position may, according to Tobias (1982), be described as little short of ingenious, as will be seen in the discussion to follow. The acquisition of the upright position has been made possible by anatomical adjustments affecting every part of the skeleton and locomotor apparatus from the cranial base to the feet (Tobias, 1982).

Why the bipedal and upright posture developed in early hominoids is not clear at present [see Steudel (1996) and Tobias (1982)]. The human form of bipedalism was certainly not an adaptation for speed, since most mammals of similar body size can outrun a human (Wolpoff, 1996). The real advantages of the upright posture are manifold. Firstly it increases the visual range (Ravey, 1978). Secondly, the consistent use of the hind limbs alone frees the hands for carrying food and offspring, and manipulating the environment (Wolpoff, 1996). Thirdly, humans have evolved particularly low energy forms for locomotion. Striding allows them to cover long distances, without expending undue amounts of energy (Wolpoff, 1996), and without developing excessive metabolic heat (Wheeler, 1984). Whether the latter two served as an incentive to the early hominoids to develop an upright position is still a debatable issue, since it is doubtful whether the energetic efficiency found in modern man, was accrued by the early bipeds (Steudel, 1996). Increased locomotive efficiency and improved body temperature control, however, allow present day runners to compete in long distance events such as the Comrades marathon.

Some obligatory structural and functional changes had to be made before permanent upright posture was possible. These changes had serious consequences for the control and management of the human posture, and the function of some muscles. This should be taken into account in the daily functions of the body and in the prescription of exercise, especially to the aged, and those with a history of having been inactive for extended periods of time, with a proven postural abnormality and/or deficient muscle coordination.

Central to the adaptations for the upright posture were the pelvic bones and the spine, the muscles associated with these structures, and the way in which the body is propelled forward (Krogman, 1962; Lovejoy, 1988; Wolpoff, 1996). These changes preceded that of the changes towards a large cranium and brain size (Tobias, 1982) (also see 3.3.1). In order to understand these changes the basic mechanism responsible for the forward propulsion of the quadruped has to be considered (Figure 3.1), and the way in which this led to the eventual evolution of structures and function, to accommodate for the permanent upright posture.

3.3.2.1 Forward locomotion in the quadruped

As an introduction to this and the following section (3.3.2.2) it should be stated that locomotion and posture are physiological correlates (Phelps *et al.,* 1956). The structure and physiology of quadrupedalism and bipedalism, as well as their distinctive pelvic features reflect the different mechanics of two legged and four legged locomotion (Lovejoy, 1988). **Insight into locomotion is essential since it was quadrupedal locomotion that eventually gave rise to upright bipedalism** (Phelps *et al.,* 1956).

In the quadruped the centre of gravity lies well ahead of the hind legs (Bürger, 1986; Froissard, 1988; Krogman, 1962; Lovejoy, 1988). In order to propel itself forward the quadruped must apply a force in the opposite direction to the direction of travel. This is accomplished by extending all the joints of the hindquarters, structures which lie between the centre of gravity and the ground. Lengthening a leg therefore gives the propulsive thrust to move the animal forward (Figure 3.1). The required lever action is achieved by means of active

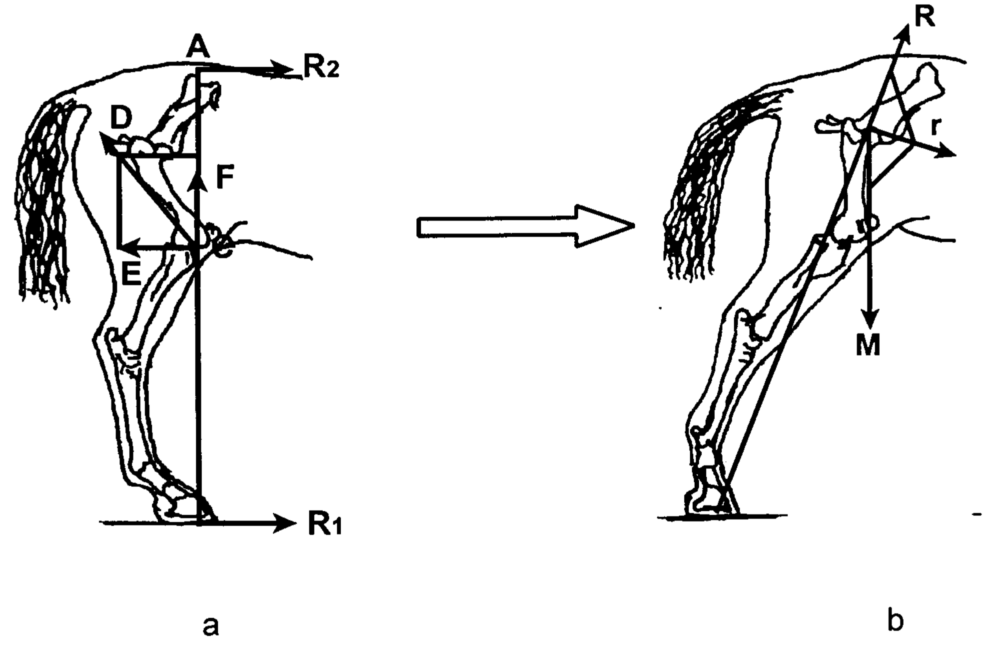

Fig. 3.1 Quadrupedal locomotion. a. The hind limb as a propulsive lever. AB = long limb axis, hip joint to toes. CD = line of action of hip extensor muscles, which resolves in force E which extends hip, and force C along the long axis, AB. R_1 = reaction of ground against backward pressure of foot. R_2 = reaction of acetabulum against backward pressure of femur. Forces E and R_2 produces a couple which extends the hip joint, forces $R_1 \cdot R_2$ and E have bending action on the limb long axis. b. The hind limb as a propulsive strut. W = mass acting through the hip joint. R = reaction from ground. r = resultant of M and R causing forward movement of the trunk (Adapted from Belasik, 1994; Krogman, 1962; Lovejoy, 1988).

extension of the hip joint by contraction of the well developed *gluteus medius* and *gluteus minimus* muscles, resulting in a backward pressure of the foot on the ground (Figure 3.1) (Krogman, 1962; Lovejoy, 1988). During this phase the knee and ankle joints are kept slightly bent, and their passive extension, which may occur due to the pressure of the foot on the supporting surface, is prevented by the action of the strong extensor muscles in the hip joint. This is where muscles that span two joints - in this case the hip- and knee joints for the hamstrings - exert their effect (Krogman, 1962). When the long axis from the hip joint centre to the ground contact slopes down - and backward, the hind limb acts as a propulsive strut. The portion of the body mass resting on the extended (retracted) limb plus the reaction from the ground gives the resultant force required to propel the body forward (Krogman, 1962; Lovejoy, 1988), hence, the hind limb is a **passive** propulsive strut. When the limb is well retracted, extension of the knee is useful in the last part of the propulsive phase, since the limb now functions as a propulsive strut. Complete extension of the knee is prevented by the action of the *hamstrings* and the *gastrocnemius* muscles.

Because the hip- and knee joints are tightly flexed at the start of each propulsion cycle their extension can be prolonged and powerful (Lovejoy, 1988).

3.3.2.2 Bipedal locomotion

The upright human posture, in contrast, places the centre of gravity almost directly over the ankle joint (Kendall & McCreary, 1983; Lovejoy, 1988). Although this arrangement allows the human to maintain the upright position with relatively little muscle effort (Krogman, 1962; McArdle, Katch & Katch, 1991), it created unique problems for the upright biped in so far as forward locomotion and maintaining of balance were concerned.

If the standing upright human mimics the action of the quadruped hind limb, and lengthens his legs by straightening the knee and rotating the ankle, the direction of the thrust will be vertical, and the individual will only manage to stand on his toes (Lovejoy, 1988).

Upright walking on two legs is at the best of times a precarious affair, something which led to Napier's (1967: 56) statement that human walking is *"a unique activity during which the body, step by step, teeters on the edge of a catastrophe."* The great teacher of physical anthropology, Hooton, referred to man as *"this tottering biped"* (Tobias, 1982: 16), or as Gorman (1981) aptly commented that human gait is a constant play between loss and recovery of equilibrium.

In order to propel the upright body *forward* the human has to reposition its centre of gravity ahead of one leg (Lovejoy, 1988). This is accomplished when the calf muscles relax and the walker's body sways forward. The sway then places the centre of gravity of the body in front of the normal pedestal formed by standing on the two feet. This necessitates one of the two legs to swing forward, to keep the trunk from falling, and when his foot makes contact with the ground, the area of the supporting pedestal is widened, and the gravity line again rests within it. The pelvis plays an important role in this action; its degree of rotation determines the distance the swinging leg can move forward, and its muscles keep the body balanced while the leg is swinging (also see 3.3.2.3.2) (Napier, 1967).

During the forward swinging of the leading leg the trailing leg is then lengthened, which allows this leg to behave as a propulsive strut (Krogman, 1962; Lovejoy, 1988) (Figure 3.2). This is accomplished by pushing against the ground first with the ball of the foot and then with the big toe (Napier, 1967).

In erect walking the action of the *gluteus maximus* acts on the hip, the *quadriceps* on the knee, and the *soleus* on the ankle in order to preserve the respective joint integrity. Since hip extension contributes very little to bipedal locomotion, active propulsive thrust is accomplished by plantar flexion of the ankle and extension of the knee (Krogman, 1962; Lovejoy, 1988). This action then lengthens the trailing limb, thus producing its forward thrust on the surface, while the other leg is swung forward to prevent the trunk from falling (Lovejoy, 1988).

3.3.2.3 Anatomical changes required for the upright position in the human

Undoubtedly, an erect squatting posture was as common among the early mammals, as it is among the modern ones. This act, however, did not, and still does not, require any change in structure, for squatting merely required a backward swing of the body and thighs upon the knees - a movement which was, and still is, well within the normal range of knee joint and ankle joint movement (Morton, 1926).

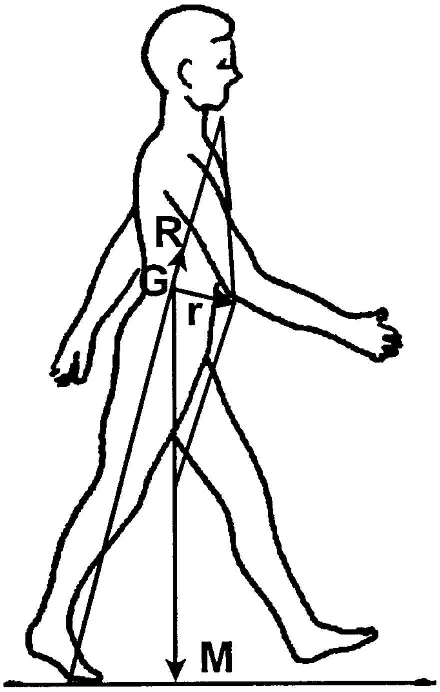

Fig. 3.2 **Human locomotion (Krogman, 1962; Lovejoy, 1988; Napier, 1967) showing the lower leg as propulsive strut. M = mass acting through the centre of gravity (G), R = reaction from the ground, r = resultant of M and R. Note pelvic position in comparison to that seen in the quadruped (Figure 3.1).**

Many quadrupeds are able to raise themselves into an upright position on extended legs for short periods of time. This, however can only be accomplished by an abnormal motion of the hips in non-humans, something for which they are entirely unfitted (Morton, 1926).

With the new bipedal position new roles for structures in the human body were necessary. These changes are listed below in Table 3.1, those pertaining to this study will be discussed in more detail. Probably the most important of these changes were those in the lower limb and pelvic area (Figure 3.3) (Hansson, 1945; Krogman, 1962; Lovejoy, 1988; Napier, 1967; Wolpoff, 1996). Perusal of

1945; Krogman, 1962; Lovejoy, 1988; Napier, 1967; Wolpoff, 1996). Perusal of these adaptations will reveal that all of the activities found in the vertical climbers and the brachiating primates are those that come naturally in man - activities which presently are still found in our repertoire of movement. Examples of these are tree and rock climbing, hanging from one support and then swinging from one to the other as in gymnastics.

Lewis (1972) postulated that the knuckle walking in African apes was the result of limitations of their brachiating capabilities, while Tuttle (1975) argued that these anatomical adaptations evolved together.

Table 3.1 ***Anatomical features necessary for brachiation, vertical climbing and upright bipedalism. The table shows both hominid uniquenesses and characters that reflect the human climbing and arboreal ancestry (Hansson, 1945; Marzke, Wulstein & Viegas, 1992; Phelps et al., 1956; Wolpoff, 1996).***

ANATOMICAL SITES	ANATOMICAL FEATURES		
	Vertical climbing	**Brachiation**	**Bipedalism**
Upper limbs	Large primates use long and powerful arms (especially at elbow). Grip is with support held diagonally across the fingers.	Powerful grip and longer arms, much longer fingers to surround support (example branch). Grip much stronger, diagonal with fingers, but without involvement of thumb and palm. Finger bones long and curved.	Powerful grip and long arms long fingers. Grip is between thumb and fingers. Human is only primate with precision grip between finger(s) and thumb.
Shoulder girdle	Climbing does not necessarily require a flattened chest. In a flattened chest, however, the scapulae could migrate posteriorly, with the development of a long collar bone with an outward-facing shoulder joint. The shoulder joint itself is shallow - allowing wider motions.	Scapulae migrated posteriorly. Glenoid fossa cranially oriented.	Scapulae migrated posteriorly. Glenoid fossa cranially oriented.

ANATOMICAL SITES	ANATOMICAL FEATURES		
	Vertical climbing	Brachiation	Bipedalism
Spine & thorax	Thorax funnel shaped and probably flattened.	Spine and trunk short with only three lumbar vertebrae. Chest funnel shaped, short and flattened.	Trunk not shortened. Spine has 2 primary and 2 secondary curves, with 7 cervical, 12 thoracic and 5 lumbar vertebrae. The thorax is funnel shaped and flattened.
Pelvis	Sacrum and ilium long, tilted horizontally.	Sacrum and ilium long, tilted horizontally.	Sacrum and *ilia* tilted vertically. Shortening of sacrum, ischium and iliac bones. Broadening of pelvic rim. Reorganization of musculature associated with pelvis.
Lower limbs	Short legs, grasping feet and offset big toes.	Grasping feet and offset big toes.	Loss of grasping ability. Adapted for mass bearing and plantigrade locomotion.

3.3.2.3.1 Changes in the structure of the sacrum and ilium

Undoubtedly, the human upright posture has been derived from the horizontal posture of the ancient quadruped (Phelps *et al.*, 1956). In the quadruped position the iliac bones and the sacrum lie more or less in a horizontal position (Figures 3.3 & 3.4), and they do not in essence fulfil the function of supporting the mass of the upper body. When the quadruped such as a chimpanzee tries to stand upright, the situation, however, changes. Both the sacrum and iliac bones are then tilted into a vertical position and now have to support the upright trunk, with a skeletal and muscular system functioning at a biomechanical disadvantage by having the centre of gravity well above their hip joints (see 3.3.2.3.2 below). In the upright standing chimpanzee the sacrum is tilted backwards relative to the ilium (Figures. 3.3 & 3.4), and supports the upright spine when the chimpanzee leans slightly forward (Wolpoff, 1996), which pushes the centre of gravity line well in front of the ankle joint, resulting in an unstable position, requiring considerable muscle output to maintain.

Once man was on its feet, the result was that all the mass of the body had to be transmitted downwards through the pelvis and legs (Tobias, 1982).

In the upright human the function of the sacrum became one of supporting the entire mass of the upper body (Wolpoff, 1996). To keep the centre of gravity line passing through the acetabula, the knee- and ankle joints the sacrum had to be tilted forward relative to the ilium (the advantage of this arrangement will be discussed in 3.3.2.3.2 below). A second change brought the centre of gravity point of the upper body closer to the hip joints. This was accomplished by the shortening of the height of the ilium and the sacrum. The shortening of the ilium brought the articular surface of the last lumbar vertebra nearer to the hip joint, and enabled the mass of the trunk to be transmitted more directly to the lower limb, thus enhancing stability (Campbell, 1974).

The sacrum also became broad and flaring (Hansson, 1945; Kummer, 1975; Lovejoy, 1988; Pilbeam, 1990; Wolpoff, 1996). This and the backward bending of the ilium affected the posterior displacement of the sacroiliac articulation, thus equipping the human innominate bone better to carry and transmit mass (stress) between the axial skeleton and limbs, while at the same time providing an adequate birth canal (Gorman, 1981; Tobias, 1982).

The lumbar lordosis, the thoracic kyphosis and cervical lordosis of the human vertebral column were brought about by the changes in the orientation of the sacrum, in order to bring the centre of gravity of the upright body above the hip-joints, and to ensure that the body mass is more or less evenly distributed in front or back of the line of gravity (Gorman, 1981; Wolpoff, 1996).

The pelvic rim broadened in order to provide firstly an increased leverage of the balancing (abductor) muscles and secondly to produce a broader bowl-like surface in order to provide support to the viscera (in the quadruped the visceral support is the responsibility of the ribs) (Wolpoff, 1996). Bipedalism also caused the development of a prominent iliac pillar which is uniquely human.

This structure extends from the tubercle of the iliac crest down to the posterior part of the acetabulum and helps to bear the compression exerted by the *gluteus medius* muscle when it tilts the pelvis during human walking, and so draws the trunk over the stationary limb, enabling the contralateral limb to clear the ground (Tobias, 1982).

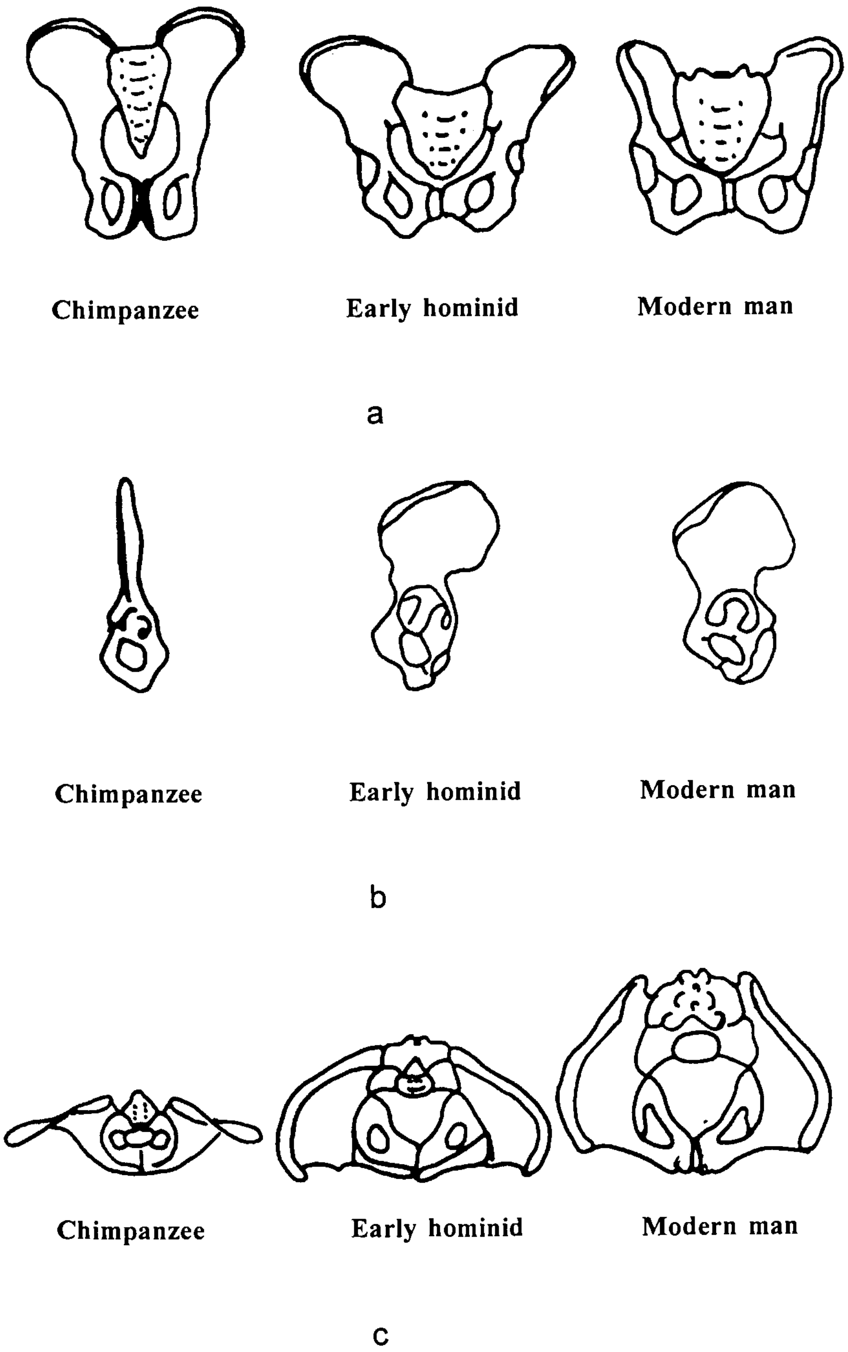

Fig. 3.3 Front (a), side (b) and top (c) views of the pelvis of a chimpanzee, early hominoid and modern man. Note the shortening of the sacrum and iliac bones, the broadening and rotation of the pelvic rim. [a and b from Wolpoff, (1996), and c from Lovejoy, (1988)].

3.3.2.3.2 Changes in the pelvic musculature

The need to stabilize an upright torso required a dramatic change in the body musculature. The most conspicuous change occurred in the *gluteus maximus* muscle, which is a relatively minor muscle in the quadruped (see chimpanzee in Figure 3.4), into the **largest and most powerful muscle** in the human body (Gorman, 1981; Lovejoy, 1988; Wolpoff, 1996). The *gluteus maximus* originates over much of the back of the pelvis and is attached to the back and side of the femur (Gorman, 1981; Lovejoy, 1988; Williams & Warwick, 1980; Wolpoff, 1996). As such it is classified as a hip extensor, and many classical anatomists believed that it served as the major propulsive muscle in upright walking (Lovejoy, 1988; Wolpoff, 1996). This is achieved, according to them, by the active extension of the hip, an action which results in a backward pressure of the foot on the ground similar to that seen in the quadruped (Krogman, 1962; Lovejoy, 1988). In the human, however, the hip is almost completely extended in erect walking and running, and therefore the contribution of the *gluteus maximus* to this function is limited (Lovejoy, 1988). Why then the hypertrophy of this muscle? This muscle fulfils the role of a **stabilizer of the trunk**, and when it acts from below (femur) it rotates the pelvis backwards, thus shifting the body's centre of gravity backwards. This is done in conjunction with the hamstrings (Gorman, 1981). The muscle`s role as trunk stabilizer is best seen in walking and running. When the human runs the trunk tends to flex forward at each foot strike due to its momentum; the *gluteus* then prevents the trunk from pitching forward (Lovejoy, 1988, Wolpoff, 1996). It is the author's opinion that this function is lost in many individuals during standing and even sitting, who then rely on muscles in the lower back in order to remain in the upright position. This issue will be discussed in more detail in section 3.4.

A major modification of the pelvis made the stabilizing task of the *gluteus* considerably easier (Lovejoy, 1988). In the chimpanzee and other primates the pelvic iliac bones are considerably longer than they are in humans. This lengthens the torso of these animals when they rear up - which disadvantages them by having their centre of gravity well above their hip joints. Biomechanically the animal will be at a handicap, since the trunk now forms a long lever arm, which makes it difficult to maintain the upright position for extended periods. A *gluteus maximus* working to hold such a trunk upright will fatigue rapidly (Lovejoy, 1988; Wolpoff, 1996).

In the human the problem of the upward shifting of the centre of gravity was elegantly solved by the dramatic shortening of the iliac bones and curving the innominate bone in a lordotic sense (backward rotation of the ilium) so that the sacrum and spine could be brought in a more upright position, bringing the trunk`s centre of gravity much closer to the hip joints, thus reducing the muscle`s mechanical disadvantage (Figures 3.3 & 3.4, and section 3.2.3.1) (Hansson, 1945; Kummer, 1975; Lovejoy, 1988; Pilbeam, 1990; Wolpoff, 1996).

In the quadrupedal locomotion the hamstrings serve as powerful hip joint extensors (see 3.3.2.1). In the biped, by contrast, the function of the hamstrings decreased in importance in that they do not serve to extend the lower limb any more but to **control** it (Lovejoy, 1988). In man they now serve to stabilize and flex the knee-joint, and decelerate the forward swinging leg during walking and running (Baratta, Solomonow, Zhou, Letson, Chuinard, & D`Ambrosia, 1988; Lovejoy, 1988; Wolpoff, 1996). As a consequence of the decreasing importance of the hamstrings the lower rear portion of the pelvis, where they originate, namely the ischium, became shorter (Wolpoff, 1996). In an upright positioned pelvis stiff or shortened hamstrings will, by way of its small lever action on the pelvis, have little effect on the pelvic position, but will of course reduce the range of motion during hip flexion. This leads one automatically to question the motivation of many to resort to stretching of the hamstrings in order to, amongst other things, alleviate low back pain (Cailliet, 1995).

The anterior gluteal muscles (*gluteus medius* & *gluteus minimus*), which in the quadruped play an important role in hip extension during locomotion (Sigmon, 1975, and also see 3.3.2.1), assume a new role in the human. These muscles now acquire a stabilizing function, and also take on the function of abductors. The stabilizing function is best demonstrated during standing on one leg (something which occurs naturally during walking and running). On their own the pelvis and trunk will tip toward the unsupported side, but this is prevented from happening by the action of the anterior gluteals (Lovejoy, 1988; Sigmon, 1975).

The transformation of the anterior *gluteals* from propulsive muscles to stabilizing ones necessitated major changes in their position and pelvic structure. Firstly it required the forward rotation of each ilium (see Figure 3.3), and with it the upper origin of the anterior *gluteals* (Figure 3.4). Their insertion are now on the greater trochanter of the femur (Figures 3.4 & 3.5) (Lovejoy, 1988; Napier, 1967; Sigmon, 1975), an arrangement which suits their abduction and stabilizing function perfectly.

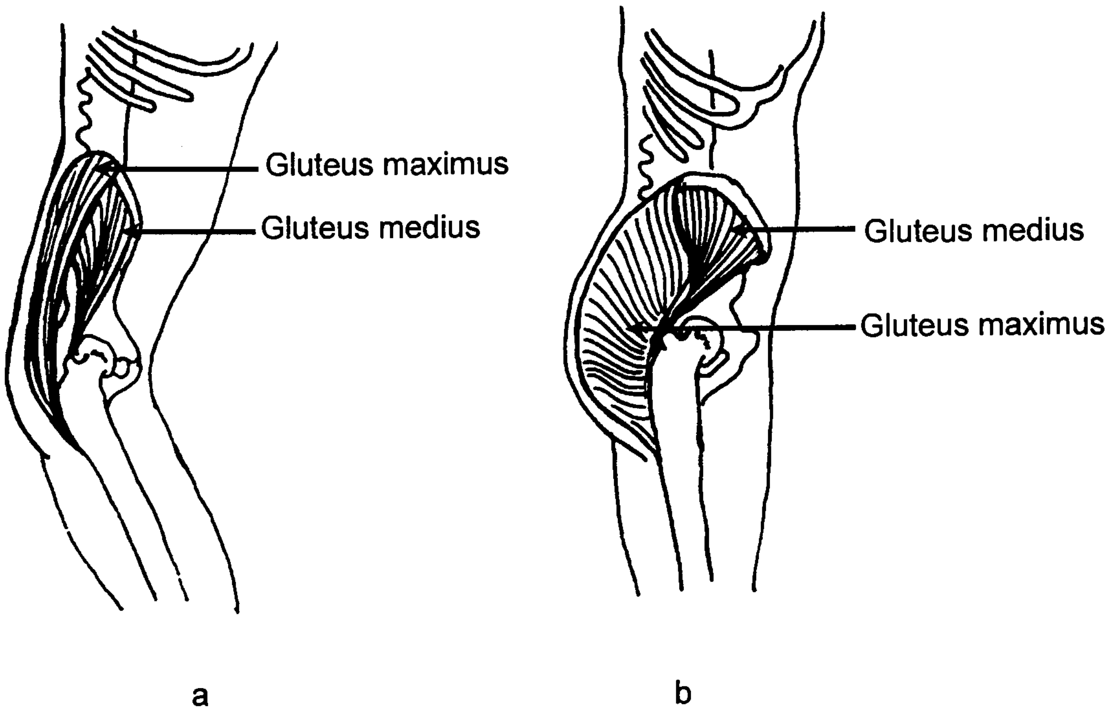

Fig. 3.4 **Anatomical adaptations in the pelvic area for the upright posture. (a) Quadruped (chimpanzee), (b) Human. Note new positions of muscles such as the *gluteus maximus*, and *gluteus medius* (Phelps *et al.*, 1956).**

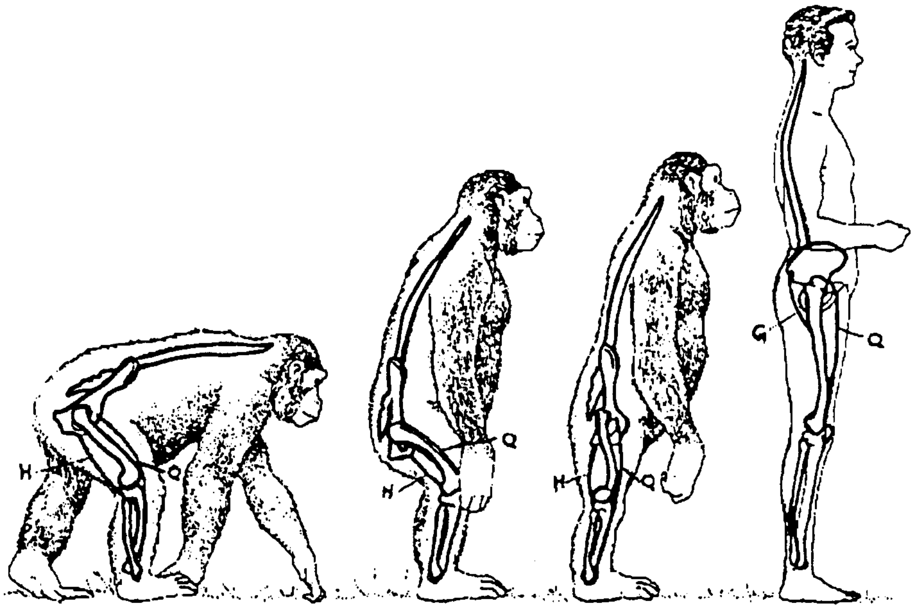

Fig. 3.5 Quadrupedalism and bipedalism in a chimpanzee compared with bipedal man. G = Gluteus maximus, H = Hamstrings and Q = Quadriceps (Wolpoff, 1996).

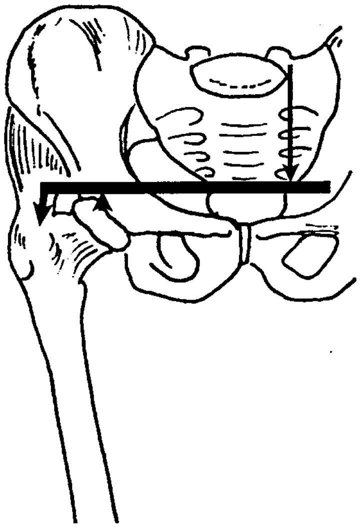

Fig. 3.6 The function of the hip abductors in counterbalancing the torso when standing on one leg or with the body mass unevenly distributed. Note the long lever arm of the trunk in comparison to that of the abductors. The fulcrum is the hip joint (Lovejoy, 1988).

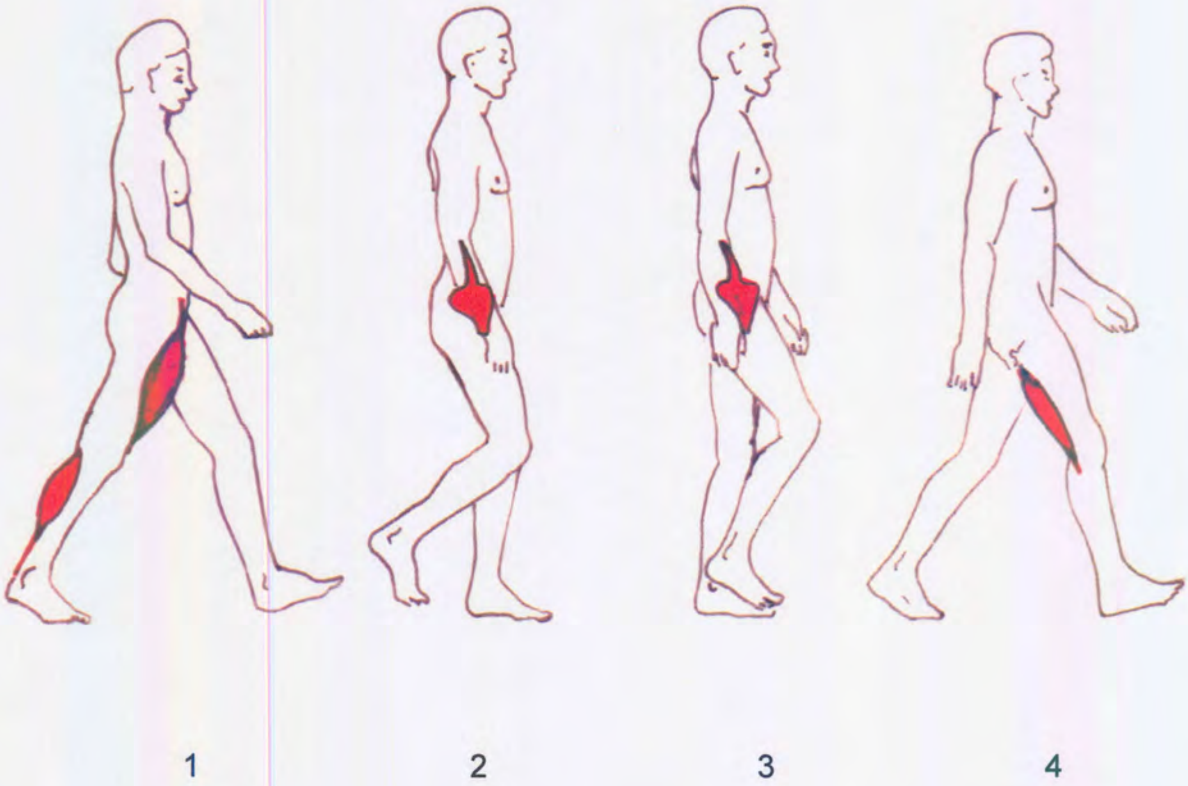

Fig. 3.7 **Muscle activity during human striding. As the mass-bearing (right) leg becomes angled behind the torso (1) two muscle groups contract to extend it - the plantarflexors, which rotate the foot around the ankle, and the quadriceps, which straighten the knee - generating a "ground reaction" that propels the body forward. The right foot then leaves the ground as mass is transferred to the opposite leg. Contraction of the right *iliopsoas* begins to tug the right leg forward (2) while the knee flexes passively (3). Near the end of the right leg's swing the hamstrings contract to stop the forward motion of the right leg, and the foot is planted (4) (Lovejoy, 1988; Napier, 1967; Wolpoff, 1996).**

In human beings, then, the demands of stabilizing the upright pelvis and controlling the limb occupy several muscle groups that serve for propulsion in quadrupeds. Only two muscle groups, the quadriceps and the plantar flexors, are left in positions to enable them to produce forward thrust during forward locomotion (Lovejoy, 1988), a situation which could be responsible for the human`s lack of speed when compared to that of quadrupeds.

Krogman (1962) postulated that human (as contrasted with hominid) evolution may well have begun in the pelvis. Three stages may be envisioned: 1) erect posture, due to changes in the size and proportions of the ilium; 2) balance, due to iliac-tubercle and iliac pillar changes; and 3) more nearly perfect bipedalism, as in man, due to ischial shortening and tubercle changes. This supports Morton (1926), who maintained that humanoid adaptations of the locomotor apparatus for terrestrial bipedalism preceded and outstripped the gross appearance of human changes in other structures. In any event, as seen above, the pelvis and hip region have been radically remodelled, producing low and broad iliac blades with outwardly oriented gluteal muscles permitting controlled rotation and tilt of the pelvis to minimize the centre of gravity displacement. A linked pattern of hip, knee and ankle flexion and extension and a particular pattern of weight transmission through the foot also emerged (Pilbeam, 1990).

Phelps *et al.* (1956: 11) were of a different opinion in that:

> *Man`s hip joint mechanism is less well adapted than the shoulder. It is a much later acquisition. The lumbo-sacral junction is even less adapted. It is still in a transitory state of evolution.*

This is more in agreement with the recent viewpoint that changes in the shoulder and arm were primitive adaptations to life in the trees (Gebo, 1996).

3.3.2.4 Changes in the structure and function of the spine, thorax and neck

Function and structure of the spine adapted again when brachiation changed to terrestrial bipedalism. In brachiation it acted as a tactile support when hands were used in locomotion; in stance it became the supporting column. The rounded forward spinal curve, which previously extended throughout the length of the spine, remained, but was concentrated in the upper dorsal region (Phelps *et al.*, 1956).

The size of the vertebral bodies increases from the cervical area to the lumbar area to compensate for the increase in pressure from the head to the pelvis (Gorman, 1981; Williams & Warwick, 1980). The shapes of the vertebra are such that they cause the very human characteristic of the more curved spine. The cervical and lumbar areas of the human spinal column curve strongly convexly forward, while the thoracic and sacral regions have a concave curve. The most human features of the vertebral arrangement are the strong concave curvature of the sacrum and the powerful promontory at the lumbo-sacral border (Schultz, 1936, cited by Tobias, 1982).

The top of the spine migrated from its position in the back of the skull, to a point almost directly under the skull (Leonard, 1973). The brain developed upward and backward and the increase in size was offset by a reduction in the snout. The combination of facial flattening and bipedal posture resulted in a foramen magnum being relatively far forward (Pilbeam, 1990). Thus the cranium could be balanced over the centre of gravity of the body (Phelps *et al.*, 1956, Tobias, 1982). With an erect posture more of the mass of the head is carried directly by the neck vertebrae. The human head is thus well-balanced on the atlas and therefore does not need large muscles to keep it in place as is the case with the other primates. Subsequently the spinous processes of the cervical vertebrae decreased, reflecting the lesser role of the nuchal muscles (Tobias, 1982, 1983). Poking the head forward is a regression towards the ancestral ape-like condition, and puts unnecessary tension on the muscles in the neck, the upper back and shoulder girdle. This habit requires the use of long spinous processes such as found in the cervical spine of the ape (Tobias, 1982).

The elongated sternum of the human skeleton is a typical mammalian structure, probably confined to land vertebrates as it is absent in fish (Gorman, 1981; Williams & Warwick, 1980). It is considered as being part of the axial skeleton but has been associated with the shoulder girdle and ribs from its earliest appearance. Man has a flatter thoracic cage, compared to that of other primates and subsequently, the sternum lies closer to the spinal column (Tobias, 1982). The bodies of the thoracic spinal vertebra project well forward into the thoracic cavity, encroaching into the thoracic space and causing the horizontal section of the thorax to be kidney-shaped (Goldthwait *et al.,* 1952; Gorman, 1981).

The shape of the thorax is a matter of considerable significance from the point of view of body mechanics. According to Goldthwait *et al.* (1952) at the level of the ninth rib the antero-posterior diameter should be about two thirds of the lateral diameter and the circumference at this level should be greater than in the axillary region. The sternum in the erect posture should be convex anteriorly, with the lower end considerably anterior to the upper. Goldthwait *et al.'s* (1952) ideal shape of the thorax in the horizontal section seems rounder compared to the phylogenetically developed genetic shape proposed by Tobias (1982) and current average shape (Martini, 1992; Rolf, 1977; Tobias, 1982). Horizontal sections of this body part are not common in publications and only an approximate comparison can be made. However, from a biomechanical view the barrel shape of the monkey and ape chest is a sign of poor body mechanics when found in the human (Goldthwait *et al.*, 1952).

The curve of the thoracic spine is a remainder of the original foetal (or primary) curve which extended throughout the length of the spine. Throughout the phylogenetic development of man, the change in the thoracic spine was less marked than in the rest of the spine because the ribs and attachments of the chest discouraged flexibility (Phelps *et al.*, 1956). Flexion in the region is of relatively small range, extension is almost non-existent (Gorman, 1982).

3.3.2.5 Changes in the structure and function of the cranium

Kruger (1988) is of the opinion that man could only have a developed a human face in the presence of an upright posture. This became possible since the mouth lost its function of fighting or catching/holding prey. The massive jaw muscles could be dispensed with, and since the jaw is now less important in the self preservation of the individual, the human skull could develop upwards in order to accommodate a larger brain.

Because of the upright posture, smell has lost its orientative function, while vision and hearing have assumed domination. In the animal all structures associated with grasping and gripping, such as the jaws and muzzle are placed in the viceline of the eyes. The reason for this is that the arms, now being free to grasp, hold and carry, have taken over these functions (Kruger, 1988). These changes allowed the human to use the eyes to:

> *.....concentrate with an open look at distant things and rest fully on them, viewing them with detached interest and of wondering. This changing or changing of the human face into a seeing face is well expressed in the German word 'Gesicht', the Afrikaans 'gesig' and the English 'visage'* (Kruger, 1988: 46).

Having transformed the prominent animal and primate jaws into human mouths, one of the conditions for the development of language were fulfilled (Kruger, 1988). The front to back shortening of the human skull also ensured that the skull could be balanced with minimal muscular effort on the top of the cervical spine (see 3.3.2.4) (Tobias, 1982).

When highly developed vision was required for accurate targeting, binocular vision was acquired, giving three-dimensional vision and accurate assessment of distance. This happened when the eyes were brought to the front of the face, below the large brain. This meant that our ancestors had to tilt their heads backwards in order to see the front - producing the first concave curve of the spine, that of the neck (Barker, 1985).

3.3.2.6 Changes in the structure and function of the shoulder girdle and upper limbs

Phelps *et al.*, (1956) held the theory of two distinct stages in prehuman development. The first was the preparatory stage when quadrupeds grew upright into tree-living types and the second stage began when they moved to the ground and underwent the final transitions towards humanity - taking the first step on the road to modern humans (Leakey, 1995). This first adaptation required profound anatomical changes, especially to the arms and hands which had been used as forelimbs for walking, then for suspension from the trees and finally achieving freedom for tool-using when they became the upper extremities. During this process the shoulder girdle bones and muscles altered their positions and number. The scapulae migrated posteriorly from the lateral position and the *pectoralis minor* insertion shifted from the humerus to the *coracoid* process. Shoulder movements then became complex and precise (Phelps *et al.*, 1956). Waterland and Munson (1964) referred to the shoulder girdle and -joint as the most mobile arthrodial complex in the body, also noting that it has the same cortical area of representation in the brain as the little finger. The motor coordination of the multi-jointed upper extremities seems to be dependent on appropriate shoulder girdle modulation. The scapula, clavicle and shoulder joint form a mechanical unit joining the rest of the skeleton at the sterno-clavicular joint. In the human the clavicle rotates around the sternum, the scapula around the clavicle and the humerus around the scapula (Gorman, 1981).

Human shoulder structures and their positions were probably developed during the arboreal era. In this stage locomotion was divided between swinging from branches and walking on the ground. Suspension of the total body mass from the arms caused considerable traction and the structures of the shoulder joint, scapula and clavicle were profoundly modified. The greatest change was the development of power while the arms were in circumduction and in particular, abduction. Man is unique in this respect - he can move his arms in an infinite variety of positions and retain the grasping power in all of them (Gorman, 1981; Phelps *et al.*, 1956).

In the quadruped the scapulae lie symmetrically laterally on the sides of the thorax (Phelps *et al.*, 1956; Tobias, 1982). With the additional functions and movements of the arms, the scapulae came to lie further back on the thoracic wall, side by side, decreasing the distance between the scapulae and the midline of the back (Gorman, 1981; Phelps *et al.*, 1956).

The clavicle is absent or reduced in many running mammals (Gorman, 1981; Phelps *et al.*, 1956). In primates it was strengthened during the development of the arms for climbing and grasping activities and serves as a mobile strut for the limb to be steadied in a variety of positions (Gorman, 1981; Phelps *et al.*, 1956). In man this seemingly innocuous clavicle is central to the balance of the shoulder girdle and very important to the structure of the body as a whole (Rolf, 1977).

The size, shape and position of modern man's scapulae and clavicles seem to have developed their full and optimal potential during his arboreal stage (Phelps *et al.*, 1956). Present day's misuse leads to deformed shapes of the chest such as kyphosis, "wings" and hollow chest. One may speculate that doing exercises which emulate the movements of the arboreal stage, in other words, swinging from elevated supports, might return the bony structures of the shoulder girdle to their ideal locations.

A grasping type of hand evolved with the thumb becoming opposed to the fingers; shoulder girdle muscles altered their positions and number; the scapula migrated posteriorly and the *pectoralis minor* insertion shifted from the humerus to the coracoid process. Shoulder movements thus became complex and precise (Phelps *et al.*, 1956; Wolpoff, 1996). The clavicle was strengthened to give a firmer anchor for the powerful shoulder girdle muscles (Leonard, 1973).

3.3.2.7 Changes in the structure and function of the lower limbs

The head and neck of the femur, as well as the supra-acetabular region of the ilium of the human, adapted to mass bearing internally, by developing specialized trajectories of cancellous bone (Tobias, 1982). Externally the head of the femur and the acetabulum became relatively much larger in man, with a femur having a relatively long neck, straight and slender shaft, narrower condylar surface, with the line of mass passing through the lateral condyle (Dangerfield, 1996; Tobias, 1982).

The angle of the neck of the femur is depressed from 150 degrees to 125 in the adult human. The femur head and neck are rotated forward, so that during standing, most of the head faces forward. The femur is also bowed forward in man. While most quadruped knees are held in flexion [see literature on conformation of animals such as horses (Bürger, 1986) and dogs (Canadian Kennel Club, 1982)], in man the knee is held in extension (Hansson, 1945).

In quadrupeds the use of the **anterior** part of the feet, metatarsals and digits constitute the most important contact with the supporting surface such as the ground or tree branches. In the plantigrade foot the most important contact was moved backwards to a position between the heel and the metatarsal bones, especially as proficiency in plantigrade locomotion increased (Phelps *et al.*, 1956). The tarsal and metatarsal bones are in closer apposition than are the corresponding bones in the other primates (Hansson, 1945; Wolpoff, 1996). In quadrupeds all digits are normally held in flexion, but in the human the big toe is held in extension and the other toes in flexion (Hansson, 1945).

Lack of divergence of the big toe and loss of the grasping function of the foot are the most obvious modifications in the development of the human foot. The toes became shorter and weaker, the foot narrower, the calcaneus elongated and flexibility in the foot decreased. The human foot became a highly specialized organ of support and bipedal locomotion. The calcaneus became enlarged to give a firm base for mass bearing and greater leverage for the Achilles tendon during locomotion (Barker, 1985; Lawson-Wood & Lawson-Wood, 1977; Phelps *et al.*, 1956; Tobias, 1982). Gorman (1981: Section II, 7), however, emphasised that the evolution of the calcaneal lever system is a mammalian, and not a human modification:

> *Its high development in the human foot and the fact that other primate feet are more like hands, may give rise even to the superficial assumption that it is a human characteristic exclusively.*

Lewis (1972) has shown that there have been a number of rather subtle changes of individual tarsal and metatarsal bones and their articulations. He proposed that instead of the big toe becoming adducted towards the other toes, it rather appears that the lateral four digits became realigned towards the great toe and the subtalar axis, while at the same time the bones of the first digital ray became relatively larger.

The double arch of human feet - the transverse and the very well developed longitudinal arch - was an adaptation to balance and mass support during upright standing and locomotion (Gorman, 1981; Hansson, 1945; Latimer & Lovejoy, 1989). One load line runs through the human big toe, and even though the human foot is narrowed in comparison to that of the other primates, a new load line has evolved along the fifth ray (Lewis, 1972; also see Gorman, 1981). In this way during standing, the body mass of upright man is distributed through a left and right tripod, each comprising three mass-bearing centres: The heel, the big toe and small toe (Lewis, 1980).

During locomotion, however, the longitudinal arch serves a critical additional function by producing leverage for the muscles that are important in toe-off (see 2.3.2.2) - a function non-human primates do not have - and plantar flexing as the foot leaves the ground (Gorman, 1981; Latimer & Lovejoy, 1989, 1990a,b; Martin & Coe, 1991; Wolpoff, 1996).

Modern shoes, in view of the fact that they favour narrowing at the toes, tend to work against what was intended for proper functioning of the foot, in that the big toe is now abducted towards those lateral to it. By doing so some of the foot's most crucial functions are minimised, or even abolished, such as its mass bearing abilities and its provision of leverage for some muscles during toe off.

3.3.2.8 The double-spiral arrangement of the body musculature

> *In restoring the normal alignment of the head and neck with the trunk, they (the righting reactions) give man one of the most*

> *important features of human mobility; that is, rotation within the body axis, between the shoulders and the pelvis. For all our movements are in reality rotatory and even our joint surfaces are obliquely orientated* (Bobath, 1980: 6).

Dart's (1925, 1946, 1947, 1950, 1970) interest in the study of human evolution, the control of the body musculature and postural problems led to the eventual discovery of the double spiral arrangement of voluntary musculature, and from this discovery he was able to explain not only the development of *poise* (see Chapter 4) in man, but also the origins of malposture with great clarity.

In the first half of this century Dart (1947: 81) expressed concern about the lack of understanding *in respect of the apparatus of movement, that is the muscles, the nerves that supply them, and the manner in which they move the parts of the body by pulling on the bones.* Today this sentiment still applies, for although voluminous literature is available on the structure and function of different nervous structures and muscles, reductionistic approaches are given preference to integrated neuromusculo-skeletal function in texts on movement- and exercise science as well as in standard physiological textbooks. Dart (1947: 81) further stated:

> *The failure of the anatomist to present a simple picture of the musculature and its innervation is doubtless due to the recency of our comparative anatomical knowledge about these two systems; and the failure to understand the ancestral simplicity of the bodily needs and elementary material, from which their seeming complexity in man has been derived.*

3.3.2.8.1 The origin of the double-spiral arrangement of the body musculature in the vertebrates

The brain and spinal cord, the skeletal musculature and the skeleton together form a single purpose or unitary apparatus: ***a neuromusculo-skeletal (tripartite)***

movement apparatus (Dart, 1947, 1950). Initially this apparatus was developed in order to keep the body straight while it moved forward by means of undulant *lateral bending,* movement directed to keep the mouth end the body continuously pointed forwards and in active contact with food and the back end into a wagging tail (Figure 2.8) (Coghill, 1929; Dart, 1947).

When the ancestral coelenterates (sea anemones and jellyfish) first became transformed into a chordate[7] creature (Romer, 1964) with a permanently maintained antero-posterior orientation, the voluntary musculature became adapted anteriorly (cranially) to the bodily functions of eye movement, food seizure, swallowing and respiration and posteriorly to the bodily functions of defecation, micturition and parturition (front and back development) (Dart, 1950). This ability occurred as a result of the first splitting of the muscle producing embryonal tissue, and its cleavage into antero-posterior and bilaterally arranged somites[8], which then developed into segmentally arranged muscles of the body wall (Dart, 1950; Moody, 1953).

The segmental musculature became bilaterally arranged, each a mirror image of its fellow on the opposite side of the body. The *tripartite movement apparatus* enabled the early vertebrate creatures to produce massive lateral-bending movements of the whole body by alternating contractions of the entire

---

[7] The Phylum: Chordata include all creatures with a *notochord* - a long flexible rod-like structure extending from head to tail - a structure still prominent in lower vertebrates where it forms the main support of the trunk. In other vertebrates (Subphylum: Vertebrata), including man, the notochord is only present during the early embryonic stage, but is later replaced by the vertebral column during further development of the embryo (Romer, 1964; also see Williams & Warwick, 1980).

[8] Somites develop on both sides of the embryonal neural tube - these are more or less cubical blocks of mesodermal tissue forming between the ectoderm and endoderm. The first somite forms just below posterior to what will be the head. Their number is subsequently increased by somites posterior to these ones. Somites form, amongst other things, segmentally arranged **muscle plates** of the body wall - the **muscle segments or myotomes**. In the human embryo they develop during the third and fourth week. Myotomes eventually give rise to all skeletal muscles except certain muscles in the head, neck and those of the limbs. Since the muscle systems of all vertebrate embryos agree in beginning as rows of somites this pattern is probably an ancient one (Figure 3.8) (Coghill, 1929; Moody, 1953; Williams & Warwick, 1980).

musculature of the two sides (Coghill, 1929). This is the side to side wriggling movement of eels and tadpoles which allows them to move forward, and is the most ancient of all directional movement (Dart, 1947).

In the human foetus the first movement to appear at 8 weeks is lateral bending of the trunk and neck, a wriggling movement that can be elicited by stimulating the *upper lip* (Hooker, 1942). The corollary is that this is the oldest and functionally the most important tactual reflex pathway, involving head and body segments, as it brings the head in contact with the food supply.

The transverse processes of the spinal vertebrae, if taken serially, give rise to a most important morphological line - the lateral line of the body - which, superficially in fishes, is marked by a row of sense organs supplied by the vestibular nerve (Dart, 1947; Eckert & Randall, 1983). This lateral line of the body gave rise to the second fundamental division of the segmental musculature which was the antero-posterior splitting of the segmental musculature. This splitting separated the anterior or flexor half of each muscle segment in the body from its posterior or extensor half, each half being innervated by its corresponding anterior or posterior division of the spinal nerves (Figure 3.8) (Dart 1946; 1947). Division of the segmental musculature into four halves allowed the ventral halves of the myotomes on both sides of the body to contract or relax, separately or as a whole, independently from and antagonistically to the relaxing or contracting dorsal halves of the myotomes (Dart, 1950).

The laterally-bending creature could now also extend the body dorsally or flex it ventrally. At this stage it became possible for one part of the body to be in a state of tonic flexor contraction while simultaneously the other part remained in a state of tonic extension. The body could thus also bend up and down (Dart, 1947).

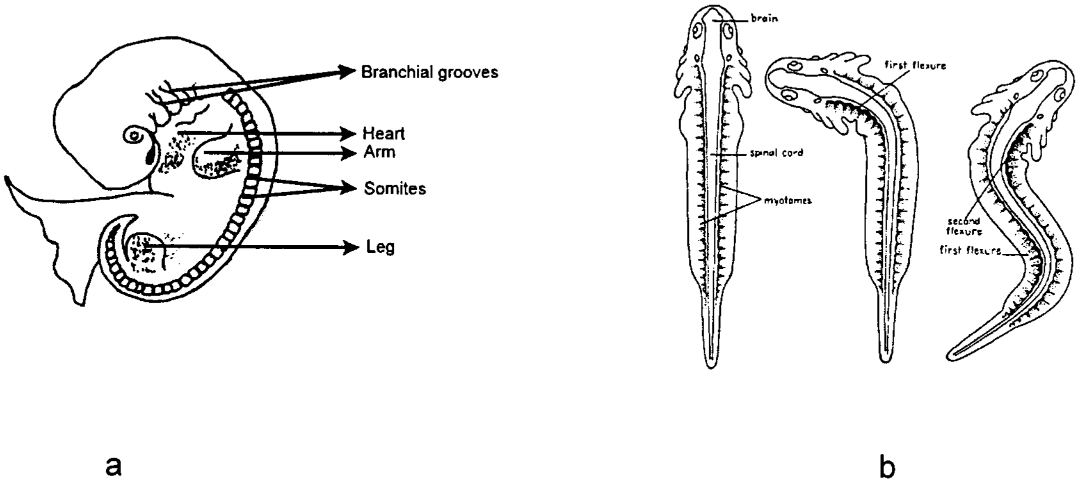

Fig. 3.8 **Somites and myotomes in embryos. (a) Human embryo at the end of the first month. Somites can be seen on its posterior aspect. Action of segmental body muscles is shown in (b) (Dart, 1950; Moody, 1953; Romer, 1964).**

In creatures such as these, a number of different movements could be executed depending upon how the functions of lateral upward and downward bending were combined (Dart, 1946, 1947). Of these, one kind of movement, however, is of outstanding importance for the purposes of the present study. This is *rotation, torsion or twisting;* actions which are the result of combining simultaneously the three movements already described. Any asymmetry in the contracting parts leads to a rotation in the junctional region between the tonically flexed and tonically extended halves of the moving body with a resultant **postural torsion** (body twisting to one side) (Dart, 1947).

Rotational movements however, became increasingly important for maintaining the body's posture during evolution. This arrangement allowed the entire voluntary musculature of animal bodies to assume a perpetually twisted arrangement in order to produce:

a) Permanent postural twists. Examples of these are the inward rotations of the fore and hind limbs in all four footed creatures and the **upward rotation of the trunk upon the thighs in man** (Dart, 1947).

b) Facilitation of the further reflex and volitional twisting of the body and its parts.

The twists are phylogenetic achievements and are symmetrical in character. The interwoven spiral muscular sheets that encircle the human trunk (see below and Figure 3.9) resulted from the dominant part rotation plays in **each** body movement (Dart, 1947).

Since no further voluntary muscle development (splitting up of myotomes) took place, no other types of movement effected by voluntary musculature became possible. Splitting as it occurred, has therefore, been principally confined to the production of a three-sheeted layering assuming the form of two interwoven spirals:

a) Inner or transverse (circular),

b) Intermediate or internal oblique (diagonal) and

c) Outer or external oblique (diagonal) characteristic of the trunk flexors.

In a like fashion, the longitudinally split arrangement, characteristic of the double sheeted limb flexors and extensors, was produced, as were the subdivisions of the *sacrospinalis* mass (Dart, 1950). The double spiral arrangement of the body musculature is described by Dart (1950: 267-268) as follows:

> *This splitting into sheets, however, has given origin to a simple double-spiral mechanism of great importance to bodily economy, but the essential simplicity of which is frequently forgotten amidst anatomical detail. For example, let us follow the oblique direction of the fibres of the external oblique muscle, from the midline of the body, pubic symphysis and iliac crest upwards through the single morphological sheet formed by the external intercostals, ribs and scalene musculature to the transverse*

processes of the cervical vertebrae, and thence through the deeper-lying sheet, formed by the semi-spinalis musculature, to the cervical spines and occiput. Thus we get a picture, or bird's eye view, of the manner in which the single superficial sheet, formed by these two opposed diagonally-running flexor muscles in front, is continued, through a deeper-lying extensor sheet on each side of the spine behind, to suspend the pelvis from the occiput and neck vertebrae. This diagonal suspensional arrangement becomes the more impressive when we recognize that the diagonal direction of pull exercised by each external oblique sheet (intercostal muscles and levatores costarum) is continued across the midline through the deeper-lying internal oblique sheet to the perimeter of the pelvis on the opposite side of the body. Thus, any postural twist of the body (and the customary twist of a right-handed person is a twisting of the trunk to the left) results in a postural rotation of the thorax, shoulder (right) and head, together with the vertebral column itself, towards the opposite (left) iliac crest: there is also a relative inability to rotate the opposite or heterolateral (left) shoulder towards the homolateral (right) iliac crest.

These diagonally-disposed sheets, when followed in their continuity around the body, constitute two interwoven spiral layers. The pull exercised on the circumference of the pelvic basin, through the deeper-lying (internal oblique) sheet from the ribs and the transverse processes of the spinal vertebrae of the contralateral side, by the superficial layer of muscles (external oblque, quadratus lumborum, external intercostal, levatores costarum and scalene) is a plane of traction that is being simultaneously exerted upon the transverse processes themselves, and again along the deeper-lying plane of pull of the deep (multifidus-semispinalis)sheet of the sacrospinalis from the

> *spines of the vertebrae and the occiput. Thus, in a very real sense, the occiput and the spines of the vertebrae suspend the body by means of two spiral sheets of muscle encircling the trunk.*
>
> *This arrangement of the trunk musculature, in the form of interwoven double-spiral sheets, is continued across* the dorsal *midline just as it is carried over the ventral midline. The superficial layer of the sacrospinalis sheet (ilio-costalis, longissimus and splenius) continues on to the posterior aspect of the ribs, cervical transverse processes and mastoid process the same oblique line of traction as is being exercised on the spines by the deep (or multifidus) sheet of the opposite side of the back. The whole trunk repeats, in its own fashion, the muscular story of the intestinal tract and of the heart, by becoming enwrapped by spiral coils of muscle, which are only prevented by the bony framework of the thorax and pelvis from completely emptying its contents when they are contracted forcibly.*

This double-spiral arrangement, discussed above can easily be pursued into the head, neck and limbs (Figure 3.9).

3.3.2.8.2 The postural twists, posture and malposture

Dart (1946, 1947, 1950) argued convincingly that man's postural twists contributed to his becoming upright and keeping him there. The permanent inward rotation of the leg musculature provides flat surfaces for the feet, inward rotation of the arms affords implement-using hands also capable of grasping and swinging. **Finally, the powerful hip musculature allows the whole body to twist permanently upwards**:

> *···and poise it in a state of postural fixation on top of his thigh bones. Thus, paradoxically enough, it is nature's most twisted, distorted creature (i.e. crooked Man), that is capable of the supreme achievements of poise: balancing on head, hand, heel or toe* (Dart, 1946: 12).

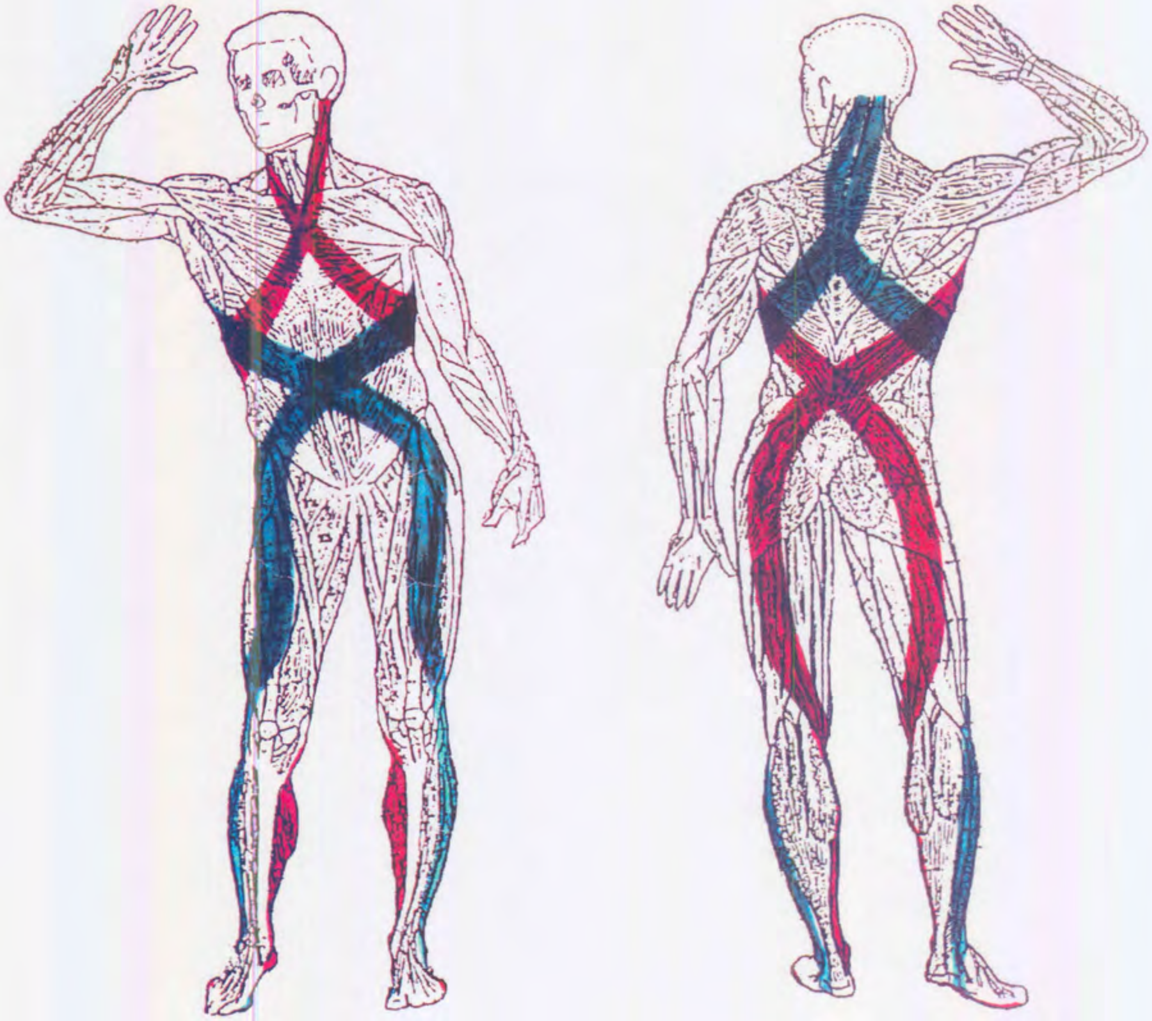

Fig. 3.9 The spiral arrangement of the body musculature. [Original drawings kindly provided by Mr Walter Carrington of the Constructive Training Centre (London)].

Hence man's place in nature is due to his conquest of the problems of *poise* by means of **postural twisting** (Dart, 1946). **Failure to develop a perfectly**

poised body merely represents a developmental arrest (Dart, 1946; Feldenkrais, 1985). This arrest in development is purely functional, and is not, as commonly accepted by the lay public, an inherited problem.

The consequence of the development of the tripartite movement system is that all muscles are either flexors or extensors: all torsions of the body as a whole or of its constituent parts - whether they be rotation of the spinal column, pronation, supination, inversion, eversion, abduction, adduction or circumduction of the extremities - are all based upon tonically maintained differential pulls between adjacent groups of flexor and extensor segments (Dart, 1950). The importance of these differential pulls should be one of the considerations in the prescription of exercise or physical activity programmes. This is so because any habitual asymmetrical adjustment of the body, either during states of mental anxiety that suppresses respiratory rhythm or during physical activity or exercise, results in postural torsion of the head, vertebral column and trunk, as a whole, towards the more commonly favoured or used side (Dart, 1950).

An example of the spiral arrangement of voluntary muscles in man is shown in Figure 3.9. In Dart's (1946, 1947, 1950) scheme both monoarticular and polyarticular muscles contribute to the spiral arrangement of the skeletal muscles, further emphasising the interrelation between posture and voluntary movement (Latash, 1998a; Roberts, 1995).

Thus we finally have man, the erect terrestrial biped with his large head balanced on his thin neck; a centre of gravity in a nearly straight line from the occipital condyles to the pelvis; free arms; manipulative hands and two feet on the ground.

3.3.2.9 Upright man - the sum total of it all

The sum total of the anatomical adjustments accompanying the acquisition of the upright posture and bipedal gait has produced an efficient mass-bearing system in the human. The result is a line of gravity of the body extending from the occipital condyles, in front of the spinal column to the upper, anterior sacrum, then across the ilium, through the femoral head, down the legs to the feet which form the pedal tripods (Dangerfield, 1996; Gorman, 1981).

The effect is 1) enhanced stability; 2) better balance while standing and walking and 3) minimal expenditure of muscular energy (Joseph, 1962; Tobias, 1982).

The recent notion that the size of the head (brain and cranium) does not determine intelligence (Gould, 1987) leads one to speculate, in the light of the importance of erectness in humanness, whether the large head did not lead to improved balance in the upright stance. This is inferred from the fact that newly found balance in the one to two year old is accompanied by perfect posture at a stage when the head is disproportionately large compared to the rest of the body (Gelb, 1981). Good posture is achieved in cultures with the habit of transporting burdens on their heads. This again causes an exorbitantly large head area, yet with an interesting consequence - the attainment of good posture.

Man's erectness allowed him the freedom to develop his intellect, culture and religion. This put the crown on his terrestrial success (Phelps *et al.*, 1956).

3.4 THE MECHANISM OF THE UPRIGHT HUMAN POSTURE DURING STANDING AND SITTING: BASED ON PALEO-ANTHROPOLOGICAL EVIDENCE

> *Nature has over-emphasised the extensor mechanism of man so that he might achieve the erect posture* .....(Dart, 1946: 6).

3.4.1 General

The changes in design and function of anatomical structures which led to the upright position were considered in sections 3.3.2.1 to 3.3.2.8. In order to maintain the upright posture over a small base of support such as the feet and sitting bones, the integrated function of various musculo-skeletal structures and systems are required. DeVries (1965, 1968) was probably the first to show that upright standing requires some muscular action, although only to a small extent as will be discussed next.

Man's upright posture is nothing but a delicate balancing act, which requires the subtle **balancing of body structures** on top of one another as shown by Rolf (1977). This balancing act, which should be regarded as a skill, is maintained by the coordination of all the neuromuscular-skeletal (tripartite) systems in the human body. Standing or sitting upright in many ways requires learning like all other motor skills (Massion, 1992; Richardson, 1992).

Because of its ingenious design, man's upright position can be maintained with little energy expenditure (Hellebrandt, Brogdon & Tepper, 1940; Joseph, 1962; Joseph & McColl, 1961; McArdle *et al.*, 1991). **From this it can be concluded that the upright position should not be associated with undue muscular effort or parasitic muscle action** (Alexander, 1932; Feldenkrais, 1985; Robinson & Fisher, 1998). When posture is considered the emphasis should be on balance, and not the use of brute strength for something which relies on balance, the use of the correct muscles such as the deep slow-twitch extensor muscles (Armstrong, 1980), and therefore correct neuromuscular control and function. The emphasis on balance is indeed the general approach taken by those involved in bodywork (Barlow, 1990; Dart, 1947; Feldenkrais, 1972, 1985; Hanna, 1988). The main aim of all these techniques is to teach the individual the correct employment of the tripartite system in the body. These techniques will be discussed in greater detail in Chapter 7. From a physical point of view all the instigators of these techniques agree on one salient point, which is that the minimum muscular force should be used for whatever physical task needs to be done, in fact large parts of these techniques are devoted to the inhibition/release of unwanted muscle tension(s). It is with this aim in mind that the biomechanical/kinesiological control of posture will be discussed.

3.4.2 The standing posture

In Figure 3.10a,b the proposed function of the different anatomical structures in the maintenance of the upright posture is shown in accordance with paleo-anthropological evidence.

3.4.2.1 The pelvic structures

During standing, the upright human pelvis is balanced on the thighs, which act as fixed points from which the hip muscles act in order to stabilize the hip. Of particular significance in this model is the introduction of the *gluteus maximus* and other mono-articular (stabilizing) pelvic muscles in the creation and maintenance of the upright position and stabilization of the pelvis and the trunk (DonTigny, 1993).

Being an antigravity muscle (Richardson & Sims, 1991), the *gluteus maximus*, when acting from below[9] (the femur - see Figure 3.10) (Gorman, 1981), it is by way of its structure and position eminently suitable to tilt the top of the pelvis to the rear and to maintain the upright pelvic position. This action automatically positions the sacrum in such a way that it is now able to support the upright and lengthened spine above it. The small inner (stabilizing) muscles of the back are then allowed to take over the function for which they were originally intended, namely the maintenance of the position and stability of each vertebra and those adjacent to it.

Seen from the above perspective, the common modern malaise - low back pain - (Deyo, 1983), should be seen for what it really is: A disease of muscle imbalance

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[9] It is only for convenience of description that musculo-skeletal attachments are described as origin and insertion. The direction of pull of a muscle depends on which end is fixed (Bürger, 1986). When the origin of the biceps brachii is fixed, for example, its contraction will result in flexion of the elbow and lifting of the forearm and hand. When, on the other hand, the insertion (forearm) is fixed, contraction of this muscle will again lead to flexion of the elbow, but with the shoulder being pulled down towards the forearm and hand.

and its consequent malposture. Rehabilitation exercises for those who suffer from low back pain, should therefore rather concentrate on the functional cause of this malaise, which is to alleviate the functional imbalances[10] found in the lower back and pelvic areas (Janda &Schmidt, 1980). Janda (1993) and Janda and Schmidt (1980) for example, found a combination of tightness in the short hip flexors and *erector spinae* and a weakness in the abdominal and gluteal muscles - the pelvic crossed syndrome (Jull & Janda, 1987). The correction of structural imbalances such as these, as suggested by Barker (1985), Janda (1993), Jull & Janda (1987) and Richardson (1992) is, in view of the present theory, more acceptable than regimens in which exercising and strengthening of those muscles normally associated with voluntary movement of the back, such as the *erector spinae (sacrospinalis)* are recommended (Flint, 1958, 1964; Flint & Diehl, 1961; Graves, Pollock, Foster, Leggett, Carpenter, Vuoso & Jones, 1990; Manniche, Hesselsøe, Bentzen, Christensen & Lundberg, 1988).

Forward tilting of the pelvis is a function of muscles acting in an opposite direction to that of the *gluteus maximus*; the *iliopsoas* and to some extent, due to its anatomical position, the *gluteus minimus*. When the *iliopsoas* muscles contract from below they powerfully flex the pelvis and trunk forward during actions such as raising the trunk from the lying to the sitting position (Gorman, 1981). In this model these muscles contribute to the forward tilting of the pelvis during standing, not only if they contract or are tightened, but also if they are shortened (Jull & Janda, 1987; Lawson-Wood & Lawson-Wood, 1977; Rolf, 1977). The main function of the *gluteus medius* and *gluteus minimus* would be to keep the pelvis from sagging to either the left or right, especially apparent during standing on one leg (Gorman, 1981), but likewise seen so often in those supporting themselves mainly on one leg with the hips sticking out. When acting from below the mono-articular leg adductors (*adductor brevis, adductor longus,*

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[10] Muscle or functional imbalances in this context do not only imply muscular contraction, but also parameters such as habitual resting muscle length, the role of muscle connective tissue (fascia, for example), ligaments and use of tonic reflex or voluntary patterns in determining this length and the resistance of a muscle to lengthening (Alexander, 1932; Ayub, 1987; Barker, 1985; Bobath, 1980; Rolf, 1977; Smith, 1957). Muscle imbalance is further discussed in Chapter 5, section 5.9.7.

adductor magnus, and the *pectineus)* (Gorman, 1981; Kendall & McCreary, 1983) and other muscles such as the *piriformis* assist in laterally stabilizing the pelvis. The *gluteus medius* and *gluteus minimus* muscles are also involved in trying to right the trunk when the human leans backward.

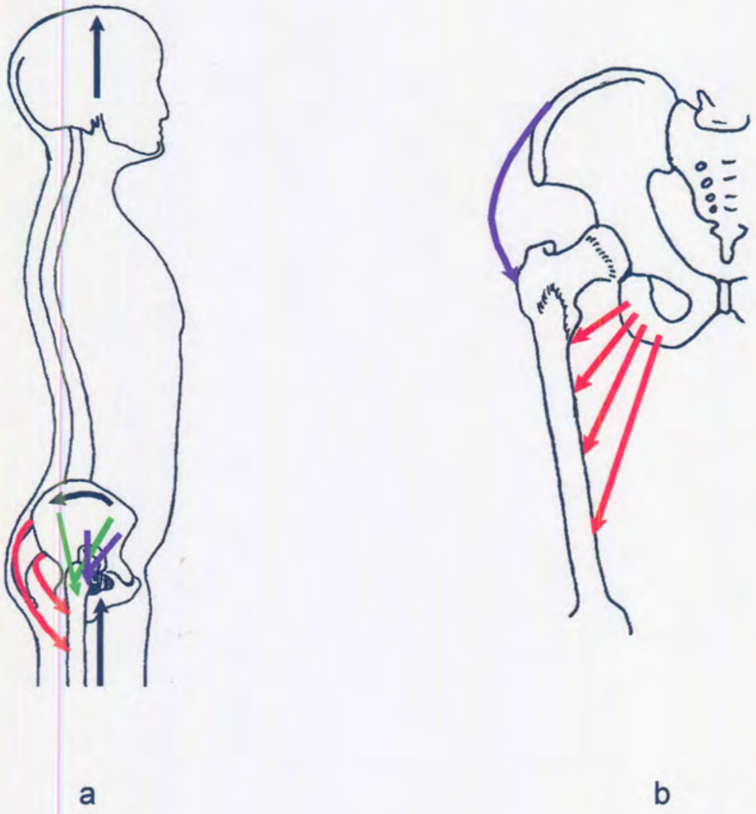

Fig. 3.10 A paleo-anthropological model for the muscular control of the upright posture. The arrows indicate the direction in which the various muscles act in order to support the position of the pelvis on the femur. (a): Lateral view of the pelvis and spine, with direction of action of the *gluteus maximus* (red), the *gluteus minimus* (blue) and the *gluteus medius* (green). The direction and position of the upward force via the femur is also shown. Note that this is anterior to the spine. (b): The side to side stabilization of the pelvis by the *gluteus minimus, -medius* (blue) and the monoarticular adductor muscles (red). Spiral arrangements of the muscles are not shown.

We thus have a ring of muscles linking the femur to the pelvis fulfilling the important role in the standing human to stabilize and fix the pelvis in the correct position in order for it to support the structures above. It should be kept in mind though, that pelvic position is the result of the interaction between these and other muscles, and that it may be affected by the action of muscles near or even distant from it. This will be true, especially in cases where imbalances in the spiral muscle arrangement exist (see Figure 3.11) (Barlow, 1990; Dart, 1950).

Positioning of the hip joint sufficiently far forward in the pelvis so that the whole **of the spine and the line of gravity is posterior to the acetabula** ensures that the vertical force from the legs will have the tendency of moving the top of the hip backwards (Figure 3.10a) (Dontigny, 1983; Gorman, 1983). The best demonstration of the advantage of a system like this is when a large vertical force from the legs (during landing from a jump for example) acts on the pelvis, the natural response **is rounding, and not hollowing** of the lower spine. The latter response may lead to damage to the spine (Gorman, 1983). Forward tipping of the pelvis and sacrum, heavily strains the entire vertebral column with some vertebrae being wedged apart and others being crowded together (Rolf, 1977), and also releasing the self-bracing mechanism of the sacroiliac joint (DonTigny, 1993) (see Chapter 5, section 5.7.2).

When all or some of the muscles discussed above are inactive or weakened - as frequently seen in those with brain damage - an inability to laterally stabilize the pelvis makes it difficult for these patients to attain or maintain the upright position (Loots, J.M. - personal communication). Trying to compensate for this inability by means of the abdominal and quadriceps muscles is not successful.

3.4.2.2 The spine and thorax

> *The importance of the spinal column cannot be overemphasized. It provides for the foundation around which man's internal skeleton is built. Every animal that moves vigorously benefits from some stiff material to which to attach its muscles* (Leonard, 1973: 101).

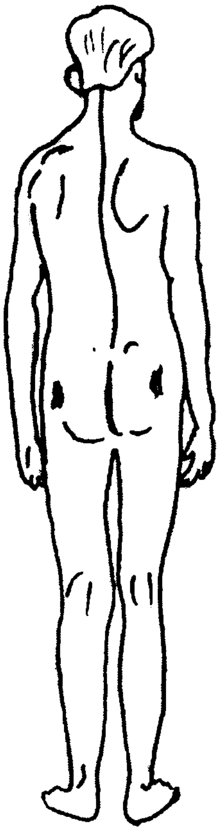

Fig. 3.11 Example of a young boy with scoliosis and distortion in the spiral arrangement of the musculature, seen in the torsion of the trunk (adapted from Barlow, 1990)

A column is found underneath the structure it upholds. In understanding the function of the spine it is important to realise that the spine is not a true column, since it is nearer to the dorsal surface of the body. It is rather like a beam upended. In the quadruped the spine acts as a horizontal beam. In man it became a vertical beam - a structure which cannot support itself (Rolf, 1977). Even though the spine is supported from below by the sacrum, and though each vertebra supports those above it, its off-centre position necessitates special measures to keep it upright during standing and sitting (Rolf, 1977). One of these is the spinal joints and ligaments (Macintosh & Bogduk, 1987) - a system which is able to stabilize an inert upright spine. The back, however, is subjected to continuous displacement, with the back muscles serving to correct such displacements (Macintosh & Bogduk, 1987).

To complicate matters further in man, the spine must meet two contradictory requirements: Plasticity and rigidity. The upright position of the spine, plasticity and rigidity are achieved by the presence of muscular stays built into it's very structure. Viewed as the mast of a ship resting on the pelvis as the deck, the mast extends to the base of the head, and at shoulder level supports a mainyard - the scapular girdle (Figure 3.12a) (Gorman, 1981). Unlike the rigid mast in a yacht the human mast (spine) is made up of a number of moveable elements (the vertebrae), which then necessitates a series of diamond shaped systems in which one vertebra is dependent on the support of the vertebra below it, and the action of the small back muscles and ligaments which link them together for stability (Figure 3.12b). Therefore, at all levels there are ligaments and muscle tighteners arranged as stays, linking the mast to the pelvis at the bottom. A second diamond shaped system of stays is related to the shoulder girdle. Careful examination of this system shows the possibility that the lower stays on the one side of the body connects to those linked to the shoulder girdle on the opposite side of the body, thus making sense of the idea that when the forces on either side of the body is in equilibrium with each other, the mast (spine) and the thorax will be straight, unrotated and vertical (also see Dart's spiral arrangement of body musculature - section 3.3.2.8).

The plasticity and rigidity of the spinal column lies in its makeup - multiple components superimposed on one another, interlinked by means of ligaments and short muscles, which are covered by sheets of larger muscles, which are in turn responsible for the torsional movement of the spine and thorax. The structure of the spine and thorax can thus be changed while at the same time maintaining its rigidity (Dart, 1950; Gorman, 1981).

Since the *erector spinae* muscles are multi-articular they are better suited for movement, such as extension and lateral flexion of the spine (Gorman, 1981), rather than serve as postural muscles. Postural function, such as the control of the upright position of the spine is best left to the deep short muscles of the back (*multifidus, rotatores, interspinalis* and *intertransversarii*) (Gorman, 1981).

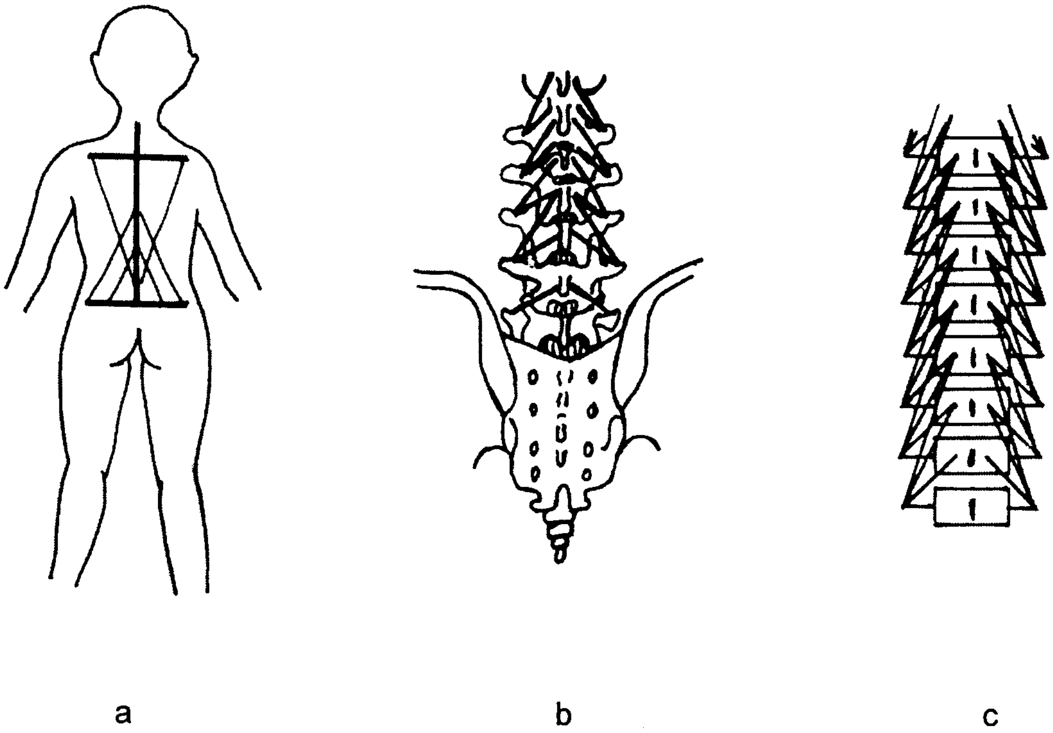

Fig. 3.12 Maintenance of stability in the spinal column. The spinal column as a mast (Gorman, 1981; Rolf, 1977) (a). Maintenance of stability of individual vertebrae by those underneath, the interconnecting ligaments and the small muscles of the back (b) and (c). In (b) the connections of the *rotatores* are shown, and in (c) those in the smaller muscles of the spine, for example, the *multifidus*. Note the similarity to the system shown in (a), and its spiral arrangement.

The role of the abdominal muscles in issues such as low back pain and posture has been the subject of much debate (Norris, 1995; Plowman, 1992; Pope, Frymoyer & Lehman, 1991b). Fox (1951), for example, found that forward pelvic tilt is not associated with any significant weakness of the abdominal muscles. Since the abdominal oblique muscles insert on the *erector spinae* fascia, a mechanism has been suggested in which strong oblique muscles reinforce the *erector spinae* and pull it laterally. This wide reinforced fascia is more efficient in supporting the spine, and in the process puts less strain on the spine (Plowman, 1992). This, of course, will depend on the point from which these muscles act. If they act from below (pelvis fixed), the tendency will be to pull the lower back forward, and if from the other direction, the pelvis will tend to rotate backwards. In this respect these muscles will then support the action of the *gluteus maximus* when it acts from below (see 3.4.1.1.1 and the following paragraph).

Action of the abdominal muscles will tend to tilt the pelvis backwards if the thorax is fixed (Gorman, 1981), but whether this is the intended function of these muscles is debatable. According to Gorman (1981) the antero-lateral group of abdominal muscles serve to provide a firm, but elastic wall to retain the abdominal viscera in position and to oppose the effect of gravity on them in the erect position. They may, however, be used in conjunction with the gluteal muscles to flatten the lumbar curve when effort is needed (Gorman, 1981). More correctly would be to view them as part of the double spiral system of the body musculature in which their principal role is twofold:

- Due to the fact that the fibres of the external oblique on one side with those of the internal oblique on the other these muscles as whole form a slanted web which determines the hollow of the waist (Gorman, 1981; Robinson & Thomson, 1999),

- These oblique and rotatory connections to the pelvis from the one side to the rib cage on the opposite side of the body allow them to participate in positioning these structures relative to each other, but to some extent also in the absolute positions of these structures. The outcome of rotation is shown in Figure 3.11.

3.4.2.3 The lower limbs

In the standing position the balance between the muscles surrounding the ankle must be such that the lower leg forms an angle of 90° with the supporting surface [see for example Barlow, (1990)]. This will then ensure that the knee- and hip joints are placed on the centre of gravity line. In the regulation of stance and gait the extensor muscles predominant role (Dietz, Horstmann & Berger, 1989).

3.4.2.4 The neck and head

Support for the head must come from below. Cohen-Nehemia (1983) and Cohen-Nehemia and Clinch (1982) have indicated a delicate interaction between the hips and the neck. Therefore it may be postulated that if the spine is supported as described in the previous sections the cervical vertebrae will rest on the thoracic in such a way that the head will balance on the top of the spine. Poking or retraction of the head will disturb this balance (Barlow, 1990; Jones, 1979).

3.4.3 The spiral arrangement of the body musculature and posture

According to paleo-anthropological evidence it seems that *poise* is based on two basic requirements namely support and balance of body structures in relation to each other. In the sections above (3.4.1 - 3.4.2) the development of-, and the need for a system to support body structures on top of each other, in the upright human, were extensively dealt with. It is clear that proper support depends on correct positioning of structures in relation to each other. The functional background of the system responsible for the balancing and positioning of body segments has not been dealt with up to this stage. According to Loots J.M. (personal communication) the solution is to be found in the double spiral arrangement of the body musculature (Dart, 1946, 1947, 1950). A spiral arrangement of the body musculature **allows the body to be suspended from the head (occiput) and spine** (Dart, 1946), thus “wrapping” the different body segments on top of each other. In order to function properly the system should be kept “taut”, and once slackness enters the system, bulging of the belly and its concomitant hollowing of the lower back will be the consequence, for example (Loots, J.M. - personal communication). Each and every postural deviation can be thus traced back to a malfunctioning of this system, as put forward by Dart (1946; 1947). *Poise* on the other hand, depends on the proper control of this delicate mechanism, control, as will later emerge, which in modern civilization depends on conscious control (Alexander, 1996; Dart, 1947; Feldenkrais, 1985; Howorth, 1946).

3.4.4 The sitting posture

The reader is referred to the statement by Tobias (1982) that sitting gives greater stability to the body than standing, and it is therefore the preferred position when the hands are used in activities such as tool-making and tool-using. It is here that the greatest danger of sitting lies; and since it is so frequently used, it tends to be abused.

Sitting upright requires the same delicate neuromusculo-skeletal integration required for standing. Gorman (1983) suggested that the time and manner of sitting is the primary cause of the unnatural shape and joint mobility of the spine and thus the primary cause of low back pain.

Gorman (1983) is of the opinion that the human spine is inherently unsuited for sitting with the muscles of the spine relaxed, since it leads to the slumped position. Continuous sitting in this position, eventually leads to elongation of the posterior supra spinous ligament and distortion of the intervertebral discs. The correct shape of the spine should therefore be maintained by the judicious use of the back and trunk musculature.

During sitting the body mass should be borne by the sitting bones, rather than by the thighs (Figure 3. 13). This will ensure tilting of the pelvis and sacrum in such a way that the spine above it is supported in the upright position with the minimum of muscular effort. As in standing the *gluteus maximus* muscles should function from below in order to tilt the pelvis into the proper position for sitting and to position the centre of gravity line of the upper body ahead of the sitting bones. Correct and incorrect sitting positions are shown in Figure 3.13.

As shown in Figure 3.13 it is important to allow for open space beneath the chair for more optimal positioning of the legs (Keegan, 1953).

Grieco (1986) saw sitting at work for long periods at a time as “enforced posture”, something which should be seen as a risk factor for spinal problems of the same magnitude as the lifting of heavy weights and vibration, and that in particular, the most important risk factor for spinal problems is poor mobility of the workers.

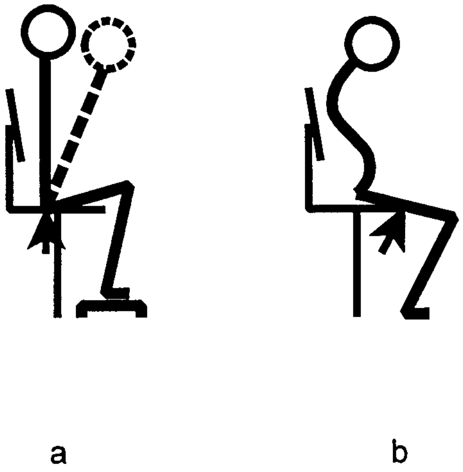

Fig. 3.13 The correct sitting posture (a) and sitting on the thigh position (b) (Gorman, 1983). Note the position of the sitting bones and the hip joints relative to the knee-joints in (a), where the knee joints are slightly higher than those of the hip. Leaning forward should be from the hip joint (Macdonald, 1998). Arrows indicate position of fulcrums.