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POSTURAL AND PHYSIOLOGICAL CRITERIA FOR SEATING — A REVIEW

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IO. INTRODUCTION

For centuries chair sitting has been a major posture for western people. They adopt this body position during most of their daily occupations, let them be working or leisure time activities. Changing patterns of work(increasing paper work), development of industrial technologies(automation, remote controls) and changes in the modes of recreation (TV) increase the time during which people sit. Parallel to the increase of the sitting workers and to the increase of the interest in the factors influencing worker efficiency, there started the studies on the ergonomics of sitting and seating. Since late 1940s there have been many attempts to formulize the optimal requirements for seats. These requirements were usually based on the concept of the physiologic comfort of the user. The aim of this paper is to review some of these past studies and thus to present a collective argument that leads to the physiologic criteria for seating design.

Two points need to be emphasized here immediately.

1) Both the literature reviewed and the resultant criteria take into consideration primarily of the physiologic characteristics of sitting posture and the corresponding requirements for a physically healthy seat. It should never be forgotten that a complete seating criteria have to regard the effects of social and cultural implications, psychologic comfort of the user, formal and expressive characteristics of the design, influences of the materials and manufacturing methods, economics of production, etc. Thus, the following is to be considered only as a partial presentation of the seating criteria.

2) Extremely wide spectrum of the activities and situations that require a sitting position results in a wide variety of seating types.[1] While certain parts of the seating criteria may apply to all of them, certain parts show differences from one type to another. Consequently it becomes important to know which type(s) of seating is being considered while using a set of seating criteria. Due to having a major interest in occupational activities and occupational health, the literature reviewed consider

1. Variety of the seating types can be based on the differences in : (1) activities carried out sitting, (2) various sitting postures, (3) physical environment, (4) cultural environment, (5) techoologic conditions, (6) economic conditions.

primarily the seating types used in the work environment (factories, offices, vehicles). But the postural and the physiological criteria can be accepted as the least variable according to the seat type and thus the following can be employed for almost any type of seating design(with the obvious exceptions as the seats for the handicapped, dentists seats, wheelchairs, etc.). Yet, it should still be noted that while the criteria remain the same, their transfer to dimensional and other properties change with the type of seat.

20. SITTING AS A POSTURAL NECESSITY

Man chooses to act in a standing position and to rest lying down. Both have their reasons. Standing up, the body has a maximum mobility and working capacity, but it is also the most fatiguing position. Even simply standing up without doing a bodily work the postural muscles work continuously to counteract the forces developed by the gravity at body joints and to maintain a stable posture.[2] Since the base area of the standing body is defined only by the two feet, keeping the center of gravity of the body in this small area makes these forces quite reasonable. On the other hand, in a proper supine position the base area is maximized and almost all of the body parts are supported by the ground surface. Consequently the muscular activity is almost nil, enabling one to relax and to rest his body. Yet, lying down, the possibility of working and performing other bodily activities are limited. Tasks requiring eye-hand coordination is extremely tiring in supine position and while prone position can be more fitting for some hand operations this will load the nape muscles and pressurizes the viscera.

2. S. Carlsöö, The Static Muscle Load in Different Work Positions : An Electro-myographic Study, *Ergonomics*, v. 4, n. 3, 1961, pp. 193-212.

Between these two extreme postures of standing and lying, people try to assume intermediary body positions which are suitable for physical activities while being less tiresome than standing. Such intermediary postures can be extremely variable all over the world. Hewes points out that the human body is capable of assuming nearly thousand different steady postures which are conditioned by culture as well as physical training and habits.[3] For the western cultures(and its followers) that steady-intermediary-posture has been developed as"chair sitting". This posture can be defined as transferring the major body weight through buttocks to a plane elevated from the ground level(i.e. the seat surface) so that the trunk-thigh angle approximates 90 degrees. In such a position the base area of the body is defined by the two feet and the buttocks(Fig.1) and sometimes(i.e.when the trunk-thigh angle is more than 95 degrees) the projection of the backrest surface on the ground. Since the base area is large the vertical line from the center of gravity of the body can be kept in this area for most trunk positions. The lower limbs are freed from carrying the total body weight, the lower leg muscles which are among the weakest in the body are always inactive.

3. G. W. Hewes, The Anthropology of Posture, *Scientific American*, v. 196, n. 2, 1957, pp. 123-132.

Besides simply "taking the load off the feet", chair sitting exhibits several other benefits for the working man : due to the increased stability of the body (compared to standing) capacity for precision tasks or fine manipulative movements is increased. Onset of fatigue at tiresome tasks is delayed since the muscles are partially relieved from their work to

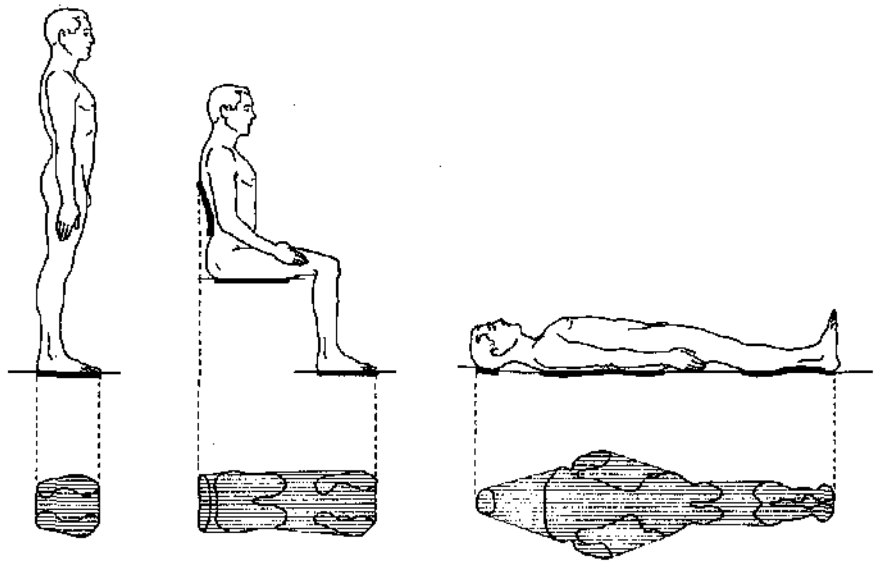

Fig. 1 Base areas of the body while standing, sitting and lying.

keep the body stable. Since the feet are free, they can be incorporated into the work and control operations. Outside work conditions, it is possible to relax the whole body in a suitably designed seat. Thus, sitting becomes a major posture for western man for both occupational and leisure activities unless total body mobility is required.

30. POSTURAL CRITERIA FOR SEATING

Posture is usually defined as the positions of trunk, head and the limbs in relation to each other. It can be expressed by the angles at major joints of the body. The efficiency of a posture can be determined by the degree it loads the skeleton and the skeletal and/or postural muscles. Effects of faulty sitting postures show themselves through spine disorders and fatigue of back muscles. Thus in the chair sitting posture special attention is paid to the spine, pelvis and femurs as skeletal parts and the neck, back and abdominal groups as the musculature involved.

31. SKELETAL IMPLICATIONS

Spine is a half-flexible joint between the two extremities of the body. Besides playing a major role in standing erect, it has the vital function of housing the spinal cord which is the second important nerve center in the body. Spine is made of 33 vertebrae(Fig.2). Of these, the uppermost 7 are called the cervical vertebrae, the next 12 are the thoracic vertebrae, and the next 5 are the lumbar vertabrae. Of the remaining 8, 5 are fused to each other and called the sacrum, and the last 4 are the coccyx. These are also the names that denote the five sections of the total column. The first cervical vertebra (atlas) establishes contact with the head(i.e. the skull). The sacrum is fixed to the hipbone by strong muscular and ligamental ties to form the pelvis. This has consequential importance for the sitting posture. Because of the thorax, the thoracic vertebrae cannot move very much. Thus the movements of the trunk are realized mostly by the movements in cervical or lumbar vertebrae.

In the front(or rear) view the spine shows a straight-line

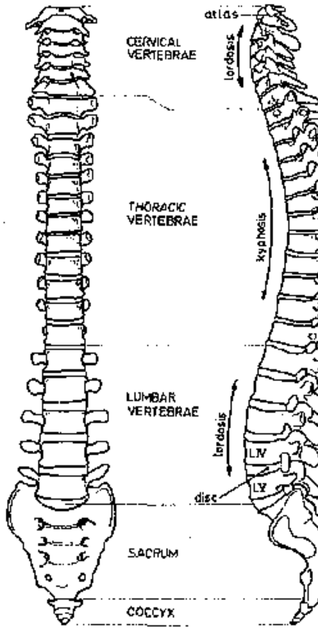

Fig. 2 The spine

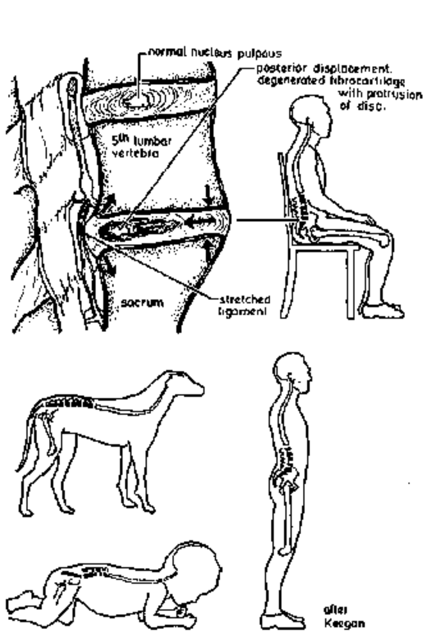

Fig. 3 The lumbar curve in dog, infant and adult man.

formation. In the side view it forms certain curves. It makes a lordosis in cervical and lumbar areas and a kyphosis in the thoracic area. Lordosis is a curve outwards(backwards) while kyphosis is its opposite, that is a curve inwards. While certain changes in the amount of these curves are naturally inevitable during body movements, their extreme changes pose serious hazards to health. When the natural curve of the column changes the even pressure on intervertebral discs become uneven(Fig.3) causing certain misplacements of discs with resulting back-ache in the short-run and disc degeneration in the long-run.

The lumbar part is usually the most strained part of the spine. Its lordosis itself is the result of a stress due to the erect position of man. The lumbar lordosis is not present in the newborn infant or in quadruped animals(Fig.3). It is formed in the first five years of life when the child is learning to walk and is the direct result of the inability of the pelvis to rotate ninety degrees and to maintain alignment with the vertical trunk.[4] Yet, once became a natural formation for the adult man, its maintenance is necessary for a normal spine. The critical character of maintaining the lumbar lordosis comes from two reasons. The first one is the concentration of trunk movements when the hip joint is fixed(Fig.4a). Because of the aforementioned limited moveability of the thoracic vertebrae, most of the forward, backward and sideways movements of the trunk are centered in the lumbar area. The second one is the effect of leg movements(Fig.4b). During the flexure of the thighs the limited length of posterior thigh muscles between the pelvis and the knee joint(femoral biceps)rotate the pelvis with the consequential rotation of the sacrum and the flattening of the lumbar curve.

Changes in the lumbar lordosis can be both an increase or a flattening. According to Keegan the most natural curve of the lumbar area happens when the trunk-thigh angle is 135 degrees[5] (Fig.4b). This posture is assumed when lying laterally or sitting on a chair with thighs moved forward. Increase of the lumbar lordosis happens when standing up

4. J.J. Keegan, Alterations of the Lumbar Curve Related to Posture and Seating, *Journal of Joint and Bone Surgery*, v. 35, n. 3, 1953, pp.589-603.

5. J.J. Keegan, Alterations of the Lumbar Curve Related to Posture and Seating, *Journal of Joint and Bone Surgery*, v.35, n.3, 1953, pp.589-603.

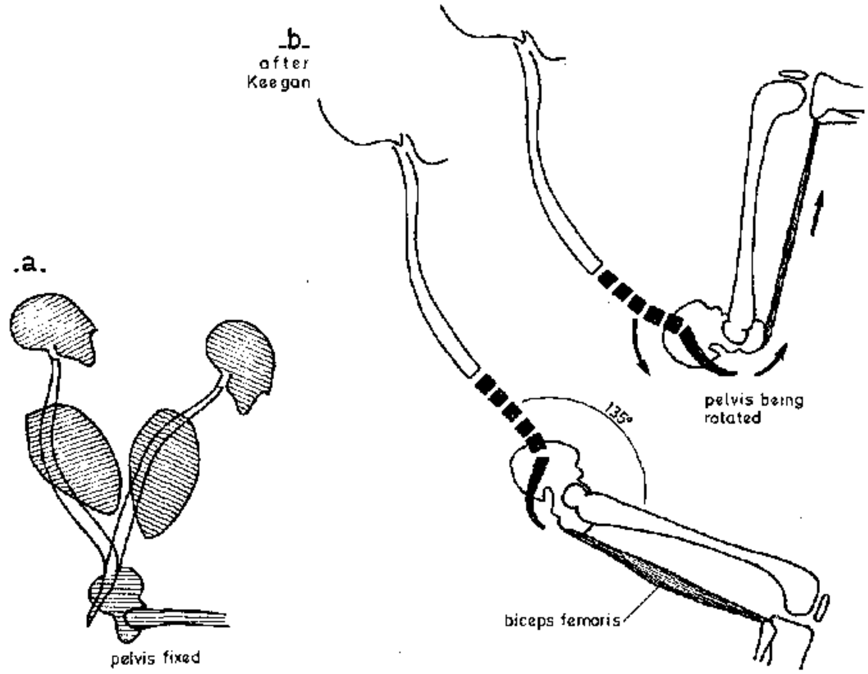

Fig. 4 - (a) Change in the lumbar curve due to trunk movement when the hip joint is fixed
(b) Change in the lumbar curve due to hip flexure.

(Fig.3). This is the partial reason of the back-ache at the lumbar area when standing for a long time. On the other hand the extreme flattening happens in the stooping position. In fact in this position the lordosis becomes a kyphosis. Weight lifting in this position applies great pressures(sometimes 10 to 15 times the weight lifted)on the lumbar intervertebral discs[6], sometimes with the result of the herniation of the certral fibro-cartilage of the disc. In case of chair sitting, both the biomechanics of the hip joint and the mechanics of sitting cause flattening. Former one is due to the fact that in normal sitting the trunk-thigh angle tends to be around 90^0-110^0. Being narrower than Keegan's normal 130^0 this angle range is supposed to flatten the curve. The latter is due to the shape of the pelvis and the weight transfer during sitting. In sitting position approximately 50% of the body weight is transferred to the seat surface through the two protruberances of the pelvis. These are called the ischial tuberosities(Fig.5). While actually

6 F.K.Bradford and R.G.Spurling, *The Intervertabral Disc: With Special Reference to Rupture of the Annulus Fibrons, With Herniations of the Nucleus Pulpous,* Illinois: Charles C. Thomas, 1945.

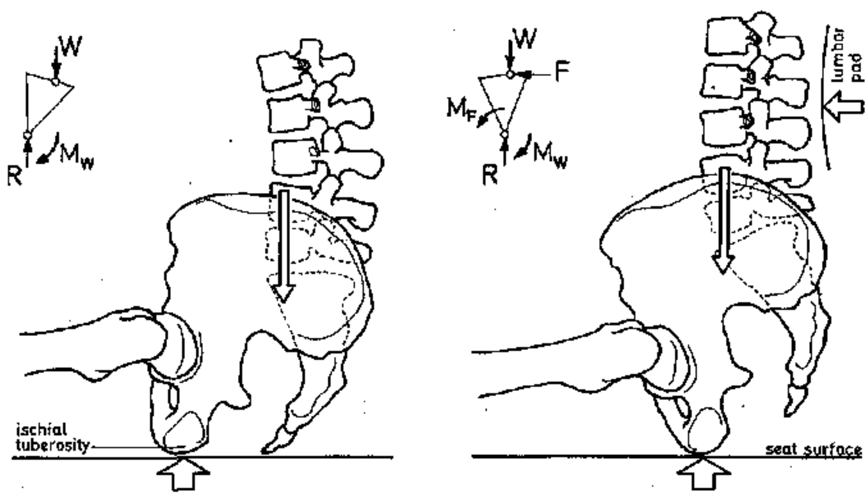

Fig. 5 Rotation of pelvis around the ischial tuberosities by the body weight.

carrying the body weight they also act as a point of rotation for the pelvis. Sitting on a horizontal surface, the pelvis rotates backward under the weight around the ischial tuberosities, moving the sacrum together and flattening the lumbar lordosis[7]. Where there are no external facilities to help to stop this rotation(i.e. correctly designed seats)man tries to diminish this rotation by crossing his legs. When the thighs are adducted and one knee is imposed on the other, by a triangulation in the skeletal link system an internal rigidification of the body structure can be attained, decreasing the tendency of the pelvis to rotate.[8]

When due to either or both of these causes the lumbar lordosis flattens during chair sitting, the resultant wedging pressure on the intervertebral discs(especially the ones near the sacrum, i.e.the fourth and fifth lumbar discs) partially displace them.

They start to protrude posteriorly and stretch the nearby ligaments(Fig.3). This ligament stretch is the reason of most back-pains.[9] Since the eleasticity of the intervertebral discs decrease by age, back-ache seems to occur more in the middle-aged and old people. Besides, the continual effect of the pressure on them is a factor that hastens their degeneration.

Certainly the lumbar section is not the only part of the spine that is affected by the sitting posture. Usually an increase in the thoracic kyphosis(slumping forward) can be seen(Fig.7). The reason for that is related to the muscular activity and will be given in the next section. The results of an increase in a kyphosis is exactly the same as a decrease in a lordosis. There happens a posterior wedging with resultant back-pain. Yet, the onset of pain is more delayed since here there is not a very stiff element like the sacrum and the distribution of pressure can be adjusted more freely between 12 discs. The increasing kyphosis is perhaps more important for the viscera (see section 45) than the spine itself.

Thus, from the skeletal health point of view two things emerge as most important:
- keeping the lumbar lordosis as much as possible;
- to help this, preventing the pelvis from a backwards rotation.

32. MUSCULAR IMPLICATIONS

In keeping a normal sitting posture the position of the trunk may show small differences. That is it may be in what can be called the anterior, the middle or the posterior positions. These can be observed in people sitting on a stool without a backrest and at a proper height. These three positions are described by the location of the center of gravity of the trunk and by the force transmitted by the feet to the floor, expressed in the fractions of the total body weight.

> "In the anterior position the trunk is bent forward. Consequently the center of gravity of the torso falls in front of the ischial tuberosities, and the feet transmit more than one fourth of the body weight to the floor...In {the middle} position, the trunk is held erect or bent forward slightly and the feet transmit about one fourth of the body weight... In the posterior position the trunk is held slightly inclined backward. The center of gravity is above or somewhat behind the tuberosities and the feet carry less than one fourth of the body weight to the ground."[10]

7. K. H. E. Kroemer and J. C. Robinette, Ergonomics in the Design of Office Furniture : A Review of European Literature, *Industrial Medicine and Surgery*, v. 38, n. 4, 1969, pp. 115-125; P. Branton, Behavior, Body Mechanics and Discomfort, *Ergonomics*, v. 12, n. 2, 1969, pp. 316-327.

8. P. Branton, Behavior, Body Mechanics and Discomfort, *Ergonomics*, v. 12, n. 2, 1969, pp. 316-327.

9. J.J. Keegan, Alterations of the Lumbar Curve Related to Posture and Seating, *Journal of Joint and Bone Surgery*, v. 35, n. 3, 1953, pp.589-603.

10. K. H. E. Kroemer, and J. C. Robinette, Ergonomics in the Design of Office Furniture : A Review of European Literature, *Industrial Medicine and Surgery*, v. 38, n. 4, 1969, pp. 115-125.

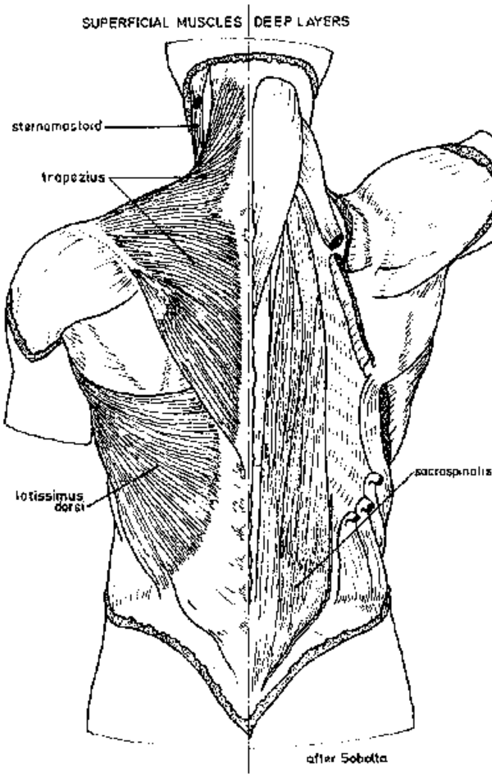

Fig. 6 Back and neck muscles.

According to Schlegel, as mentioned in Kroemer and Robinette[11], maintaining the middle position requires continuous isometric tension, i.e. static contraction[12] of the back-muscles (sacrospinalis and latissimus dorsi, Fig.6). Since the energy consumption in static muscular work is so disproportinately great compared with mechanical work[13] such continuous static contractions are very fatiguing. Subjective efforts to keep the position increases in time continuously[14], finally leading to a posture change that requires less contraction. One way is to assume an anterior position by slumping the back forward. This lessens the tension in the back muscles but increases the contraction in the nape muscles(Fig.7), strains the spinal ligament and the gluteal muscles[15], causes an increased kyphosis in the thoracic vertabrae and pressurizes the thorax. This leads labored respiration and stresses the digestive system partially.

11. K. H. E. Kroemer and J. C. Robinette, Ergonomics in the Design of Office Furniture, A Review of European Literature, *Industrial Medicine and Surgery*, v. 38, n. 4, 1969, pp. 115-125.

12. When a muscle develops tension which is insufficient to move a body part against a given resistance it is said to be in static contraction. The length of the muscle remains unghanged. (P. J. Rasch and R. K. Burke, *Kinesiology and Applied Anatomy*, Philadelphia : Lea and Febinger, 1963.)

13. A. J. S. Lundervold, Electromyographic Investigations of Position and Manner of Working in Typewriting, *Acta Physiologica Scandinavica*, v. 24, (supplement 84), 1951.

14. W. S. Cain and J. C. Stevens, Measurement of Muscle Fatigue by Constant-Effort Procedure, *Resumes, 4th International Congress of Ergonomics*, Strasbourg, 1970.

15. W. F. Floyd and D. F. Roberts, Anatomical and Physiological Principles in Chair and Table Design, *Ergonomics*, v. 2, n. 1, 1958, pp. 1-16.

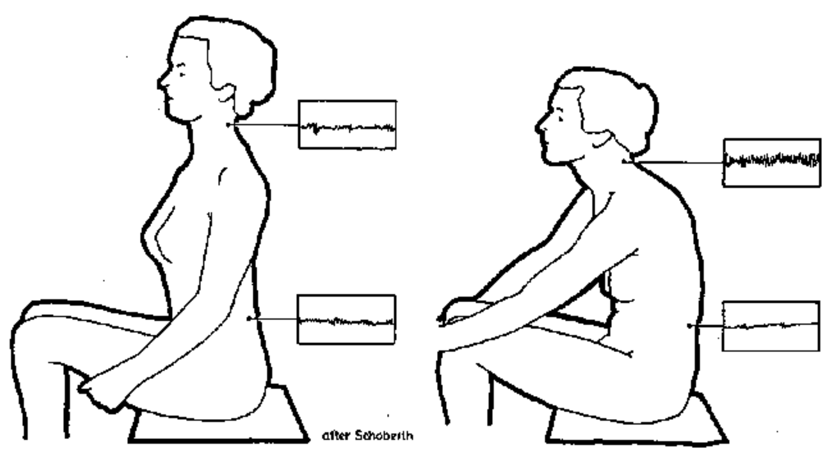

Fig. 7 Electromyographic evidence to the working of back and nape muscles in straight and slumped sitting positions.

Also the posterior position lessens the back muscle contraction but it results in the antagonistic muscle-activity, i.e. a muscular contraction in the anterior abdominal muscles (rectus abdominis group), and in the neck muscles(sterno-mastoid and trapezius, Fig. 6).[16] Yet, it is possible to prevent the loading of these abdominal muscles by mechanical measures, that is, by providing a support that stabilizes the backward inclined torso, similar to a buttress that stabilizes a wall. Leaning the back to such a support minimizes the back- and nape-muscle activities and eliminates the activity of the abdominal muscle.

16. F. P. Jones, *et. al.*, Neck Muscle Tension and Postural Image, *Ergonomics*, v. 4, n. 2, 1961, pp. 133-142.

Whether less or more, the static work is ever present in one or other group muscles in any posture. Even the "most comfortable" posture turns out to be tiresome after some time during which the muscles employed add up their energy consumption to a fatiguing level. Delaying or preventing such a result can be realized by making minor or gross postural changes.[17] The reason is twofold: First, the new posture may decrease the static work of the muscle group involved by engaging a new set of muscles. Secondly, the mechanical work which is produced during the posture change tends to be a relief from the static contraction. It is sort of renewal of resource which is consumed during contraction. As an example to the latter, Lundervold points out that, besides some other factors, minor flexions or extentions of the spinal column can stop the static muscular activity in dorsal groups for some time.[18] "Varying the posture" is also one of the eleven recommendations for healthy work given by Van Welly.[19]

17. H. Vernon, *Medical Research Council Report*, v. 29, 1924, p. 28; and W. F. Floyd and D. F. Roberts, Anatomical and Physiological Principles in Chair and Table Design, *Ergonomics*, v. 2, n. 1, 1958, pp. 1-16.

18. A. J. S. Lundervold, Electromyographic Investigations of Positions and Manner of Working in Typewriting, *Acta Physiologica Scandinavica*, v. 24, (supplement 84), 1951.

19. P. Van Welly, Design and Disease, *Applied Ergonomics*, v. 1, n. 5, 1970, pp. 262-269.

The above considerations of the general muscle work related to sitting postures are made according to a rather theoretical posture where the hands are not engaged in any work and the feet are touching the ground fully with femurs parallel to the ground and the knee forming a right angle. Certainly any deviations from these positions (and in normal daily routine these strict positions can hardly happen at all) create additional muscle work. For example in case that the feet do not touch the ground there happens an increase in the activity of back-muscles. Sitting on a slippery sloping surface has the same effect and also produces contractions in the leg and foot musculature. Raising the shoulders (e.g. resting arms on too high rests) cause fatigue in shoulder and nape muscles and increase the back muscle activity. Several other examples can be given which are not the outcomes of the sitting posture itself but of the faulty positions due to faulty environmental situations.

In respect to the main chair sitting posture itself the summarizing points for muscular efficiency are two:
- keeping postures that minimize the isometric tension in the dorsal and neck muscles,
- relieving the muscles off their activity by minor postural changes.

33. PHYSICAL CONSEQUENCES OF POSTURAL COMFORT

It is necessary to translate these postural requirements into concrete specifications that shape the the physical elements of a seat.[20] These specifications make up the postural criteria for seating.

20. Physical definiton and the elements of a seat is given at the end of the paper(section 60).

Minimization of the muscular work for trunk stabilization reflect itself in the necessity of a stabilizing element for the torso, namely the back-rest. For this purpose, the mere existence of the back-rest is sufficient. On the other hand, once the back-rest is accepted, its shaping and position becomes the most crucial point for maintaining the lumbar lordosis and prevention of the pelvis rotation.

Observation of a person sitting on a common straight chair shows that after a short time he slides his buttocks forward and continues to sit in this position. The reason is that the common straight chair stabilizes the back by supporting it at the scapular height. This freely allows the backward rotation of the pelvis and the flattening of the lumbar curve. Besides, although the design may seem to provide an approximate 95 degrees trunk-thigh angle, pelvis rotation and increased kyphosis make the effective hip joint angle less than 90 degrees, which lead to discomfort in respiration. Sliding the buttocks forward, the person widens the trunk-thigh angle and thus lessens the constraint on his respiration and lumbar area. This position is prone to rotate the pelvis even more and to prevent this, person usually crosses his legs. Even in the common easy chairs where the seat allows a large trunk-thigh angle the rotation of pelvis cannot be prevented. The feeling of comfort is more due to the trunk-thigh angle that approaches the Keegan's normal of 135 degrees and also to the wider area on which the back is supported. Apart from its inefficiency for skeletal comfort in chair sitting position[21], large trunk-thigh angles (especially when more than 120^0) are not suitable for work-positions and usually make the change of posture difficult.

In reality the back-rest should be a mechanical means to help the lumbar-vertebrae form its lordosis and to prevent the rotation of the pelvis. This is possible only by supporting the back first and foremost at the lumbar area.[22] Such a support is named as "lumbar pad". The lumbar pad should be near the lumbo-sacral joint and its shape should encourage a lordosis, i.e. it should have a convex curve in the vertical section. In straight chairs (back-rest inclination approximately 95^0, minimum 93^0) lumbar pad becomes the most important aspect of the back-rest. Where the movability of the torso is important (like the typists' chairs) the whole back-rest can be nothing more than the lumbar pad itself. However when the back-rest inclination increases beyond 105 degrees it becomes necessary to support the thoracic region as well. Yet, even then the lumbar pad should not be forgotten (Fig.8). Center of the lumbar pad is usually recommended to be 22 cm above seat-surface.[23]

In all cases, for a proper contact between the lumbar pad and the lumbar area there need to be enough space provided for the sacral protrusion (Fig.8). This can be done either by leaving an opening between the seat surface and the back-rest (specification of the backrest lower-edge height becomes important, usually 17 cm) or by shaping the backrest profile so that it does not touch the sacrum (specification of the back-rest vertical curvature becomes important). Still for the same reason, the seat-depth should be less than the buttock-poplietal length of a sitting person. It is obvious that an excessive seat-depth keeps the person from reaching back-rest.

Correct seat-height is important, too. When it is too high there happens, as already noted, a muscular activity to counteract the disbalance caused by the weight of the legs.

21. Large trunk-thigh angles certainly have no such inefficiencies when assumed in a lying position.

22. B. Akerbolm, *Standing and Sitting Posture*, Stockholm : A B Nordiska Bökhandeln, 1948; W. F. Floyd and D. F. Roberts, Anatomical and Physiological Principles in Chair and Table Design, *Ergonomics*, v. 2, n. 1, 1958, pp. 1-16; J. J. Keegan, Evaluation and Improvement of Seats, *Indust. Med. and Surg.*, v.31, n. 4, 1962, pp. 137-148; E. Grandjean, et. *al.*, The Development of a Rest Chair Profile for Healthy and Notalgic People, *Sitting Posture : Proceedings of the Symposium, Zurich, 1968*, London : Taylor and Francis, 1969, pp. 193-201; E. Grandjean, *et al.*, An Ergonomic Investigation of Multipurpose Chairs, *Human Factors*, v. 15, n. 3, 1973, pp. 247-255.

23. Unless there is reason for cervical support the height of the backrest itself should not rise beyond Scapulae. In this case, back-rest upper edge height becomes approximately 50 cm.

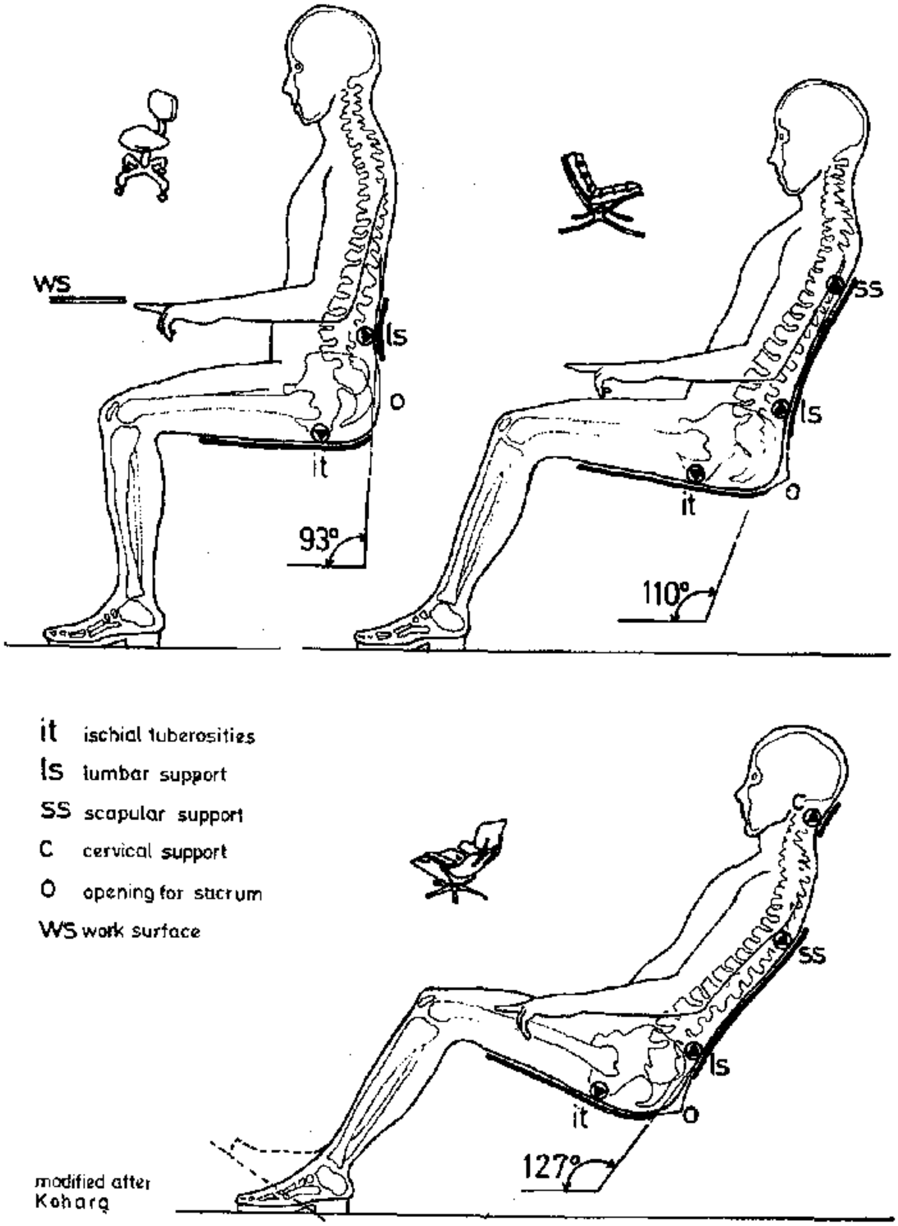

Fig. 8 Body supporting in three sitting postures.

When it is too low it diminishes the trunk-thigh angle radically unless it is possible to extend the legs forward (which may not be desirable socially and operationally). The correct seat-height is to be determined by the poplietal height (refer also to section 46).

Resting the torso on the back-rest imparts a forward sliding force to the buttocks. This leads to the muscular contraction of the back, leg and foot muscles. Relieving those muscles from that activity can be possible by the design of the surface finish of the seat surface so that the friction force between the buttocks and the seat surface can be used to counteract the sliding force. In this respect rough textured flexible materials are much better than shiny hard or flexible materials for surface coverings. Also, tilting the seat surface slightly backwards (having a seat inclination) helps to overcome that force. Besides its this advantage, Yamagushi and

Umezawa has found a relation between the seat inclination, back-rest angle and the lumbar-intervertebral disc distortion[24] (Fig.9). According to them, the neutral state for the lumbar discs (i.e. no distortion) is attained when the seat-inclination is 5 degrees and the back-rest angle is about 125 degrees. By increasing the seat inclination it is possible to decrease the back-rest angle. Of course it should be remembered that when the seat inclination is greater than a certain degree it starts to cause problems during ingress and egress.

Seat inclination is usually recommended to be around 7^0 for straight chairs[25] and around 25^0 for easy chairs.[26] Wotzka et al. recommends 15^0 for an auditorium seat.[27]

For muscular relief a seat should allow the sitter to change his posture during sitting. This has been one of the most agreed upon requirements since Akerblom mentioned it.[28] Seat and back-rest curvatures and the softness of the seat surfaces affect the freedom of the sitter to change his posture. *Excessive seat curvature, especially in transverse direction,* limits the movement of the buttocks and consequently the postural changes related to these movements. Similarly, excessive back-rest horizontal curvature limits the movements of the torso and probably the arms.[29] Apart from the excessive curvatures, the seats which are made to fit the body as if a plaster cast of it are as much limiting the posture changes. In case of posture changes in such seats the moulding of the surfaces becomes the sources of discomfort.

Back-rest horizontal curvature is recommended to have a radius of 45 cm at lumbar pad and 65 cm at shoulder height by Grandjean et al.[30] Barkla recommends a general 80 cm radius for the same curvature.[31] Transverse seat curvature is supposed to have even a wider radius, about 100 cm.

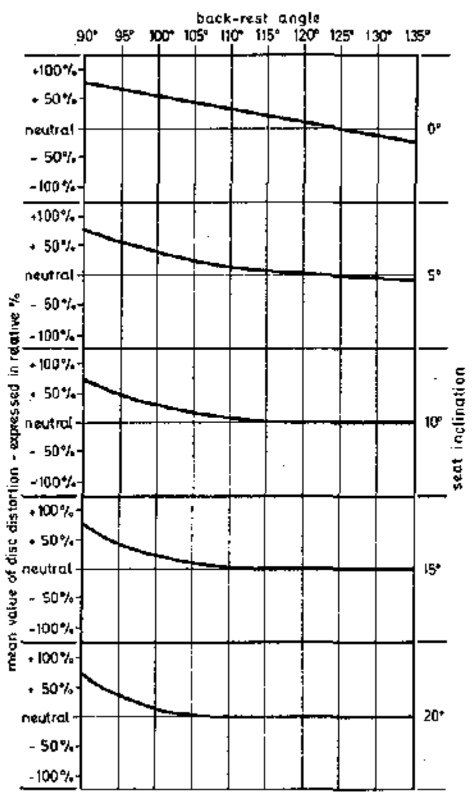

Fig. 9 Effects of seat inclination and back-rest angle on the intervertebral disc pressure.

24. Y. Yamaguchi and F. Umezawa, The Development of a Chair to Minimize Disc Distortion in the Sitting Posture, *Resumes, 4th International Congress of Ergonomics*, Strasbourg, 1970.

25. E. Grandjean, *et al.* An Ergonomic Investigation of Multipurpose Chairs, *Human Factors*, v. 15, n. 3. 1973, pp. 247-255; J. C. Jones, Methods and Results of Seating Research, *Sitting Posture : Proceedings of the Symposium, Zurich, 1968*, London : Taylor and Francis, 1969, pp. 57-67, J.J. Keegan, Alterations of the Lumbar Curve Related to Posture and Seating, *Journal of Joint and Bone Surgery*, v. 35A, n. 3, 1953, pp. 589-603; J.J. Keegan, Evaluation and Improvement of Seats, *Industrial Medicine and Surgery*, v. 31, n. 4, 1962, pp. 137-148; B. Akerblom, *Standing and Sitting Posture*, Stockholm; A B Nordiska Bokhandeln, 1948; M. Oshima, Optimum Conditions of Seat Design, *Resumes, 4th International Congress of Ergonomics, Strasbourg, 1970.*

26. E. Grandjean, *et al.*, The *Development of a Rest Chair Profile* for Healthy and Notalgic People, *Sitting Posture : Proceedings of the Symposium, Zurich, 1968*, London : Taylor and Francis, 1969, pp. 193-201; E. Grandjean, *et al.*, An Ergonomic Investigation of Multipurpose Chairs, *Human Factors*, v. 15, n. 3, 1973, pp. 247-255.

27. G. Wotzka, Investigations for the Development of an Auditorium Seat, *Ergonomics*, v. 12, n. 2, 1969, pp.182-197.

28. B. Akerblom, *Standing and Sitting Posture*, Stockholm : A B Nordiska Bokhandeln, 1948.

29. It may also discourage the sitter to lean on the backrest if it squeezes the shoulders. One example is that of P. Branton and G. Grayson, An Evaluation of Train Seats by Observation of Sitting Behavior, *Ergonomics*, v. 10, n. 1, 1967, pp. 35-51. Shoulder breadth of Turkish male is 49.8 cm for 95th percentile. H. T. E. Hertzberg, *et al. Anthropometric Survey of Turkey, Greece and Italy*, Oxford : Pergamon, 1963.

30. E. Grandjean *et al.*, An Ergonomic Investigation of Multipurpose Chairs, *Human Factors*, v.15, n.3, 1973, pp.247-255.

31. D.M. Barkla, The Estimation of Body Measurements of British Population in Relation to Seat Design, *Ergonomics*, v. 4, n. 2, pp.297-304.

As to the softness of the seats, the seat can be so much soft that the body sinks into the material, loosing its ability to move afterwards. Even getting up may become a problem in too soft seats. Still another disadvantage of excessively soft seats is that the body "floats" on the soft upholstery and the posture is maintained by the muscular contraction instead of the seat surfaces.[32] This is very fatiguing in the long run though it may feel comfortable at the beginning.

32. K.H.E. Kroemer and J. Robinette, Ergonomics in the Design of Office Furniture: A Review of European Literature, *Industrial Medicine and Surgery*, V. 38, n. 4, 1969, pp.115-125.

Thus, the seat surfaces should be soft enough only to be physiologically comfortable (see section 46). In fact the Stone and Thompson study shows that the harder seats tend to be preferred by people.[33]

33. P.T. Stone and G.S. Thompson, *Seating for Motor Vehicles: (i) The Comfort of Car Seat Cushions*. Report No. MVR3, Dept. of Ergonomics and Cybernetics, Loughborough College of Technology (not dated).

Apart from these major specifications two more points can be made:

- Keegan also claims that while sitting upright, flexing the legs beneath the chair relaxes the posterior thigh muscles and helps to preserve the lumbar curve nearer to the natural one.[34] In this respect, the support structure should allow the legs to have such a flexion (this is easier said than done if the popular cross bar between the chair legs is remembered). Knee flexion is necessary during standing up from a chair (Fig.10)
- Armrest should not cause raised shoulders or similar positions that induce muscular activity. Armrest height is to be derived from the sitting elbow rest height. The average (50th percentile) value of this dimension is 22.4 cm for Turkish male population.[35]

34. J.J.Keegan, Alterations of the Lumbar Curve Related to Posture and Seating, *Journal of Joint and Bone Surgery*, v.35A, n. 3, 1953, pp.589-603.

35. H.T.E.Hertzberg, *et al.*, *Anthropometric Survey of Turkey, Greece and Italy*, Oxford : Pergamon, 1963.

All the postural criteria are summarized in figures 11 and 19.

40. PHYSIOLOGICAL CRITERIA FOR SEATING

Apart from the conditions and working of skeletal and muscular system, certain other bodily functions are affected by the sitting posture and the physical properties of seats. Namely, they are blood circulation of the lower limbs, the compression of superficial tissues, the bodily heat gain and loss, the compression of nerves and the functioning of the viscera.

41. EFFECTS ON THE BLOOD CIRCULATION

The effects of the sitting posture and the seat/sitter interaction on the blood circulation of the lower limbs are observed in the changes of venous pressure in the lower extremities and its consequences and in the local anesthesia due to constricted arteries.[36]

36. Sitting posture also affects the heart rate. J.A. Hanson and F.P. Jones, Heart-Rate and Small Postural Changes in Man, *Ergonomics*, v.13, n.4, 1970, pp.483-487. Although the difference of 13 beats between sitting and standing postures may be quite negligible in the range of heart rates the heart can withstand, it gives an example for the physiologic importance of the comfortable posture and thus of a chair which allows one for it.

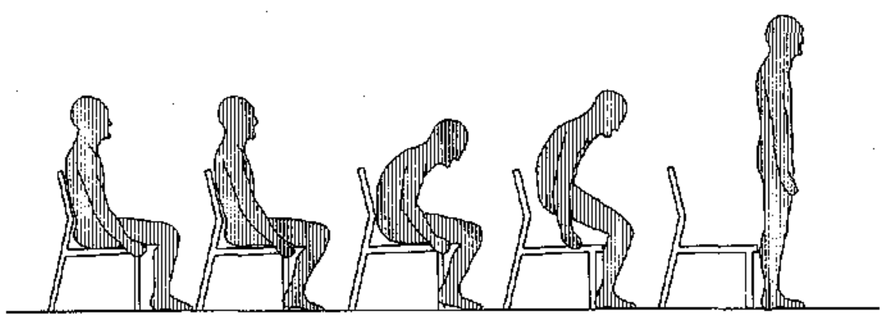

Fig. 10 Knee flexion during egress from a chair.

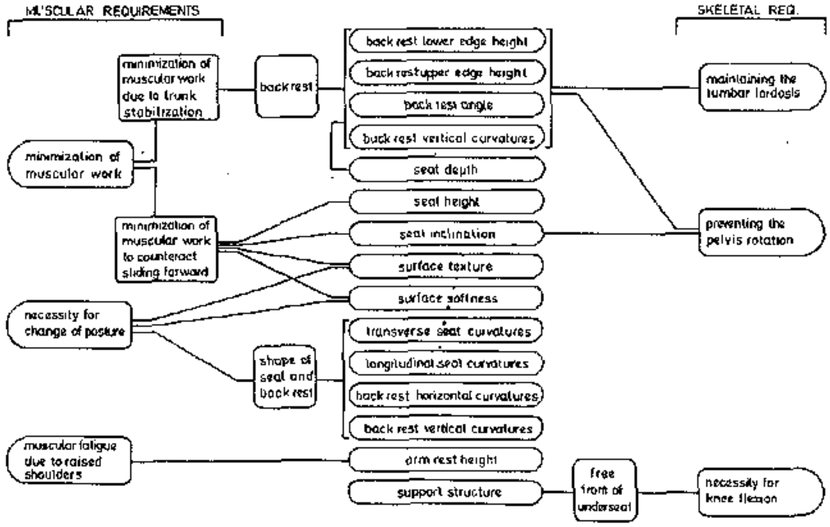

Fig. 11 Postural seating criteria.

The venous pressure in the lower extremities is largely governed by the hydrostatic pressure of the column of blood in veins. Thus the position of the body and the veins in space is a crucial aspect in determining that pressure. Lying on a horizontal surface results in a venous pressure much lower than the one in standing upright since in the former position the major veins are in a horizontal position creating a low hydrostatic pressure. In a standing position they form columns as high as the heart from the ground level. When concerned with the venous pressure in the lower limbs, sitting posture results in a pressure between standing and lying. Pollack and Wood study has given results for the venous pressure at the ankle as 11.7 mm Hg for lying posture, 56.0 mm Hg for sitting posture and 86.8 mm Hg for standing (average values).[37] When walking, the standing venous pressure is decreased because the rhytmic play of leg muscles help the blood to travel upwards in veins.

37. A. A. Pollack and E. H. Wood, Venous Pressure in the Saphenous Vein at the Ankle, *Journal of Applied Physiology*, v. 1, 1949, pp. 649-662.

Being a completely static position, sitting posture has no such muscular help to reduce the pressure. The consequence of this is the flow of fluid through capillary membrane into the interstitial space, causing a swelling in the feet. When the sitting posture is kept for a long time this increase in the volume of foot may amount to 2% of the original volume of foot.[38]

38. M. Pottier, et al, The Effects of Sitting Posture on the Volume of the Foot, *Ergonomics*, v. 12, n. 5, 1969, pp. 753-758.

This swelling is increased even more if the vein is constricted at some point, obstructing the venous return. Such a constriction usually happens to femoral and poplieteal vein when sitting on a too high chair. When the seat is higher than it should be the feet cannot touch the ground properly and the part of the body weight that should be transferred to the ground by the feet squeezes the hind muscles of the thigh and the poplietal artery and vein between the seat surface and the femur (Fig.12). The poplietal vein, being sequeezed somewhere above the knee, starts to build up a venous reserve in the lower leg and the foot. This leads to an increase in the volume of the foot, and when continued, in the volume of the ankle and the lower leg. Pottier et. al. note that when the underthigh is compressed by the front edge of the seat, the volumnar increase of the foot due to the obstructed venous return amounts to about 25% of the increase caused by the posture alone.[39]

39. M. Pottier, et al., The Effects of Sitting Posture on the Volume of the Foot, *Ergonomics*, v. 12, n. 5, 1969, pp. 753-758.

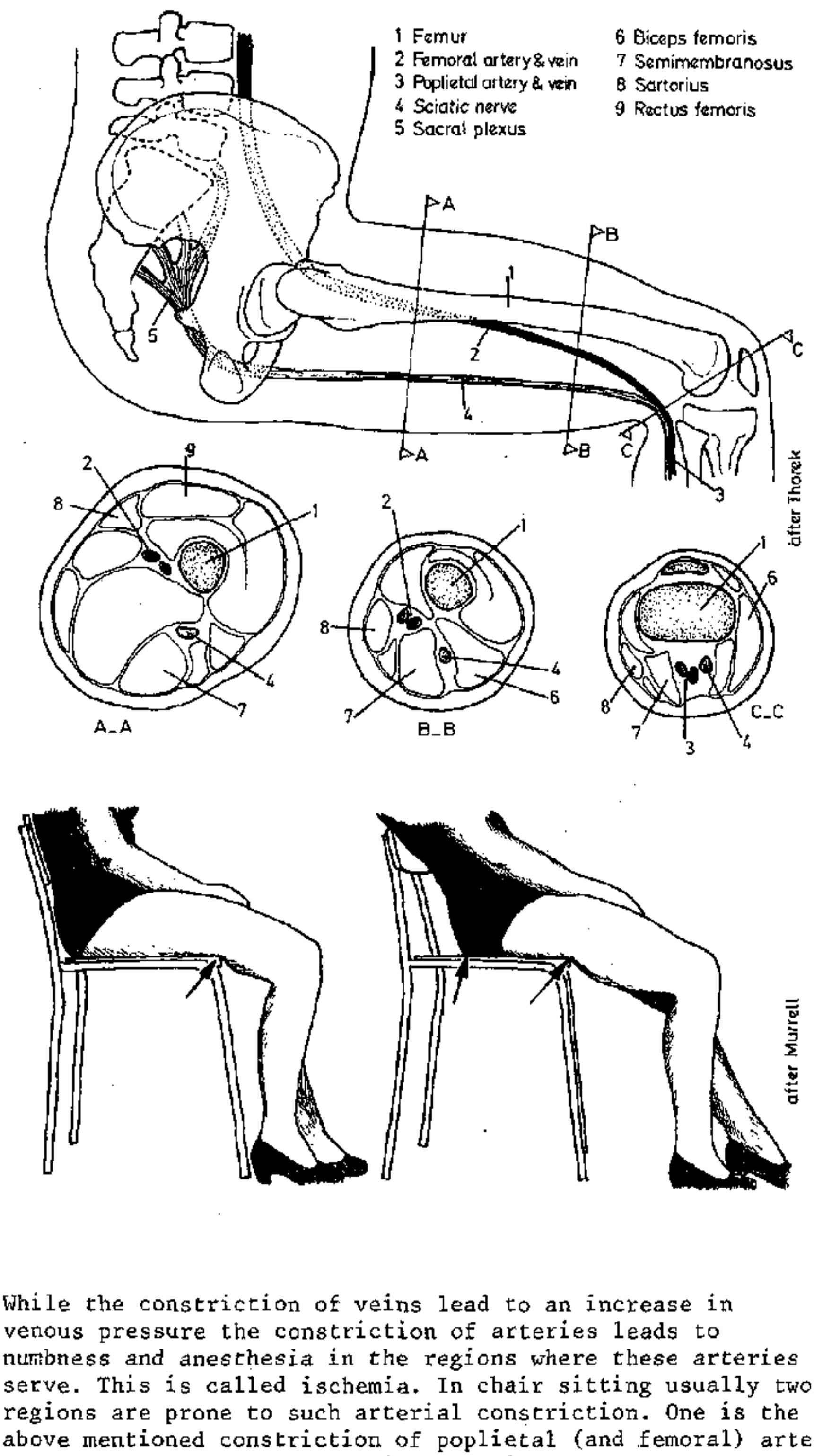

Fig. 12 Femoral and poplietal blood vessels and the sciatic nerve in the upper leg. Underthigh and buttocks compression in high chairs.

While the constriction of veins lead to an increase in venous pressure the constriction of arteries leads to numbness and anesthesia in the regions where these arteries serve. This is called ischemia. In chair sitting usually two regions are prone to such arterial constriction. One is the above mentioned constriction of poplietal (and femoral) artery by the front edge of the chair. In this case there happens a numbness in the feet and lower legs. The other one may happen at the buttocks. When, due to several reasons, the body is slid forward on the seat surface, the weight is shifted to be carried from the ischial tuberosities (by which it should be carried) to the muscular tissues of the buttocks. Such a condition compresses the superior gluteal artery. The superior gluteal artery serves the buttocks. Consequently, its constriction leads to the numbness of the buttocks.

Function of veins and arteries can be hindered also by the muscles they are passing through when excessive limb positions are assumed. Thus very low seat-heights are as well problematic when they cause excessive hip and knee flexion(i.e. when one cannot extend his legs forward). Excessive hip flexion squeezes the femoral artery and vein and excessive knee flexion squeezes the poplietal artery and vein, with the abovetold consequences. Also, the wrong placement of armrests may impart similar undesirable positions to shoulders and arms.

42. EFFECTS ON THE NERVES

As pressure on blood vessels impair the travel of blood in them, pressure on nerves(not nerve endings) cause impairments in the working of them. Such an impairment shows itself in the form of numbness or anesthesia in the areas where the nerve serves.

It is just mentioned that the areas most prone to excessive compression are the underside of thighs and the muscular mass of buttocks. Passing through both of these areas are the sciatic nerves. They are the continuation of the sacral plexus. They pass out of the pelvis through the greater sciatic foramen, and passing below the piriformis muscles and lateral to the ischial tuberosities they enter the thighs. They run straight down until branch out into two right above the knees. These two main branches and many other minor branches of the sciatic nerves serve the buttocks and the whole of two legs. Their path, as can be seen, is very open to receive pressure in sitting posture. A shift of weight from the ischiae can apply pressure on them. Besides, similar to the poplietal vessels, they may be squeezed by the front edge of the seat(Fig.12).

Another nerve which can be affected in chair sitting is the ulnar nerve which controls the little and ring fingers of the hand and that half of the palm. While passing the elbow it is very open to exterior effects(such as pressures due to armrests).

43. EFFECTS ON THE SUPERFICIAL TISSUES

Sitting in a seat, several parts of the body come into contact with the surfaces of the seat and, naturally are compressed due to the weight of the body. This compression is inevitable but its character and amount are largely determined by the design of the seat elements.

The capacity of the superficial tissues to withstand pressure changes all over the body. A pressure that can be tolerated by a certain body area turn out to be quite painful for another area. Where the compression is above the tolerable level for that area it creates pain due to excessive loading of tactile receptors and it can cause local itching and numbness due to superficial ischemia.[40] It is claimed that the pressure sensitive areas of the skin correspond to the areas of higher tactile perception which, in turn, correspond to the parts of the skin which move more actively[41] (Fig.13). In principle the toughest tissues of the body are the ones covering the heels. These are followed by the tissues covering the ischical tuberosities which have minimal number of blood vessels and no muscular underlay.This is of circumstantial importance since in the sitting posture

40. This is the local deficiency of blood at the skin due to the constriction of superficial blood vessels. It is not in the same sense of obstruction of the circulation as mentioned in the section (41) because it does not affect main arteries.

41. J. Kohara, *The Application of Human Engineering to Design : Chair, Bed, Vehicle Seat*, Chicago : Institute of Design, IIT, 1965.

points	pressure sensitivity (g)	two point discriminat'n (mm)
A	19	37
B	19	35
C	16	38
D	17	29
E	21	37
F	13	25
G	15	35
H	16	32
I	21	14
J	23	25

after Kohara

Fig. 13 Pressure sensitivity of some posterior body areas.

approximately 65 % of the body weight is transferred to the seat through buttocks[42], and as long as the primary contact with the seat surface is made through the ischiae the problem of superficial ischemia is solved in this area. On the other hand, the rest of the buttocks and the underside of thighs are made of very soft tissues that cover muscular masses. In case the body weight is concentrated on these parts (e.g. Fig. 12) painful tissue compression and ischemia may happen.

Parts of the body other than the buttocks and the underside of thighs that come into contact with the seat surfaces are the posterior surface of the trunk, the shoulders, the nape, the head, the posterior surfaces of arms and forearms, and the palms of hands. All these are medium sensitive areas where the tissue compression should be kept at a reasonable level(a very rough figure can be 40 gram/cm^2).

42. "(Hertzberg and Swearinger found out that) about one third (35.2 %) of body weight is borne by the combination of the foot-rests (18.4 %) and a back-rest slightly sloping at 15° rake(4.4 %). In effect, the seat pan carries 65 % of the weight." (P. Branton, Behavior, Body Mechanics and Discomfort,*Ergonomics*, v. 12, n. 2, 1969, pp. 316-327.

44. EFFECTS ON THE BODILY HEAT GAIN AND LOSS

Heat exchange between man and his environment is governed by his loss of heat through evaporation(and sweating), and by his loss or gain of heat by radiative and convective means. The body exchanges heat with the ambient air by convection, and with the surrounding surfaces by longwave radiation. It may lose or gain heat by these channels depending on whether the environment is respectively colder or warmer than the body surface. The convective heat exchange depends on the velocity of the ambient air, and the radiative heat exchange depends on the absolute temperatures of the surrounding surfaces and of the skin. The heat exchange of a clothed body by convection and radiation depends on the clothing as most of the heat exchange takes place at the external surface of the clothing and affects indirectly the body itself. Evaporation of water takes place in the pores of the skin. This constitutes always a heat loss. Through evaporation and sweating the body can lose great quantities of heat. The cooling effect of evaporation depends on the rate and place of the evaporation process. When the evaporation is rapid and takes place on the skin surface it cools the body very efficiently. Yet,when sweat drops are formed on the skin surface and transferred to the clothing the efficiency of evaporation is greatly reduced. Even before getting wet, clothing decreases the air velocity and increases the humidity over the skin, reducing the evaporative cooling potential of the body.

The surfaces of a seat cover most of the posterior part of the body. In this way the radiative and convective heat exchange through these parts become almost completely absent since, compared to clothing, the quality and the thickness of seating materials make them a much stronger barrier between the body and the environment. But it introduces a new factor, that is conductive heat loss or gain. In general practice the conductive heat exchange is always neglected due to the reason that the man barely touches any part of the environment directly long enough. But sitting in a seat, it becomes the major thermal environment for the parts of the body that is touching it, making the conductive heat exchange and thus the temperature and heat exchange characteristics of the seat quite important.

A seat's interference with the evaporative loss is also very strong. Forcing the clothing to the surface of the body it eliminates the air circulation over the skin. It may also restrict or stop the evaporation through the clothing, with a resultant wetting of clothes by the condensation of the sweat, drop in the efficiency of evaporative heat loss, and an unpleasant tactile feeling.

45. EFFECTS ON THE VISCERA

In sitting posture the probability of having an increased thoracic kyphosis and a flattened lumbar lordosis is already mentioned in the section(32). Such a posture has the tendency of reducing the volume of the internal cavities of the body, especially the abdominal cavity , with the resulting pressure on the viscera. Protected by the ribs, the thoracic cavity is affected less.

Long term pressure on the viscera may cause several physiologic problems. Primarily it can hinder the working of digestive organs. Although there is less load on the thoracic cavity, the activity of diaphragm can be more difficult due to the pressure on it from the abdominal cavity with the resulting difficulty of respiration. Limitation of respiration may lead to other complexities because of the diminishing oxygen intake.

In effect, the requirements for a healthy working viscera coincides with the ones for the skeletal and muscular efficiency.

46. PHYSICAL CONSEQUENCES OF PHYSIOLOGICAL COMFORT

The specifications for the physiological criteria are as follows.

Both for the elimination of excessive tissue pressure and for the elimination of the pressure on the blood vessels and nerves, the prevention of the undue pressure on the underside of thighs should be realized by the correct seat-height and depth and by the shaping of the front edge of the seat surface. The correct seat height also prevents the blood vessel contraction due to excessive knee flexion. The correct seat-height is determined by the poplietal height. In other words, seat-height of a near horizontal seat (i.e. of a seat inclination less than 5 degrees) should be some 3 cm less than that distance which is the height of the tendons of the flexors of the knees when the foot is flat on the floor and the knee is at a right angle. When the seat inclination is more (especially when more than 15 degrees) the poplietal height can be only a rough guide for the seat height because then the lower legs are not vertical (Fig.8). The ultimate criterion, in any case, is the absence of a significant pressure on the underside of thighs. The seat depth should be some 5 to 10 cm less than the buttock-poplietal length to keep the front edge of the seat cutting into the backsides of the knees. Since the poplietal height determined while the lower legs are vertical, any diversion of lower legs from this position (extending legs forward or keeping them under the seat) tends to lower the knees and compress the underside of thighs. Curving down the front edge of the seat prevents it from sharply cutting into the thighs when such leg positions occur.[43]

43. J. J. Keegan, Alterations of the Lumbar Curve Related to Posture and Seating, *Journel of Joint and Bone Surgery*, v. 35A, n. 3, 1953, pp. 589-603.

J. J. Keegan, Evaluation and Improvement of Seats, *Industrial Medicine and Surgery*, v. 31, n. 4, 1962, pp. 137-148.

As to the numerical specifications of seat height and depth according to the anthropometric data (see also section 50) on Turkish male population, the following can be said. The two necessary dimensions are :

	Percentiles				
	1	5	50	95	99
Poplietal height, sitting	36.4	37.7	41.1	44.9	46.6
Buttock-poplietal length	41.4	43.3	47.4	51.7	54.0

Source: Hertzberg, et al(1963)

In this respect the seat-height (especially in working seats) should be adjustable between 34 cm and 44 cm. Where such an adjustment is not possible the fixed seat-height can be 36 cm. This may be problematic for the very short and the very tall but it accomodates 45% of the population (5th to 50th percentile) effectively. On the other hand, when it is possible to use footrests (offices etc.) the seat-height should be fixed at 44 cm and the smaller percentiles should use 5 or 10 cm high footrests.

Where possible, the seat-depth should be adjustable, too. The range is between 36-44 cm. The fixed seat-depth has to be 38 cm. Though this is less than satisfactory for the smaller percentiles (1st to 5th), shorter seats become very small for the higher percentile. In fact a 38 cm seat-depth effectively accomodates 90% of the population (5th to 95th).

Preventing the undue pressure on buttocks, and thus on the sciatic nerve, that is, transferring the major load through the ischial tuberosities and their tough tissue coverings is realized by a correct back-rest design and seat-inclination as well as a correct seat-height and depth. As already explained in the sect.(33), by forming a lumbar pad and a sacral cavity in the backrest vertical curvature and by keeping a moderate backrest angle (min.93^0, max.115^0) and a seat inclination it is possible to keep the line of force of the body weight passing through the ischiae. Preventing the pressure on the ulnar nerve and thus the anaesthesia of the small and ring fingers of the hand is possible by the design of the armrests. They should be designed so that there are clearances beneath the elbows, i.e. the arms are supported only beneath the forearm.[44]

44. J.J. Keegan, Evaluation and Improvement of Seats, *Industrial Medicine and Surgery*, v. 31, n. 4, 1962, pp. 137-148.

As a measure against the pressure concentrations on the *posterior surfaces of the torso and arms, the edges of the* surfaces of the back-rest and armrest should smoothly curve outwards so that they do not cut into the body surface.[45] Besides, there should not be any protrusions on these surfaces. (In this argument it is accepted that all of these surfaces really follow the definition of a true surface but are not made of linear elements that form a boundary as, for example, in the back-rest of Windsor chair. Such seat and back-rest surface substitutions made of one or more linear elements are out of consideration for the physiologic comfort).

45. K.F.H. Murrell, *Ergonomics*, London : Chapman and Hall, 1969.

For all of the seat surfaces and body parts effective pressure distribution is a result of the interaction of the seat shape and the material softness (or hardness). Thus, taking the material softness as one variable the properties of shape can be decided. At one extreme there is the completely hard material. Since such a material fails to shape itself according to the contours of the body, when used flat in the seat and back-rest surfaces it creates pressure spots. On the seat-surface these pressure spots tend to be (or should be) the ischiae. High pressures at the ischiae can be tolerated as mentioned, yet in the long run even that may prove to be painful. Creation of pressure spots on the back is even more uncomfortable. Thus, with the completely hard materials, a slight profiling of the seat and back-rest surfaces is recommended to attain a more uniform pressure distribution at the back and to distribute the pressure on the ischiae to some degree (see section 33-back-rest and seat curvatures). But even when contoured, seats made of hard materials should not be used when long time sitting is required. Hard materials should not be used in vehicle seats.[46] Especially when the seat-height is below normal such as in the car seats.[47]

46. P. Branton and G. Grayson, An Evaluation of Train Seats by Observation of Sitting Behavior, *Ergonomics*, v. 10, n. 2, 1969, pp. 316- 327.

47. J.C. Jones, Methods and Results of Seating Research, *Sitting Posture : Proceedings of the Symposium, Zurich, 1968*, London : Taylor and Francis, 1969, pp. 57-67.

Specifying recommendations for soft materials is rather difficult because of the vast variability of the term "softness". Although it refers in essence to the compressibility of the material, sensorial and physical qualities of compressibility change quite much. Compressibility characteristics of a woolen mat, a plastic foam, and an air or water filled bag differ from each other while all of them are called soft materials. A "soft surface" may refer also to a layer of flexible but supported material (e.g. canvas or hide supported by a frame) as much as to the surface of a soft material. Existing literature solves this usually by using a phrase like "a material which does not give way more than one inch".[48] They claim that with that much compressibility the pressure on protruberances is sufficiently enlarged yet the posture can be altered easily and the body does not "float" in the material.

48. M.M. Ayoub, Sitting Down on the Job(Properly), *Industrial Design*, v. 19, n. 3. 1972, pp. 42-45; K. H. E. Kroemer, Seating in Plant and Office, *American Industrial Hygiene Assoc. Journal*, 1971, pp. 633-652.

For a better understanding of the surface softness the materials can be examined under three main groups :

a) Spring upholstery (Plastic foam or spring supported surfaces - Fig.14) : These are elastic materials which deflect under load and turn to their original shape when unloaded. Unit pressure increases with the amount of compression, therefore pressures are higher under the protruding points of anatomy. Thicker foam pads or spring under construction may lead to a more even pressure distribution but such thick cushioning may also lead easily to the "floating" of the body.[49] In effect, the

49. Anyway the objective is not to obtain an overall uniform pressure but a relatively wider distribution of pressure at pressure points.

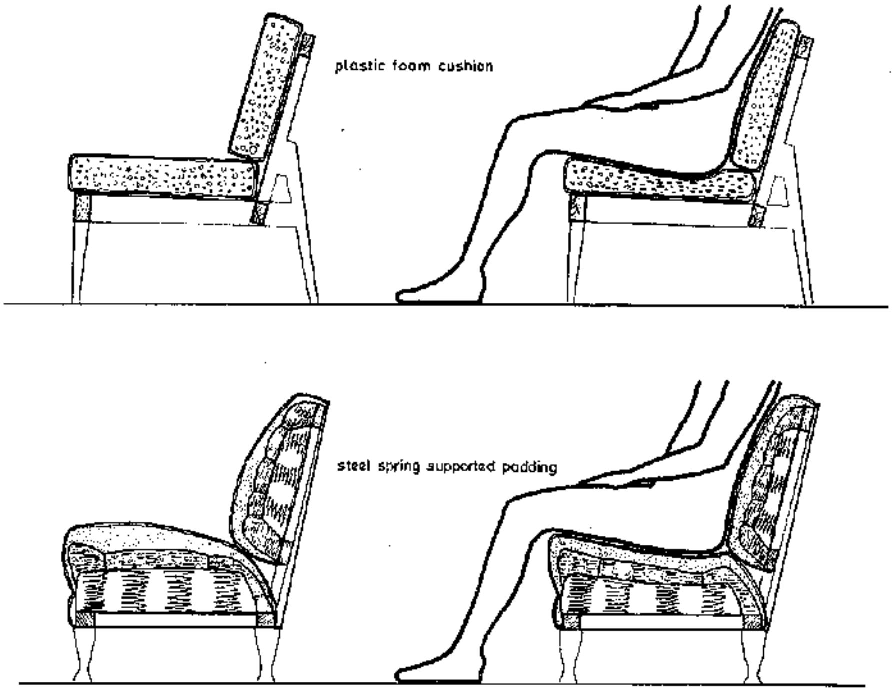

Fig. 14 Spring upholstery

recommendation of "not giving way more than 3 cm" is most applicable to these materials. Where plastic foaming is employed, the thickness of a high density foam can be around 5 cm. With low density foams and spring-supported upholstery a thicker pad is necessary but has the risk of floating the body. In general, vehicle seats may require a thicker high density foam. Stone and Thompson study show that user preferences favor a polyurethane foam car seat that deflects 7.4 cm under 40 kg/sq.ft. load.[50] Branton and Grayson show that in train seats a high density polyurethane foam cushion over GRP seat shell construction is preferred against a spring upholstered seat of the very same appearance and size.[51] When plastic foam is used the support surface should be hard and flat. Contouring it or using a flexible webbing can lead to undesirable pressure distribution.[52] (Fig.15).

50. P. T Stone and G.S. Thompson, *Seating for Motor Vehicles: (i) The Comfort of Car Seat Cushions*, Report No : MVR3, Dept. of Ergomics and Cybernetics, Loughborough College of Technology(not dated).

51. P. Branton and G. Grayson, An Evaluation of Train Seats by Observation of Sitting Behavior, *Ergonomics*, v. 10, n. 1, 1967, pp. 35-51.

52. J. Kohara, *The Application of Human Engineering to Design: Chair, Bed, Vehicle Seat*, Chicago: Institute of Design, I.I.T. , 1965.

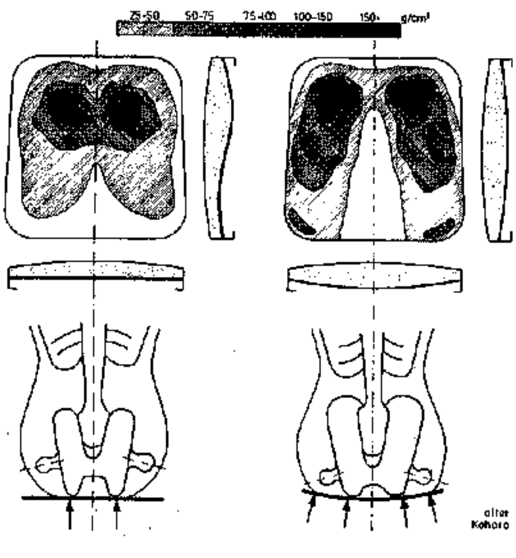

Fig. 15 Effect of seat shell in foam upholstered chairs on the pressure distribution.

b) Incompressible Upholstery (fiber, granule or liquid fillings - Fig.16) : These are made of fillings which, when compressed, slide over each other to take shape of the loading body, and keep that shape even after the load is removed. These fillings can be of several materials as long as they have the capacity of changing their relative positions under loading and equalize the contact pressures. Traditional examples can be woolen or cotton fibers or, much better, the feather cushions. Recently the water cushions (i.e.water molecules as fillings) or spherical plastic fillings are being used. Bolton experimented with several filling materials including plastic spheres and natural seeds.[53] He proposes using spherical granules of approximately 7 mm diameter with hard and smooth surfaces. Pad thickness should be so that, after settling, there should still be several layers of granules in the thinnest part of the pad. Usually an experimentation can be necessary to decide the optimum pad thickness as to the use characteristics and granule type, but a general 5 cm thickness can be taken as a guiding figure. Also for this type of cushioning the understructure should be hard and uncontoured. Compared to the spring upholstery, pressure distribution and the feeling of comfort of the incompressible upholstery is usually considered better.

53. C. B. Bolton, Ventile, *Incompressible Cushions*, *Applied Ergonomics*, v. 3, n. 2, 1972, pp. 101-105.

c) Flexible tensile materials (frame supported canvas, hide, etc. - Fig.17) : These are sheet materials stretched between the support structure of the seat. Loaded by the

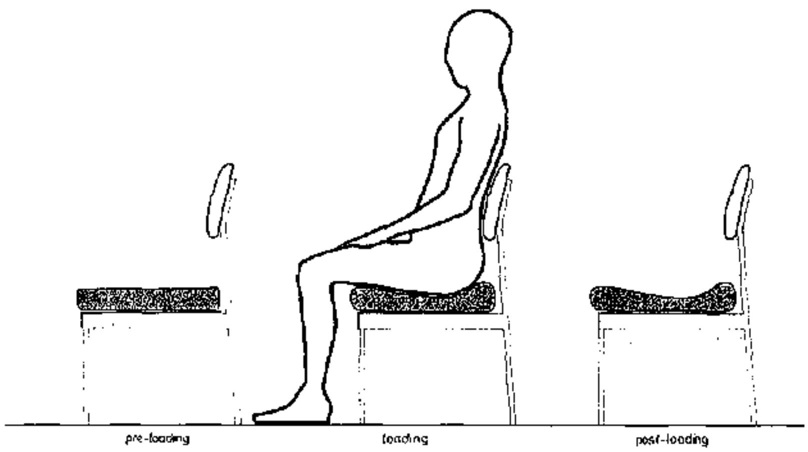

Fig. 16 Granule filling Upholstery

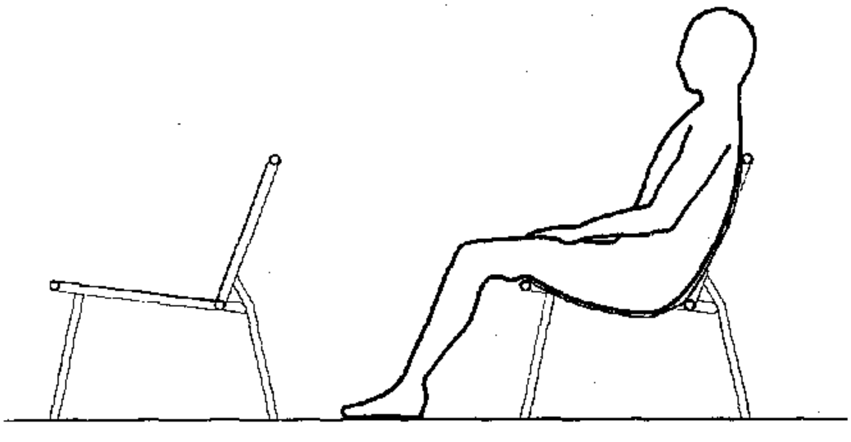

Fig. 17 Seat surfaces made of tensile material.

body, they act as tensile elements and force the body to take the shape which will minimize their internal stresses. This shape always proves to be unsuitable for body parts. It encourages the convexity of touching surfaces which, at times, may mean unhealthy spinal shapes. Due to the resulting shape of the surface, the soft tissues tend to be compressed beyond their limit, and most probably unevenly. Because of the elasticity and deflection differences, pressure concentrations happen along the lines where the flexible material meets the hard carrying frame.

In general, this sort of seat surface is highly unacceptable. Only where the stretched material is very tough (heavy fabric and/or stiff rubber sheet) and the stretching very strong the surface can become hard enough and minimally deflecting which can be acceptable.

Softness of the surface also affects the evaporative heat loss of the body because of two reasons : The softer the material the more it shapes itself to the contours of the body, decreasing the possibility of air circulation on the skin, and, in parallel, the softer the material the more the body sinks in it and is covered by its surface minimizing the surface area available for evaporation.
Evaporative heat loss is also related to the ventility and moisture permeability of the material. The material (both the cushioning and the covering materials) should allow an air circulation over the skin surface. They should also have some humidity absorbing capacity to prevent condensation of moisture produced by skin evaporation. Garrow and Wooler propose sheepskin covering of seats where long time sitting takes place.[54] They write that besides the high ventility, moisture dissipation and hygroscopicity (it absorbs up to 30% of its dry weight without feeling wet) of wool, the dense and resilient pile of fleece distribute the pressure quite evenly over the body surface. Yet, wool is also found to increase sweat secretion.[55] The thermal diffusivity[56] of the seating material should ensure a comfortable conductive heat exchange. Grandjean et al. point out that the material should also conserve heat[57], which actually means the same.

All physiological criteria are summarized in figures 18 and 19.

54. C. Garrow and J. Wooler, The Use of Sheepskin Covers on Vehicle Seats, *Ergonomics*, v.13, n.2, 1970, pp. 255-263.

55. U. Burrandt and E. Grandjean, Work-physiological Studies on Materials for Covering Flat Upholstered Work Chairs, *Int. Z. Angew. Physiol.*, v.22, n.2, 1966, pp. 167-180.

56. Thermal diffusivity is the term that accounts for the feeling of cold or warm of different materials under the same thermal conditions, e.g. timber is good to handle in most thermal environments while it is difficult to handle metals under hot or cold environments.

57. E. Grandjean *et al.*, An Ergonomic Investigation of Multipurpose Chairs, *Human Factors*, v.15, n.3, 1973, pp. 247-255.

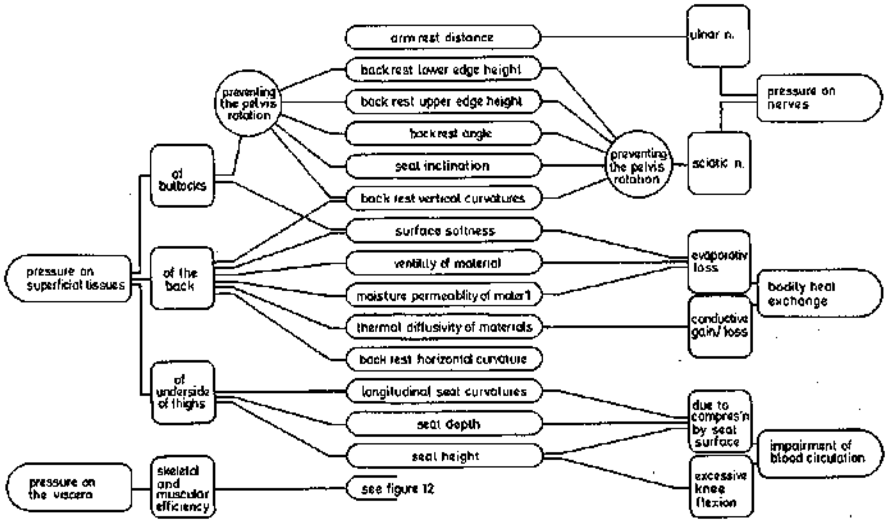

Fig. 18 Physiological seating criteria.

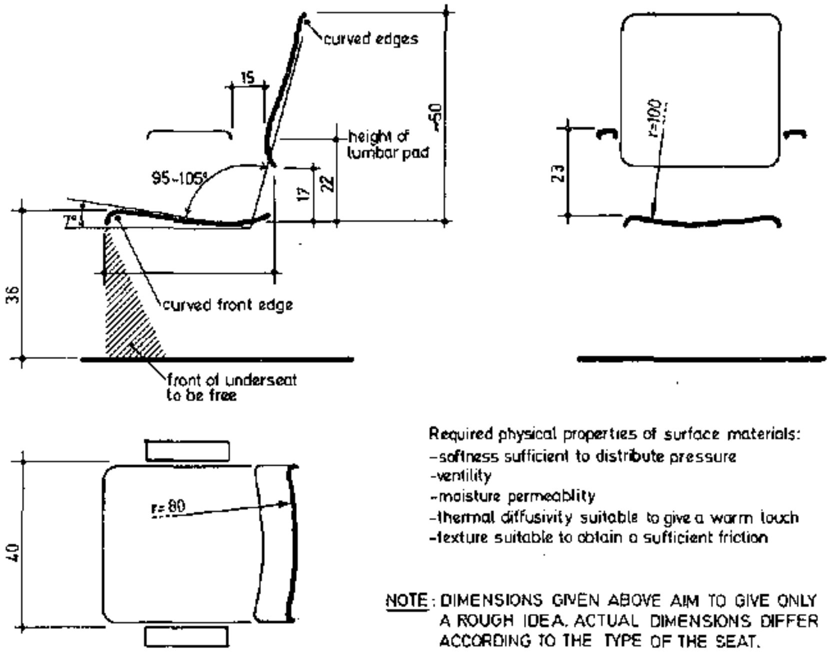

Fig. 19 Physiological and postural criteria for semi-upright chairs - Approximate dimensions.

50. A NOTE ON ANTHROPOMETRIC CRITERIA

In the specification of requirements for postural and physiological criteria there have been several attributes to the anthropometric dimensions. But during the employment and the application of these one has to observe some facts. Contrary to the general trend in seating specifications, the employment of correct anthropometric criteria does not necessarily ensure a correct seating design. This is because of :

- Anthropometric criteria can serve only to postural and physiological comfort. Yet, there are many other factors (psychologic, technologic, etc.) that contribute to the efficiency of a seat to which the anthropometric dimensioning does not contribute. Le Carpentier points out that, in the results of his experiments, the absence of correlation between the preferred dimension and the corresponding anthropometric measurements for seat height and depth (Fig.20) suggest that the significant negative correlation was due to personal choice factors other than the simple anthropometric ones.[58]

58. E. F. Le Carpentier, Easy-Chair Dimensions for Comfort, *Ergonomic* , v.12, n.2, 1969, pp. 328-337.

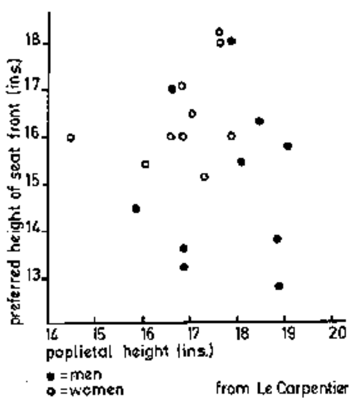

Fig. 20 Preferred seat heights and poplietal heights.

- Characteristics of the seat can make the application of anthropometric dimensions difficult. Especially when the seat material is soft, the dimensions of the seat which are governed by the anthropometry change under the weight of the person. The amount of deflection can be very difficult to foresee since it may change according to the weight of the person, the posture he assumes, the movements of the seat (i.e. the vehicle seat), the additional forces the sitter can apply and, of course, the type of the material.

60. PHYSICAL DEFINITION OF A SEAT

Conceptually a seat is a system of necessarily two, and usually three planes. The first one is called the seat surface. It is the very essence of the concept since one has to sit on a surface. The second one is the ground on which one lives. The third plane is called the back-rest. The total set of seating criteria define the relations between these planes and also their physical properties. Listed below and shown in Fig.21 are these major elements, other minor elements and their interrelations.

I. Major elements:
   A. Seat surface: The surface on which the person rests his buttocks and to which transfers a part of his body weight.
   B. The ground surface: The surface on which the person places his feet and to which transfers a part of his body weight.
   C. Back-rest : the surface by which the person stabilizes his torso.

II. Minor elements:
   a) Arm-rests: Surfaces on which the person rests his forearms.
   b) Head-rest: Surface against which the person rests his head.
   c) Support structure: The structure through which the body weight on the seat surface is transferred to the ground.
   d) Seat structure: The structure which ensures a certain set of relations between the major and minor elements.

III. Interrelations:
   1. Seat height: Height of the front edge of the seat surface from the ground.
   2. Seat depth: Distance from the front edge of the seat surface to the point of back-rest at sacral level.
   3. Seat width: Transverse dimension of the seat.
   4. Seat inclination: Angle between the seat surface and the horizontal plane.
   5. Transverse seat curvature(s): Curvature(s) of the seat surface cut by the vertical/transverse plane.
   6. Longitudinal seat curvature(s): Curvature(s) of the seat surface cut by the vertical/longitudinal plane.
   7. Back-rest lower edge height: Height of the lower edge of the back-rest from the rear edge of the seat surface.
   8. Back-rest upper edge height: Height of the upper edge of the back-rest from the rear edge of the seat surface.

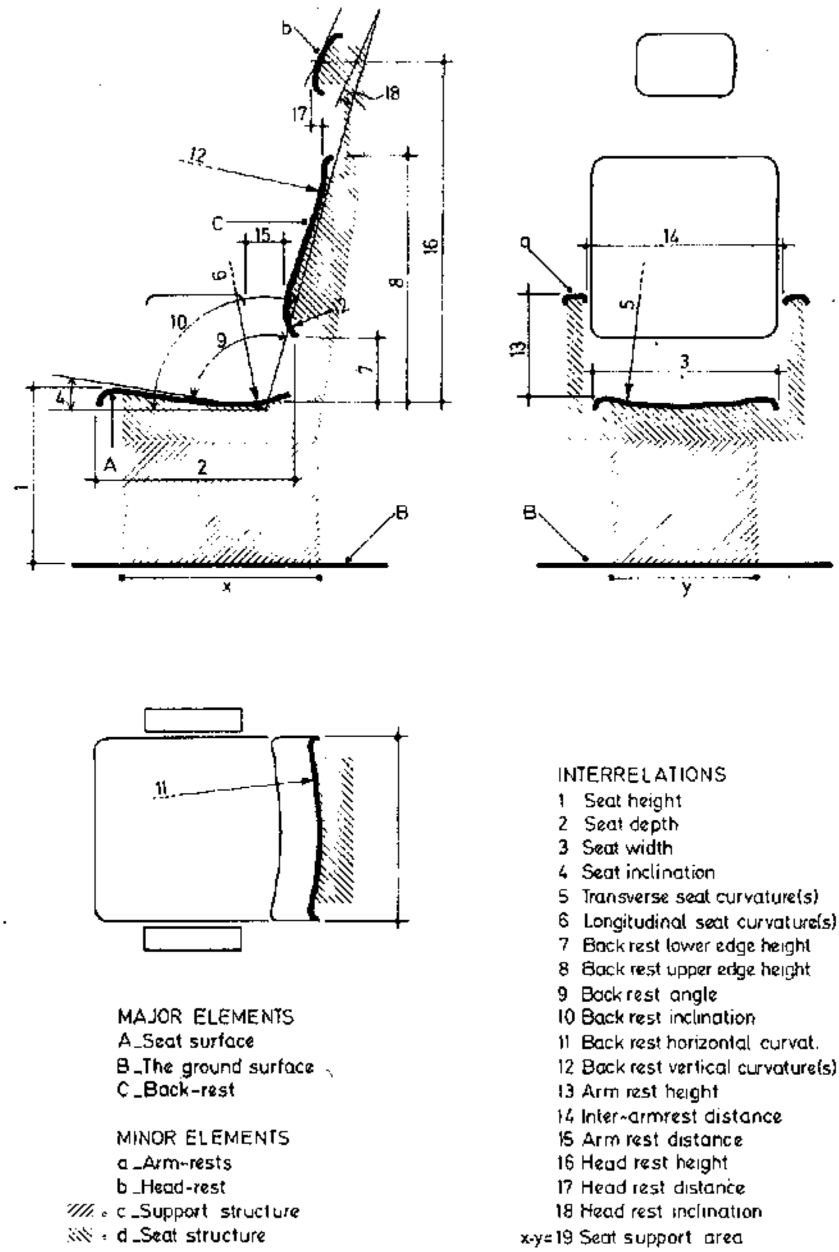

Fig. 21 Physical elements of a seat.

9. Back-rest angle: Angle between the seat surface and the back-rest surface. Where the seat surface and the back-rest have vertical curvature, it is the angle between the prolonged tangents to the reversing points of these surfaces.

10. Back-rest inclination: Angle between the back-rest surface and the horizontal plane

11. Back-rest horizontal curvature(s): Curvature(s) of the back-rest cut by the horizontal plane

12. Back-rest vertical curvature(s): Curvature(s) of the back-rest cut by the vertical plane.

13. Arm-rest height: Distance between the seat surface and the arm-rest surface

14. Inter arm-rest distance: Distance between the inner surfaces of the arm-rests.

15.Arm-rest distance: Distance between the rear edge of the arm-rest and the back-rest surface
16.Head-rest height : Height of the head-rest center from the rear edge of the seat surface.
17.Head-rest distance: Distance of the head-rest surface from the back-rest surface.
18.Head-rest angle: Forward angle between the head-rest surface and the back-rest surface
19.Seat support area: Absolute or relative area on the ground surface that is necessary for the stability of the seat and the sitter.

IV. Physical properties:(All physical properties of material such as color, texture, hardness, etc.)

OTURMA GEREÇLERİ İÇİN FİZYOLOJİK ÖLÇÜTLER

ÖZET

Oturma gereçleri tasarımına etki eden fizyolojik ölçütler iki ana başlık altında incelenmiştir. İlk bölümde vücut biçiminin verileri tartışılmış, otururken gerçekleştirilen vücut biçiminin iskelet ve kas çalışmalarına etkileri ve iskelet/kas sağlığı için gerekli oturuş biçimleriyle bunların tasarıma dönüştürülmelerine yönelik şartlar ortaya konmuştur. Bu arada lumbar eğrinin korunması, sırt ve boyun kaslarına binen yükün azaltılması, vücut biçiminin değiştirilerek kasların rahatlatılması önemli faktörler olarak belirtilmişlerdir. İkinci bölümde oturma gereci biçimlenmesinin çeşitli fizyolojik oluşumlara etkileri tartışılmıştır. Bu oluşumlar bacak ve ayaklardaki kan dolaşımı, yüzeysel dokuların baskısı, vücutsal ısı kaybı ve kazancı, sinirlerin basınç altında kalmaları, ve iç organların sıkışması olarak belirlenmiş, oturma gerecinin ölçülendirilme ve şekillenmesinin bu oluşumların en sağlıklı devamı için nasıl olması gerektiği ortaya konmuştur. Bu iki ana bölümün dışında antropometrik ölçülendirmenin oturma gereçleri tasarımında geçerliliği, ve oturma gereçleri parçalarının fiziksel tariflerini içeren iki bölüm daha yazıya eklenmiştir.

BIBLIOGRAPHY

AKERBLOM,B. *Standing and Sitting Posture*. Stockholm: AB Nordiska Bokhandeln, 1948.

AYOUB,M.M. 'Sitting Down on the Job (Properly)'. *Industrial Design*. v.19, n.3, 1972, pp.42-45.

BARKLA,D.M. Chair Angles, Duration of Sitting and Comfort Ratings. *Ergonomics*, v.7, n.3, 1964, pp.297-304.

BARKLA,D.M. 'The Estimation of Body Measurements of British Population in Relation to Seat Design'. *Ergonomics,* v. 4, n.2, 1961, pp. 123-132.

BOLTON,C.B. Ventile, Incompressible Cushions. *Applied Ergonomics,* v.3, n.2, 1972, pp. 101-105.

BRADFORD,F.K. and SPURLING,R.G. *The intervertebral Disc : With Special Reference to Rupture of the Annulus Fibrous With Herniation of the Nucleus Pulpous.* Illinois: Charles C. Thomas,1945.

BRANTON,P. Behavior, Body Mechanics and Discomfort. *Ergonomics,*v.12, n.2, 1969, pp.316-327.

BRANTON,P. and GRAYSON,G. An Evaluation of Train Seats by Observation of Sitting Behavior. *Ergonomics,*v.10,n.1, 1967, pp.35-51.

BURANDT,U. and GRANDJEAN,E. Work-Physiological Studies on Materials for Covering Flat Upholstered Work-Chairs. *Int. Z. Angew. Physiol.,* v.22, n.2, 1966, pp.167-180.

CAIN,W.S. and STEVENS,J.C. Measurement of Muscle Fatigue by Constant-Effort Procedure. *Resumes, 4th International Congress of Ergonomics, Strasbourg,* 1970.

CARLSÖÖ,S. The Static Muscle Load in Different Work Positions: An Electromyographic Study. *Ergonomics,* v.4, n.3, 1961, pp.193-212.

FLOYD,W,F, and ROBERTS,D.F. Anatomical and Physiological Principles in Chair and Table Design. *Ergonomics,* v.2, n.1, 1958, pp.1-16.

FLOYD,W.F. and SILVER,P.H.S. Patterns of Muscle Activity in Posture and Movement. *Science News,* n.22,1951,pp.7-25.

FLOYD,W.F. WARD,J.S. Anthropometric and Physiological Considerations in School, Office and Factory Seating. *Ergonomics,*v.12,n.2, 1969, pp.132-139.

GARROW,C. and WOOLER,J. The Use of Sheepskin Covers on Vehicle Seat. *Ergonomics,*v.13, n.2, 1970, pp.255-263.

GRANDJEAN,E. *Ergonomics of the Home.*London : Taylor and Francis,1973.

GRANDJEAN,E. *et al.* An Ergonomic Invesitgation of Multipurpose Chairs. *Human Factors.* v.15, n.3, 1973, pp.247-255.

GRANDJEAN,E. *et al.* The Development of a Rest Chair Profile for Healthy and Notalgic People. *Sitting Posture: Proceedings of the Symposisum, Zurich,1968,* London : Taylor and Francis, 1969, pp. 193-201.

HANSON,J.A. and JONES, F.P. Heart-Rate and Small Postural Changes in Man. *Ergonomics,* v.13, n.4, 1970, pp.483-487.

HERTZBERG,H.T.E. *et al. Anthropometric Survey of Turkey, Greece and Italy*. Oxford: Pergamon, 1963.

HEWES, G.W. The Anthropology of Posture. *Scientific American,* v.196,n.2, 1957, pp.123-132.

JONES,F.P. *et al*.Neck Muscle Tension and Postural Image. *Ergonomics*,v.4, n.2, 1961, pp.133-142.

JONES,J.C. Methods and Results of Seating Research. *Sitting Posture: Proceedings of the Symposium,Zurich,1968,* London : Taylor and Francis, 1969, pp.57-67.

KEEGAN,J.J. Alterations of the Lumbar Curve Related to Posture and Seating. *Journal of Joint and Bone Surgery,* v.35A, n.3, 1953, pp.589-603.

KEEGAN,J.J. Evaluation and Improvement of Seats. *Ind. Med. and Surg.,* v.31, n.4, 1962, pp.137-148.

KOHARA,J. *The Application of Human Engineering to Design: Chair,Bed,Vehicle Seat*. Chicago: Institute of Design, I.I.T., 1965.

KROEMER,K.H.E. Seating in Plant and Office. *American Industrial Hygiene Assoc. Journal,* 1971, pp.633-652.

KROEMER,K.H.E. and ROBINETTE,J.C. Ergonomics in the Design of Office Furniture: A Review of European Literature. *Industrial Medicine and Surgery*. v.38, n.4, 1969, pp.115-125.

LE CARPENTIER,E.F. Easy Chair Dimensions for Comfort. *Ergonomics,* v.12, n.2, pp.328-337.

LUNDERVOLD,J.S. Electromyographic Investigations of Position and Manner of Working in Typewriting. *Acta Physiologica Scandinavica,* v.24,(supplement 84).1951.

MURRELL,K.F.H. *Ergonomics*. London : Chapman and Hall,1969.

OSHIMA,M. Optimum Conditions of Seat Design. *Resumes: 4th International Congress of Ergonomics, Strasbourg,*1970.

POLLACK,A.A. and WOOD,E.H. Venous Pressure in the Saphenous Vein at the Ankle. *Journal of Applied Physiology,* v.1, 1949, pp.649-662.

POTTIER,M. *et al*. The Effects of Sitting Posture on the Volume of the Foot. *Ergonomics,* v.12,n.5,pp.753-758.

RASCH,P.J. and BURKE,R.K. *Kinesiology and Applied Anatomy*. Philadelphia: Lea and Febinger,1963.

SHACKEL,B.; CHIDSEY,K.and SHIPLEY,P. The Assessment of Chair Comfort. *Ergonomics,* v.12,n.2,1969,pp.269-306.

STONE,P.T. and THOMSON,G.S. *Seating for Motor Vehicles: (i) The Comfort of Car Seat Cushions*. Report No.MVR3,Dept. of Ergonomics and Cybernetics, Loughborough College of Technology. (Not dated)

VAN WELY, P. Design and Disease. *Applied Ergonomics,* v.1, n.5, 1970, pp.262-269.

VERNON, H. *Medical Research Council Report,* v.29, 1924, p.28.

WOTZKA, G. *et al.* Investigations for the Development of an Auditorium Seat. *Ergonomics,* v.12, n.2, 1969, pp.182-197.

YAMAGUCHI, Y. and UMEZAWA, F. The Development of a Chair to Minimize Disc Distortion in the Sitting Posture. *Resumes: 4th International Congress of Ergonomics, Strasbourg,* 1970.