

BIOMECHANICAL ASPECTS OF THE ORGANIZATION OF THE HUMAN EXTREMITIES SKELETON

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Abstract: With the help of a great number of observations several schemes of organization of the human extremities skeleton are analyzed. Biological laws of development, mineralization and strength of bones, their degrees of freedom, volume of joint movements are considered. It is concluded regarding functional and adapted character of bone organization in shoulder and pelvic girdles having a type of pentagonal truss. The upper and lower extremities have biomechanical combination of supporting and movable parts with distal decrease of considered parameters and bone dimensions.

Key words: bone biomechanics, human extremities skeleton, shoulder and pelvic girdles, schemes of skeleton organization

The actuality of problems of extremities biomechanics is in frequent occurrence of pathologies of the human locomotor system (about 12 % of population) and in its severity (50 % of all invalids).

This article is based on the results of investigation of more than one thousand anatomical objects and adult persons without diseases of the locomotor system.

Different methods of anthropometry, morphometry, modeling, biomechanics and data from literature are used in this research.

Any movement of a bone is possible only by means of support [3]. For the bones of extremities such supports are bones of the girdles. In this relation the biomechanics of the pelvis girdle was thoroughly investigated [4].

The role and the importance of the bone organization according to the principle of pentagonal (five-cornered) truss are well known. The narrow bones are in front and the wide bones from behind. The connection of the pelvis with the axial skeleton is realized in the back part of the truss: more exactly the part of the axial skeleton is the back part of the pelvis owing to the sacral bone.

The girdle of the upper extremities is made on the principle of five-cornered truss: two collar bones, two shoulder blades and the breast bone. Contrary to the pelvis this truss is not closed from behind, it is connected by its frontal part with the axial skeleton and by two first ribs with the spine.

These ribs are flat and bent in the horizontal plane and as a result the hard ring is formed. Its plane crosses the collar bone plane at an angle of 30° , it points to the fact that the human shoulder girdle consists of two parts connected by the manubrium sterni. The costal part increases the strength of the axial skeleton, the scapuloclavicular part increases the movement volume in the shoulder joint.

The organization of bones of the upper and lower extremities can be presented in some incontradictory variants.

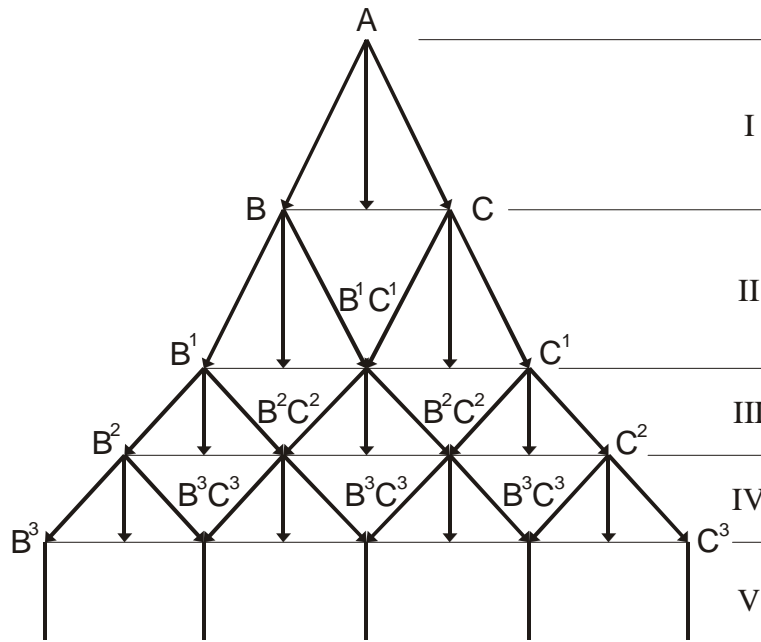
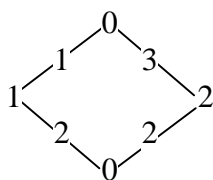


Fig. 1. Scheme of the force vectors arising in the upper extremity during locomotion and supporting. I – brachium; II – antebrachium; III – carpus, proximal row; IV – metacarpus, distal row; V – metacarpal bones [3].

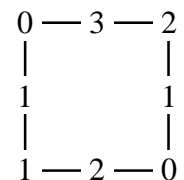
1. The first scheme: scheme on the principle of «pyramid» (Fig. 1).
2. The second scheme. The dynamical function of bones can be elucidated by the degrees of freedom and volume of movement at every joint. We assume some conditions: a) supporting structures of girdles, carpometacarpal and tarsometatarsal areas have zero degree of freedom, they are designated by zero [2]; b) the corresponding joints of the upper and lower extremities have the same degrees of freedom with different movement volumes.

The shoulder and hip joints have three degrees of freedom, the elbow and knee joints - two degrees of freedom, the wrist and ankle joints - two degrees of freedom, metacarpophalangeal joints - two degrees of freedom, interphalangeal joints of the upper and lower extremities - one degree of freedom. The degrees of freedom writing in separate line have a form of diminishing series: 0-3-2-2-0-2-1-1. By virtue of the fact that between distal phalanx and object there is no relative movement (aim of a locomotor act is reached under immobility of a taken object) the zero can be added to this series. Now the record of series of freedom degrees in extremities joints has a form of completed formula: 0-3-2-2-0-2-1-1-0.

We can see two groups of movable joints. In every group three joints exist. A proximal joint in every group has more degrees of freedom than next joints. This formula begins from zero and finishes by zero. As a result we can represent this formula in a cyclic image:



or in the form of square



The movement volume in joints of extremities diminishes also from proximal to distal part. This decrease has a definite gradient (1.24 in the upper extremity and 1.31 in the lower extremity [1]). The centre of gravity of an every part of extremity is located more proximal than a half of its length [7]. The ratio of lengths of these parts is about the square root of two.

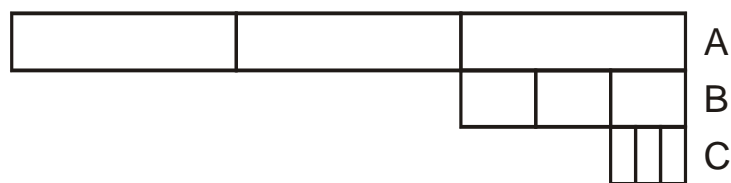


Fig. 2. The scheme of construction of extremities bones.

Distal parts of tubular bones have larger degree of mineralization, this makes bones stronger. It can be connected with their strength limit [5]. This fact is quite natural if we take into account lengths and velocities of distal parts of bones-levers.

3. The third scheme. This construction of extremities bones is a combination of three elements. Every element, in turn, consists of three elements (Fig. 2).

The first three elements (A in Fig. 2) presents the whole extremity consisting of brachium (hip), forearm (shank) and hand (foot). The second three elements (B in Fig. 2) presents the whole hand (foot) consisting of the carpus (tarsus), metacarpus (metatarsus) and phalanges. The third three elements (C in Fig. 2) presents the phalanges of the fingers where every finger, except the thumb, consists of three (proximal, middle and distal with nail) parts.

It is known that the longitudinal dimensions of parts the upper extremity by «the middle ray» are in irrational ratios close in magnitude to the «golden proportion» [6].

The obvious importance of this scheme lies in the fact that it persuades visually in realization of the principle: the more distal is the bone of an extremity, the smaller is the bone. This thesis is the structural, morphological base of the possibility to make dexterous, quick movements in order to succeed an aim exactly.

The peculiarities of the thumb and the hallux construction have arisen in connection with necessity not only to snatch but also to clasp. This problem was solved by removing the first metacarpal and the first metatarsal bones from their groups.

Along with this reconstruction it was necessary to create biaxial joint between the carpus and the metacarpus. Simultaneously it was need to take away a unnecessary element. It turned out that such element was the middle one as the distal element had a keratic nail.

The general picture of extremities movements is based on the functions of movable elements where more than three elements may exist. Three elements are necessary and sufficient for the building of «hook» in arm and «spring» in leg.

With the passage of a man to the bipedal locomotion the hallux returned to its group, but it is not possible to return all the phalanx [8].

Conclusions

1. The structure of the extremities skeleton and their girdles have the functional and adapted character providing the possibility of purposeful locomotion acts of an extremity as a whole.
2. The bone organs of extremities girdles are organized on the principle of "an pentagonal (five-cornered) truss".
3. The skeleton of a free extremity is built on the base of combination of supporting and movable parts with decrease of degrees of freedom, movement volume and dimensions of bones in the distal direction.

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БИОМЕХАНИЧЕСКИЕ АСПЕКТЫ ОРГАНИЗАЦИИ СКЕЛЕТА КОНЕЧНОСТЕЙ ЧЕЛОВЕКА

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В статье на большом материале анализируется несколько схем организации скелета конечностей человека. Учитываются биологические законы развития, формирования, минерализации и прочности костей, а также степени свободы и объем движений в суставах.

Предлагаются следующие схемы построения конечностей человека: 1) схема по принципу “пирамиды”; 2) схема, учитывающая динамические функции костей, число степеней свободы и объем движений в каждом суставе; 3) схема, представляющая каждую конечность как комбинацию из трех элементов, где каждый третий элемент состоит, в свою очередь, из трех элементов.

Делаются выводы о функционально-приспособительном характере организации костей поясов конечностей по типу пятиугольных ферм, а также о том, что свободная конечность построена на базе биомеханической комбинации опорных и подвижных участков с дистальным уменьшением рассматриваемых показателей прочности и габаритов костей. Библ. 8.

Ключевые слова: биомеханика костной ткани, скелет конечностей человека, плечевой и тазовый пояса, схемы организации скелета

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