Ministry of Health of Ukraine
Ukrainian Medical Stomatological Academy

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Methodical instructions
for students' self-preparation work at preparation for a practical lesson
at home and at the classroom

Subject matter	**Medical and biological physics**
The unit	1. Fundamentals of higher mathematics and biological physics
Theme of lecture:	**Biophysics of muscular contractions. Dynamometry. Ergometry.**
Year	1
Faculty	Stomatological
Speciality	Stomatology

Poltava - 2020

The topic significance: The mankind has used muscular force for the performance of various kinds of works. Muscular tissue has on the mechanical properties very close to elastomers, having the ability to reduce, to stretch and to spring. The force, which develops by human and animal muscles, and the work, done by them depends very mach on both morphological properties, and the physiological condition. For example, the long muscles reduce more than the short ones. At large contractions their ability to reduce decreases, and at small contractions their reducing effect is increased.

After the external force usage is stopped the muscle restores in size, but this restoration can't be complete, that fact completely characterizes the plasticity of muscles. It enables us to make a conclusion, that the muscle is not an absolutely elastic body, but has viscosive-elastic of properties.

In this connection the study of the power and power parameters of muscle contraction has a great importance for various areas of medicine, in particular, of sports medicine.

Specific targets:
1) To have general knowledge of the topic studied;
2) To understand, to remember and to use the knowledge received;
3) To know the structure of muscle tissue and the mechanism of muscle contraction;
4) To master the concepts of the muscle force and work; to know the kinds of work, which are carried out by muscles and the modes of muscle contraction, devices for the measurement of the force and work of muscles;
5) To learn to determine the force and work at muscle contraction;
6) To be able to carry out the laboratory and experimental work.

Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:

Disciplines	Obtainable skills
Previous (providing disciplines): physics, anatomy, histology, biology	To know: structure of muscles; features of a muscle tissue structure.
The subsequent disciplines: Normal physiology	To know a structure of muscles. To describe types of muscle tissue and the mechanism of muscle contraction, modes of muscle contraction. To name the types of muscle contractions of and to characterize these types. To give the definition of muscle force. To give the definition of the muscle work, to name the kinds of the muscle work and to characterize each of these kinds.

Materials for the before-class self-preparation work:

List of main term, parameters, characteristics, which student have to learn at preparation to class:

Term	Definition
Absolute muscular force	The force which is necessary to the unit of the cross section area of a muscular fibre, which form the muscle
Dynamic muscle work	Work, during which performance there is a cargo moving and the bone movement in joints.
Static muscle work	The work of muscles, at which a muscular fibre develops strength, but does not almost reduce (it occurs, when the muscle reduces in the isometric mode).

Theoretical questions to class:

1. Structure of muscles, types of muscle tissue, mechanism of muscle contraction.
2. Force of muscles.
3. Work of muscles, kinds of work of muscles.
4. Types of muscle contractions.
5. Devices for the determination of the force and the work of muscles.
6. Work of the jaw-obverse device.

Practice work executed at class. Dynamometry and Ergometry.

Execution order.

1. *Measurement of force of a hand compression with the arm dynamometer help.*

To put experimental on a chair.

To extend a hand forward and maximum to compress dynamometer by am arm; write value into table 1.

To determine force of compression till three times by each hand.

To determine average value of every arm force and to write down data in the table 1.

Table of results 1

№	*Force of compression, kg-force*	
	Right hand	**Left hand**
1		
2		
3		
Mean		

2. *Study of dependence of muscles work on value of counteracting forces and frequencies of muscles contractions*.

2.1. To fix arm of experimental person on the arm ergograph.
To get frequency of a metronome at a level 60 beats in one minute.
Switch on the ergograph mechanism and to offer experimental to bend an arm in a rhythm of a metronome up to weariness; weariness level is noted when amplitude of hand contractions decreases twice ($\mathbf{A_{min} = A_{max}/2}$);
Count arm contractions to weariness ***N***.
To calculate value of muscle work in the first and second experiences under the formula:

$$W = \frac{A_{max} + A_{min}}{2} \cdot N, \qquad (1)$$

where ***N*** – number of contraction, A_{max}, A_{min} – amplitude of compressions provided that 1 mm – 1 standard unit.
Units of muscle work are conditional units (c.u.) here.
To write down data in the table 2.
2.2. After rest to increase frequency up to 120 beats in one minute and to repeat experience.
To calculate work by the formula (1).
2.3. To impose rubber bundle (tourniquet) on the left upper arm of experimental person.
To repeat experience at 60 beats in one minute. To calculate work by the formula (1).
To compare values of works in all three cases and to make conclusions.

Table of results 2

Quantity of contractions in minute	Work before weariness, conditional units
60	
120	
60 (with tourniquet)	

3. Draw conclusions.
Contens of the topic.
The force, which a muscle develops, is determine by the size of the cargo, which it can lift, or by the maximal strength, which arises at its isometric contraction.
As the muscles have contracting and elastic elements, the strength and the work carried out are caused not only by the active contraction of the contracting complex, but also by passive strength, that is determined by the elasticity, or, the so-called, consecutive elastic component of a muscle.
Due to this component the work is carried out only in the case if the muscle was stretched previously, and size of this work is proportional to the size of the muscle stretching. It in a definite limit also explains that the strongest movements are carried out at the large amplitude that is provided with a preliminary stretching of a muscle.
Under the identical conditions the ***strength of muscles*** depends on their cross section, that is, the more this muscle cross section, the greater cargo it can lift. It is necessary also to emphasize, that the strength of a muscle with oblique fibres is much more, than the muscle strength of the same thickness, but with longitudinal fibres. Besides, the strength, developed by a muscle at the maximal contraction, depends on physiological conditions: age, training, food, tiredness and so forth.
Absolute muscular force is the force which is necessary to the unit of the cross section area of a muscular fibre, which form the muscle (due to the peculiarity of some muscle structure it does not always coincide with the muscle cross section). Absolute muscular force is measured in N/sm^2. For example, triceps muscle of a shoulder develops absolute muscular force as 170 N/sm^2, biceps muscle of a shoulder is 110 N/sm^2, chewing muscle is 60 N/sm^2, smooth muscle is 10 N/sm^2.
The activity of muscles is estimated by the external mechanical work, carried out by them. In the most simple type – the rise of a cargo – the work of muscles is measured by

the product of the force equal to the weight of a cargo, on size of contraction of muscles: $A = FS$. In this case the direction of a cargo moving of a cargo is the same, as the direction of the force. A is work, F is weight of a cargo (force), S is contraction of a muscle.

In the musculoskeletal system device of the human and animals the muscular force F frequently works at the corner (α) in relation to the direction of the movement. Thus during the rise of the body this corner can be changed. In this case the force can be shown as a vector of the sum of two independent forces F_x and F_y. The force F_y, under the action of which the body will move, is equal: $F_y = F \cdot cos\alpha$. Therefore the work in the direction of this indemnification will be equalled: $A = FS \cdot cos\alpha$.

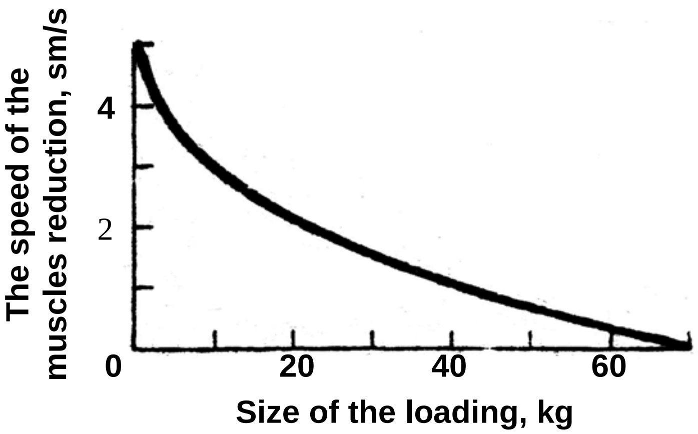

Fig. 1

In the direction of the force F_x action the moving will not take place; accordingly the force F_x does not carry out the work. The corner α is a corner between the force vector and the moving S vector for a mobile body. The unit of work in SI is J. J is the work, done by the force in 1 N at the muscle contraction (that is a cargo moving) on 1 m (1 J = 1 Nm).

It is necessary to emphasize, that the external mechanical work is done by the muscle only in the aucsotonic mode, that is developing both the strength, and contraction. In the isotonic mode the muscles are not loaded and do not produce strength. In the isotonic mode the muscle strains, but not reduces.

Thus in two last cases one of the comultipliers of work, turns to zero. The experiments show, that the external mechanical work, which is carried out by a muscle, reaches the maximal size at average loadings. Such phenomenon has received the name "of the law, of average loadings". Such law also exists for the speed of contraction. In accordance to the Hill's law, the speed of the contraction of muscles is in the hyperbolic dependence on the size of the loading (Fig. 1).

Therefore the largest external mechanical work is carried out by the muscle at average speeds of contraction. A conclusion from here arises if consisting of the fact that the absolute sizes of average loadings and average speeds are unequal for various muscles and can be changed during trainings.

The work of muscles is called ***dynamic***, when during its performance there is a cargo moving and the bone movement in joints.

The work of muscles, at which a muscular fibre develops strength, but does not almost reduce (it occurs, when the muscle reduces in the isometric mode), is called ***static***. For example, a cargo deduction or a firm body compression by teeth. The research shows, that the static work is more tiresome, than dynamic. All energy research in biomechanics requires measurement of the force and work. For this purpose the in medical practice one uses dynamometers, gnatodynamometers (in dentistry) and ergometers. The amount of work carried out due to the force of muscles per a time unit, is called capacity. The capacity, which living bodies develop can be changed in rather wide ranges, for it depends not only on the natural data of muscles, but also on a lot of physiological conditions (age, food, training and etc), as well as on a psychological condition (spirit state, surrounding and so forth). Depending on the human muscle conditions is capable to maintaining large loadings, for a short period of time.

The second important feature of muscles is their tiredness during a long-term work. Thus the force, developed by muscles, decreases, and the break is necessary for its restoration. For the definition of the muscle tiredness, that is muscle work capacity, one uses devices, such as ergometers and ergographs.

The brake bicycle (bicycle-ergometer) can serve as an example of an ergometer. In such ergometer through dinner of a rotating wheel a steel tape is thrown over. The force of a friction, which arises between the wheel and the tape, is measured with the help of a dynamometer. All the work, done by the person under the experiment, is spent for the overcoming of the friction force (other kinds of works are neglected). Multiplying the force of friction to the length of dinner of a wheel, the work, which carried out at each revolution can be found. Knowing the number of the revolutions and the time of the research, it is possible to determine a complete work and an average speed.

An ergograph is used for recording the amplitude rhythmically repeated working movement, carried out by a muscle or a group of muscles. The speed of the amplitude contraction movement testifies the tiredness of muscles. The comparison of tiredness time with the carried out work in various conditions, loadings and rhythms, the recurrence of movements, enables to develop optimum conditions of muscle work for that or another working process. It is necessary to emphasize, that the area of the written down ergogram numerically characterizes the work, done at it.

This technique is rather effective and is widely used at the realization of a physiological research.

Biomechanics of human maxillofacial apparatus includes functional craniology.

Functional Craniology: Kinematics and Dynamics

Kinematics

The measurement and description of the changes in size, shape, and location of the craniofacial complex.

Dynamics

The interpretation and description of the biological processes of the changes in size, shape, and location of the craniofacial complex.

Terminology used in Biomechanics

Force: compression, tension, bending, shear, and torsion

Deformation: Change of form due to the loading of forces

Stress: the force per unit area

Strain: the dimensional change expressed as a fraction (ratio) of the subject’s original size

Force

1) Two basic forces: Compression & Tension.
2) A combination of compression and tension: Shear & Bending.
3) A combination of the above four forces: Torsion.

Compression: compression is the direct expression of the force, which pushes everything towards the center of an object.

Tension: the opposite of compression; the force which pulls everything away from the center; where there is a compressive force, there must be a tensile force.

Shear: shear is present, when two forces are thrusting in opposite directions but offset and slide past each other.

Bending: is found between the pulling of tension and the pushing of compression.

Torsion: a result of all the other four forces. Torsion is twist. Torsion is actually a specialized bending, a circular bending.

Fig.1. Dolichocephalic head.

Fig.2. Arches.

Cephalic Form, Facial Form, and Arch Form
Dolichocephalic (long and narrow head)
Leptoprosopic (long and narrow face)
Dolichuranic (V shape, narrow maxillary arch)

Form (Structure) and Function

Form (structure) follows Function.
Function determines form (structure).
Function controls form (structure).
Function regulates form (structure).

Form (structure) is the realization of information and the product of the functional attributes.

Cranial Sutures

1. Edge-to-edge suture → No force loading
2. Beveled suture → Shear force [Squamosal suture]
3. Serrated suture → Intermittent tension force [Sagittal suture]
4. Beveled and serrated suture → Intermittent tension and shear force
5. Butt-ended sutures → Intermittent compressive force

Functional Structure of Skull
(from a mechanical point of view)

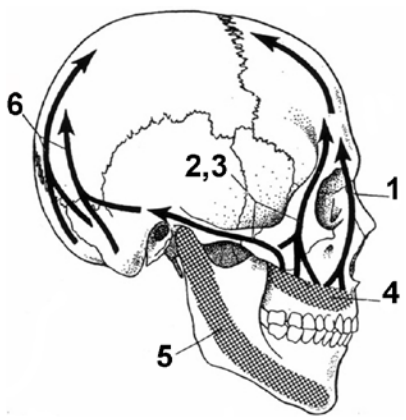

Fig.3. Loadings distribution [illegible]ll.

In the force loading areas, pillar-like struts serve as mechanically efficient reinforcements to resist and dissipate pressure and traction, especially to the masticatory force. 1) Fronto-nasal pillar
2) Zygomatic arch pillar with vertical branch
3) Zygomatic arch pillar with horizontal branch
4) Basal arch in upper jaw
5) Basal arch in lower jaw
6) Occipital pillar
7) Pterygoid-palate pillars

In the non- or less force loading areas, adipose tissue and pneumatic cavities fill those mechanically neutral areas.

1) Paranasal sinuses
   a) Frontal sinus
   b) Ethmoid sinus
   c) Sphenoid sinus
   d) Maxillary sinus
2) Accessory tympanic spaces
   e) Mastoid air cells

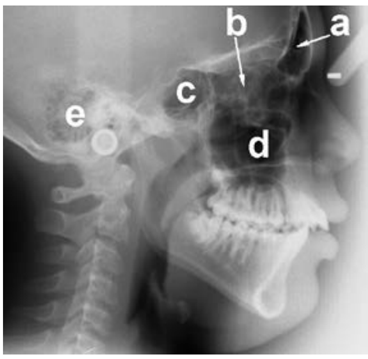

Fig.4. Allocation of adipose tissue and pneumatic cavities in scull.

Performance of chewing function by by the denti-maxillary apparatus is bound to various locomotions of a mandible.

Iin stomatology the biomechanics studies contractions of muscles and response of dens and parodentium on force of muscular contractions.

At chewing on chewing surfaces of dens there are forces. Fastness of dens depends on them quantity and direction. The load is transmitted on parodentium immediately at contact of dentitions or through nutrition. There are the elastic strains in sides of alveoluses and in spongiform material of a bone under the influence of masticatory forces. Forces causing normal and tangential strains of squeezing and a distention in tissues. Strains depend on parametres of force, a slope angle of dens, presence of contact points etc., i.e. the factors providing fastness of dens and dentitions. An osteal tissue, a periosteum, a periodontium, cement and vascular system, being exposed to these loads, react metabolism changes.

The chewing biomechanics surveys the kinematic description of movements of dens in the alveolar socket, allocation of an alimentary lump in oral region and on a chewing surface of dens, interaction of separate devices of the masticatory apparatus (temporo-mandibular joint, jawbones, dens, parodentium, the muscles actuating a mandible, the mimic muscles participating in the chewing act).

Moderate strains of a bone boost division and activity of cells. It provides innovation and growth of a bone and soft tissues.

The mandible makes vertical**,** sagittal and lateral locomotions.

At vertical locomotions of a mandible there is an opening and closing of the mouth thanks to contraction of the muscles lifting and alighting a mandible. During mouth opening simultaneously with gyration of a mandible round an axis transiting through heads of a mandible in a transverse direction, mandible heads slip on an incline of an articulate hillock downwards and forward. If value of a mouth openong does not exceed 1-1,5 cm, there is only a gyration. At larger opening the mandible rotation centre moves in a joint forward and downwards.

At sagittal locomotions the mandible moves forward and back.

At lateral mandible locomotions there are locomotions in a temporo-mandibular joint and in the area of dens, but different movement on the different jaw sides. Transverzal locomotion is realized owing to contraction of a choronomic pterygoid muscle on one side.

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Self-control material:

***A. Questions to be answered*:**

1. Structure of muscles, types of muscle tissue, mechanism of muscle contraction.
2. Force of muscles.
3. Work of muscles, kinds of muscle work.
4. Types of muscle contraction.
5. Devices for the definition of force and work of muscles.
6. Work of the jaw-obverse device.

B. Test tasks to be done:

1. What character of deformation has a muscle:
   a) elastic;
   b) plastic;
   c) elasticoplastical.
2. What tissues of muscles have cross sections:
   a) skeletal;
   b) intimate;
   c) smooth.
3. That such absolute muscle force:

a) the force is maximal which is developed by a muscle;

b) the force, which is necessary on unit of the area of cross section of muscle tissue;

c) the average force, which develops a muscle;

d) the force, which counteracts a muscle.

Literature recommended

Main sources.

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Methodical elaboration have prepared by senior lecturer, PhD Biol.Sc. Korovina L.D.