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THE IMPORTANCE OF BIOMECHANICAL ANALYSIS OF PREHENSION IN THE REHABILITATION PROCESS

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Abstract: *During the therapy process, the goal of functional rehabilitation must be regaining the patients' ability to catch and grab, but also complex movements of the distal segment in relation to other muscle-articular structures that are specific to the upper limb. The biomechanical analysis of the hand is essentially a complex study on the somatic-visceral and environmental factors that intervene in the performance of motor actions, on the established interrelations, the participation manner, and effects that it determines in the human body taken as a whole. The hand is the most complicated member segment in the body. Both its structure and function are adapted to the complexity of human activity. This paper tries to emphasize through a biomechanical analysis of all elements composing the hand the basic aspects of an effective functional rehabilitation.*

Key words: *prehension, biomechanics, functional rehabilitation.*

1. Introduction

The word "biomechanics" (1899) and the related "biomechanical" (1856) come from the Ancient Greek βίος bios "life" and μηχανική, mēchanikē "mechanics", to refer to the study of the mechanical principles of living organisms, particularly their movement and structure (Oxford English Dictionary). According to Sbenghe, T., Neumann, D., 2002, biomechanics is defined as the science studying the objective laws of the movement of living bodies, and the structures that contribute to that movement.

The first biomechanics studies belong to Borelli (1679), Weber brothers (1836), Fischer (1889), Marey (1890), Demeny (1900), Strasaer (1908), Fick (1920) etc. To these names, one can add the more recent studies of Basler, Scherb, Hartley, Leshaft, P.P., Krauskaia, A.A., Kotikova, E.A., Donskoi, D.D., Steindler, and of many others as cited in Iliescu, A, 1968.

In Romania, the first scientist introducing the study of body movements was Rainer, F. Important Romanian papers were written by great professors such as Riga, I., Repciuc, E., Jagnov, Z., Milcu, S., Rusu, Marinescu, G. (the latter has introduced cinematography in the study of

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patients with neurological disorders), and Iliescu, A., 1968, who have contributed to the study of movements, motor acts in the field of physical education and sports. Donskoi, as cited in http://www.spiruharet.ro/facultati/sport-bucuresti/biblioteca, has stated that only by knowing the laws of movement, one can foresee their result under various conditions, reveal the movement mistakes, assess correctly the effectiveness of movements, find the ways to perfect them, and finally, create the movements that would correspond the most to the aimed motor tasks. Gowerts gave a definition that integrates these tight correlations: *"Biomechanics is the science that studies the repercussion of mechanical forces on the human being's functional structure in regards to the bones, joints, muscles, as factors determining the movement".* As the study of biomechanics is not possible without knowing the morpho-functional characteristics of the body, the interdependence of between anatomy and biomechanics is obvious. Therefore, biomechanics deals not only with the mechanical analysis of movements, but also on their effects on the structure of organs that perform the movements. The study of biomechanics is, thus, tightly linked to the study of functional anatomy, according to http://www.spiruharet.ro/ facultati/sport-bucuresti/biblioteca.

The systematized biomechanics knowledge is useful to various experts, such as: physicians, physical therapists, coaches, physical education teachers, etc. Practically, everyone who uses movement in a therapeutic purpose, as prophylaxis or to obtain elite performances, needs the scientific support given by biomechanics. With the help of notions, concepts, and methods from kinematics, kinetics, and dynamics, one can determine the parameters of the upper limb movements, certain categories of forces and moments [3]. The general endurance of the body and implicitly the endurance of the kinetic biomechanical structure of the upper limb is defined in physiology as the body's ability to work for extended periods of time without getting tired [5].

The human hand was the subject of numerous paleontology, anthropology, and embryology studies. These papers generally emphasize a paradox: if from a morphological standpoint, the hand keeps ancestral anatomical traits (being derived without large transformations from a primitive time in the species' phylogeny), but from a functional point of view, the hand is the peak of evolution, being orientated towards prehension by finesse and strength, and towards fine sensory perception. The sensory and motor importance of hands for the human beings' social and professional life is considerable (www.ortokinetic.ro).

The biomechanical analysis of the hand is essentially a complex study on the somatic-visceral and environmental factors that intervene in the performance of motor actions, on the established interrelations, the participation manner, and effects that it determines in the human body taken as a whole. The hand is the most complicated member segment in the body. Both its structure and function are adapted to the complexity of human activity. The proportionally enormous surface of the cerebral cortex controlling this activity is proof of the complexity of this limb.

The hand is not only the prehension limb (for general or fine gripping) and of the most important discriminative sensitivity, but it is also the limb of the human sensitivity, of the most elaborate expression of the professions. The entire upper limb, shoulder, arm, forearm, fist, all work to put the hand into the most favorable position for a determinant action.

2. Objectives

The purpose of this analysis consists in finding the ways to improve fine movements so that there is a maximum output with a minimal energy cost.

3. Material and Methods

The hand represents the upper limb area that is positioned distally in relation to the fist joint. The hand has two major functions:

- ***the mechanical function*** - gripping and manipulating objects, implying the opposable nature of the fingers in relation to the thumb.
- ***the sensory function*** - the hand is used to differentiate objects based on touch. According to
- www.google.ro/funcţiilemâinii the non-prehensile activities demand the sensory functions of the hand: the ability to assess the shape and volume of objects (stereognosis); the ability to assess the weight (barognosis); the ability to assess the position of movements (kinesthesia).

The main kinetic functions of the upper limb are:

- hand position;
- hand orientation;
- prehension.

Corresponding to the 3 types of kinetic functions in the biomechanical structure of the upper limb, there are 3 subsystems:

- the positioning biomechanism;
- the orientation biomechanism;
- the prehension biomechanism, according to www.google.ro/funcţiilemâinii.

General considerations regarding the structural composition and analysis of an osteoarticular kinetic chain, according to http://www.mec.tuiasi.ro/diverse/Biomecanica:

- the joint represents the direct and mobile link between two bones (kinetic or moving elements);
- the joints are classified depending on the material composing the joint and the presence or absence of a cavity in the joint;
- the bone kinetic chain is defined as a chain of kinetic elements tied together through joints;
- the degree of freedom of a kinetic chain represents the total number of independent movements that the kinetic chain can have under the restriction of the joints.

The intrinsic hand muscles are 19, they have exclusive action on the fingers, representing the group of muscles that give finesse and precision to the hand, and they are divided into three groups, based on the area where they are:

- the thenar eminence - the thumb;
- the hypothenar muscles - the little finger;
- the interossei muscles and the lumbrical muscles.

Based on their function, the muscles of the hand can be grouped into two categories:

a. motion muscles - extensor digitorum, abductor pollicis, opponens muscles -

they open the hand to perform the gripping;

b. strength muscles - the flexor muscles, the adductor pollicis - they are responsible for the actual gripping**.**

The forearm muscles are the strength muscles of the hand for both the fingers and the fist joint.

The main function of the forearm is to contribute to the amplification of the functional value of the hand, particularly through pronosupination, a motion that enlarges the number of social activities a person can perform.

Thus, the human hand is the most perfect working instrument, but also the most vulnerable one. The demands put on hand through repetitive motions, performed in an imposed or cadence rhythm (e.g. working on a treadmill), strength prehension and in bad articular positions, weight manipulation, cause a pressure on the musculoskeletal structure of the hand, expressed through pain, partial or total functional impotence, etc. Tubiana, R., 1998, presents the functional role of fingers:

- ***The thumb,*** because of the opposition motions, is the finger performing the main prehension (the touch between the thumb and the other fingers). Losing the thumb can reduce the functional ability of the hand up to 60% (the hand can only perform pushing motions and of digital/palm support, and motions of interdigital prehension).
- ***The index*** is the "location finger". It has strength and it participates as a main stabilizer of the prehension motion. It has the highest tactile sensitivity (recognizing and reproducing the shape of objects).
- ***The middle finger*** is considered to be the main strength finger, being indispensable in the prehension of heavy objects and maintaining them in a hanging or supported position.
- ***The ring finger*** supports the action of the middle finger during the strength movements, having a special form of spatial sensitivity (feeling the spatial position of the tip of the foil or the tip of the scull).
- ***The little finger*** plays a smaller part. Its presence enlarges the digital-palm distance, conferring a higher stability for prehension.

According to www.creeaza.com/referate/biologie/Biomecanica-mainii, the fingers prolong the metacarpal arch whose fix element is composed of the second and third metacarpalia, while the first metacarpus became relatively independent due to the trapeziometacarpal joint. The hand can cup, thus being able to adapt to the shape of any object, starting from the hypothenar eminence to the base of the metacarpophalangeal joints.

Thus:

- o metacarpal bone II moves between 0 and 5^0
- o metacarpal bone IV between 5 and 10^0
- o metacarpal bone V between 10 and 15^0

The flexion of the metacarpal bone V is associated with a cubital inclination and an external rotation that amplifies the cup effect of the hand.

The carpometacarpal is convex both sagittally and frontally, which allows sagittal flexion-extension and frontal adduction-abduction motions. Lateral ligaments are oblique upward and forward, and are stretched in flexion and relaxed in extension. Position 0 is the one in which the phalanx is in the continuation of the metacarpal bone. The flexion closes the digital chain and leads to a closed fist.

The active flexion range is 90^0 and it increases from the second to the fifth finger, reaching up to 110^0. The passive flexion is higher by 10^0 than the active one.

Frontal motions are not possible unless the fingers are in extension in position 0 or in slight flexion. These motions are not possible with the fingers flexed. The finger can perform lateral inclination motions, of adduction and abduction, the same as the other fingers, thus one can speak of getting the fingers close and apart.

The whole range of the active and passive adduction and abduction motion is in average of 30°-40°. The adduction and abduction motion is not pure, being always associated with an axial rotation.

The axial rotation motions are associated with the adduction and abduction motions. In the index finger, where the intrinsic muscles are the most differentiated, there is an active circumduction. The instability of the metacarpophalangeal joints can be observed after traumas in the lateral ligaments of these joints.

The interphalangeal joints are hinge joints and allow only flexion-extension motions. In the proximal interphalangeal joints, the active and passive flexion is in average of 100°; the active and passive extension at this level is 0°. In the distal interphalangeal joints, the active and passive flexion is in average of 70°, the active extension of 5°, and the passive extension is between 20°-40°.

The complete flexion of the fingers normally leads to a direct contact of the digital pad with the palmar side of the first phalanx. When the fingers are flexed only from the interphalangeal joints, the pad of the fingers will touch the distal palm fold, when the metacarpophalangeal joints are extended. When the fingers are flexed from both interphalangeal and metacarpophalangeal joints, the pad of the fingers will touch the proximal palm fold.

The articulations with the metacarpophalangeal transverse arch are the most important element of the system. The fingers are one of the most beautiful examples of osteo-stabilized systems, representing a motor unit.

Of all the fingers, the analysis of the thumb motions is the most important and the most functional. The articular assessment of the thumb and of the other fingers must be integrated in the overall function of the hand.

The articular assessment must be both analytical and overall. The overall assessment, being the most important, will have to be completed with various aspects of prehension. The analytical assessment includes the examination of the three thumb joints: trapeziometacarpal, metacarpophalangeal and interphalangeal

The functional anatomy of this saddle joint, allowing movements in three planes is difficult to analyze. The neutral position is impossible to define currently. However, one can assess the trapeziometacarpal mobility by observing the axial rotation motions. The axial rotation range of the first metacarpal bone can be assessed by mobilizing the first phalanx of the thumb, this being strongly flexed to block it. The trapeziometacarpal stability can be assessed by trying to twist the first metacarpal bone on the outside, trying to simulate a trapeziometacarpal luxation or subluxation.

The laterality motions in extension are much more reduced than the ones in other metacarpophalangeal joints. During a complete flexion, the joint is complete. In extension or in a small flexion, the laterality in valgus has a low range. It is broken by the internal lateral ligament whose integrity is indispensable for the thumb to not relax during the main moments of the prehension. The extension reaches often 10°- 30° and the flexion, 30°- 40°.

The main function of the hand is prehension, the ability to grip objects, and it cannot be dissociated from the forearm, which confers it spatial orientation and ensures a wider range of motion, as a result of the movements performed in the kinetic chain forearm - hand - fingers.

The anatomy and biomechanics of the hand is complex, intriguing and fascinating. Its integrity is absolutely essential for the daily functions. The hand can be affected by many disorders, especially traumatic injuries. For every physician or physical therapist who treats hand injuries, a deep knowledge of anatomy and biomechanics is essential for an effective rehabilitation.

Prehension, according to www.creeaza.com/referate/biologie/Biomecanica-mainii the hand biomechanics is a complex function of the hand and implies multiple indispensable conditions:

- two rigid pinch arms, articulated at one end;
- a joint or a set of joints that would allow the opening - closing of this pinch;
- an intact muscular-tendinous system - the stronger it is, the higher the prehension strength;
- The suprajacent cover (with tegument and mobile soft tissue) should be sufficient to allow the closing - opening of the pinch.

Prehension is a precise gesture, adapted, conscious or reflex, which on the basis of instantaneous external and proprioceptive information is automated through repetition and it determines the optimal coordination of the hand for grabbing or catching.

According to Littler, J., 1967, the hand is divided into three motion elements:

- 1 - the thumb, the metacarpal bone I and the joints between them.
- The metacarpal bone I is not jointed with the second, thus the thumb can be opposed to fingers II-V through the thumb muscles.
- 2 - the index finger, through its 7 muscles can be independently mobilized in relation to the other three fingers;
- 3 - the fingers III-V and the corresponding metacarpal bones.

One and two form a functional unit for fine, precise prehension activities in which the third finger participates in some measure. The functional link between 1-3 ensures the strength prehension. It is emphasized by the ring finger's stiffness during extension, which makes impossible "clenching the other fingers in a fist". These three motion elements are grouped around a central, stable unit, represented by the distal line of the carpal bones, the metacarpal bones II and III, and their muscles: the flexor carpi radialis and the extensor carpi radialis (longus & brevis).

According to [7], ***terminal opposition prehension*** is performed between the extremity of the pad of the thumb, close to the nail and the extremity of the pad of each finger, particularly the index. It is a fine, discriminating bidigital prehension, used to grip small objects. The efficacy test is to grip a needle or a match on a table. This motion needs the integrity of the flexor pollicis longus and the flexor profundus of the opposite finger.

1. ***Subterminal opposition prehension*** is performed between the pad of the thumb and the pad of another finger when it is bidigital, or the pads of two fingers, when it is tridigital. This type of prehension is most often used during the daily life activities, allowing the use of thicker objects that can be gripped with two or three fingers, usually the thumb, the index finger, and the middle finger. The efficacy test for this is to try to pull a sheet of paper held between the index finger and the thumb.
2. ***Subterminal–lateral opposition prehension*** is performed between the pad of the thumb and the side of another finger, usually the index, as if one would count the money, grip a plate, or twist a key, which is why it is also called the "*key pinch*". This bidigital prehension performs a stronger grip than the previous one, because the finger opposite to the thumb, especially the index finger, is supported by the other fingers, thus the adductor muscles of the thumb can develop a maximum strength. This can be performed also with three fingers, between the pad of the thumb, of the index, and the lateral side of the middle finger; this grip is used for writing, which is why it is also called *"the writing grip".*
3. ***The thumb-fingers-palm opposition prehension*** is a strong prehension performed between the palm and the last four fingers and thumb. It is applied to heavy and voluminous objects. When the volume of the object is too large, the thumb cannot perform the grip with the other fingers, and the strength decreases.
4. ***The finger-palm opposition prehension*** opposes the last four fingers to the palm and allows the grip of smaller objects than the previous one: handling a lever, grabbing the steering wheel, grabbing a bar, carrying a suitcase. It is rarely used, because the grip is maintained with difficulty.
5. ***Lateral-lateral opposition prehension*** is performed interdigitally between the close sides of two fingers, especially the index and the middle finger. E.g.: *holding the cigarette between one's fingers.* It is secondary, but becomes precious in the absence of the thumb.
6. To this distribution, one can add the *multi-finger grip*, which opposes the distal extremity of the thumb (the pad) to the distal extremities of the other fingers. It is identified as a strong grip. E.g.: *gripping cylindrical, sharp objects.*

Another classification of the types of prehension, from a biomechanical standpoint, is as follows, according to www.creeaza.com/referate/biologie/Biomecanica-mainii:

- *type I* – between *two* of the fingers II-IV – is a prehension for small objects, in short, it is not a strong prehension; it implies the abduction-adduction of the fingers (in the metacarpophalangeal joint) – adduction through the interossei palm muscles, the interossei palm muscles and the extensor digitorum manus, the extensor digiti minimi manus, the abduction through the dorsal interossei muscles and the flexor digitorum manus together with the extensor indicis;

- *type II* - between the *last four fingers* together or isolated and the palm; the hand forms a hook and clutches, it is a strong prehension; the main muscles are the flexor digitorum profundus manus (the proximal interphalangeal joint) the muscles that open the hand through the extensor digitorum manus, the extensor indicis, the extensor digiti minimi manus, and for phalanxes II and III, the interossei and the lumbrical muscles;
- *type III* - the most complete prehension, performed between the *column of the thumb and the other fingers with the palm;* it is the most useful and most complex prehension, involving also an opposition; it combines: *the flexion of the thumb* through the flexor pollicis longus, *the extension of the thumb* through the extensor pollicis longus, *the abduction of the thumb* through the abductor pollicis longus & brevis, the extensor pollicis longus & brevis, *the adduction of the thumb* through the adductor pollicis, the extensor pollicis longus and the flexor pollicis longus.

During the therapy process, the goal of functional rehabilitation must be regaining the patients' ability to catch and grab, but also complex movements of the distal segment in relation to other muscle-articular structures that are specific to the upper limb.

Next, the authors of this study present a biomechanical analysis of the grips that play an important role in the rehabilitation process.

Terminal opposition prehension

Position: In sitting position, arm near the trunk, elbow flexed at 90^0, forearm in prono-supination, the fist flexion, followed by its extension and radial inclination determines this grip.

Muscles: main - flexor pollicis longus & brevis, the opposing muscle of the thumb and the adductor of the thumb (the oblique and transverse fascias), the extensor indicis, the carpal flexor longus & brevis; accessors – the flexor digitorum profundus manus.

This grabbing action can be combines with other motions, such as pronation (pronator teres, pronator quadratus) and supination (the long and short supinator) when the motion continues for example with getting a thread into a needle. This type of grip is performed between the thumb and the index finger.

Subterminal opposition prehension

Position: In sitting position, arm near the trunk, elbow flexed at 90^0, forearm in prono-supination, the fist flexion, followed by its extension and radial inclination determines this grip.

Muscles: main - flexor pollicis longus & brevis, the opposing muscle of the thumb and the adductor of the thumb (the oblique and transverse fascias), the extensor indicis, the carpal flexor longus & brevis; accessors – the flexor digitorum profundus manus.

This grabbing action can be combines with other motions, such as pronation (pronator teres, pronator quadratus) and supination (the biceps brachii, the long and short supinator) when the motion continues for example with getting a thread into a needle. This type of grip is performed between the thumb and the index finger.

Subterminal-lateral opposition prehension (two-finger grip)

Position: In sitting position, arm near the trunk, elbow flexed at 90^0, forearm in prono-supination, the fist flexion, followed by its extension and radial inclination determines this grip.

Muscles: main - flexor pollicis longus & brevis, the opposing muscle of the thumb and the adductor of the thumb (the oblique and transverse fascias), the extensor indicis, the carpal flexor longus & brevis; accessors – the flexor digitorum profundus manus.

This grabbing action can be combines with other motions, such as pronation (pronator teres, pronator quadratus) and supination (the long and short supinator) when the motion continues for example with getting a thread into a needle. This type of grip, performed with the thumb and the index finger, is more relaxed, and for the functionality the combined pronation and supination motions, as well as the flexion and extension of the fist are dominant.

Subterminal-lateral opposition prehension (three-finger grip)

Position: In sitting position, arm near the trunk, elbow flexed at 90^0, forearm in prono-supination, the fist flexion, followed by its extension and radial inclination determines this grip.

Muscles: main - flexor pollicis longus & brevis, the opposing muscle of the thumb and the adductor of the thumb (the oblique and transverse fascias), the extensor indicis, the carpal flexor longus & brevis; accessors – the flexor digitorum profundus manus, the carpal extensor longus & brevis, extensor carpi ulnaris, the carpal flexor longus & brevis, flexor carpi ulnaris, the palmaris longus. This grip is specific to the writing grip. This type of grip is performed between the thumb, the index finger, and the middle finger.

Multi-finger prehension (three-finger grip)

Position: In sitting position, arm near the trunk, elbow flexed at 90^0, forearm in prono-supination, the fist flexion, followed by its extension and radial inclination determines this grip.

Muscles: main - flexor pollicis longus & brevis, the opposing muscle of the thumb and the adductor of the thumb (the oblique and transverse fascias), the extensor indicis, the carpal flexor longus & brevis; accessors – the flexor digitorum profundus manus.

This is a grip but also a strewing motion.

Lateral-lateral opposition prehension

Position: In sitting position, arm near the trunk, elbow flexed at 90^0, forearm in prono-supination, the fist flexion, followed by its extension and radial inclination determines this grip.

Muscles: main – dorsal and palmar interossei muscles, lumbrical muscles

This type is performed between the index and the middle finger, and is specific to a cigarette-holding motion.

Multi-finger prehension** - **Multi-finger prehension (three-finger grip)

Position: In sitting position, arm near the trunk, elbow flexed at 90^0, forearm in prono-supination, the fist flexion, followed by its extension and radial inclination determines this grip.

Muscles: main - flexor pollicis longus & brevis, the opposing muscle of the thumb and the adductor of the thumb (the oblique and transverse fascias), the extensor indicis, the carpal flexor longus & brevis; the flexor digitorum profundus manus, adductor of the little finger, the opponent of the little finger.

This is an action of gripping heavy objects, the grip being performed between the pad of the thumb and the pads of the other fingers.

Thumb-fingers-palm opposition prehension
Position: it can vary.
Muscles: upper limb muscles
This is an action of grabbing heavy objects that need strength, the motion being supported by all of the upper limb muscles according to the direction and range of motion, and the shape of the objects.

Fingers-palm opposition prehension
Position: it can vary.
Muscles: upper limb muscles
This is an action of grabbing heavy objects that need strength, the motion being supported by all of the upper limb muscles. The thumb joint and muscles play a stabilizing role without a direct transportation action.

4. Conclusions

Based on the statements expressed above, the following conclusion can be drawn that are important for the rehabilitation process:

- the need to know the anatomical and biomechanical data that are specific to the different types of prehension;
- the application of the specific physical therapy means and methods in the context of the biomechanical analysis lead to an improvement of the intervention;
- knowing the previously presented data is useful in establishing the rehabilitation objectives according to the intervention stages;
- the action of each muscle group highlights, through the distal segment, the functionality of the upper limb.

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