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Alternative design of the equipment for the finger strength evaluation

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ABSTRACT : *Diseases, injuries, fractures, or conditions after operations on fingers and hands often cause loss of muscle strength and limit the mobility of a particular limb. Muscle strength restoration or increasing the range of motion may be achieved by the rehabilitation of the damaged area. The rehabilitation course ensures that a given area returns, in the maximum possible extent, back to the condition existing prior to the injury. To enable correct finger strength assessment or the rehabilitation success evaluation by an examining person, it was required to construct a device capable of measuring the strength of individual fingers. The submitted article deals with the alternative design of such device for the finger strength measurement, it describes the final design of the device and the measurement methodology that must be adhered to when assessing the muscular strength of fingers of a hand.*

Keywords *-Finger strength, measurement, hand.*

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I. INTRODUCTION

The main function of a hand is to grasp and manipulate with objects used in common daily activities. A hand's function is determined by the thumb motion on one side, and motions of other four fingers on the other side. The submitted article describes the design of the equipment capable of measuring the flexion strength of individual fingers, with the forearm and unmeasured fingers fixed, so that the forces exerted by them do not affect the measured values. Following the testing process, the constructed equipment for the measurement of flexion strength of fingers will be usable in common practice. It will primarily serve to the physiotherapists, who will be thus enabled to monitor the development of the strength of a rehabilitated hand.

A human hand is a complex mechanism, characteristic with the wide range of mobility levels, enabling thus significant variability of motions. [1] The range of motion depends primarily on the structure of a joint. Arrangement of muscles enables various degrees of the range of motion.

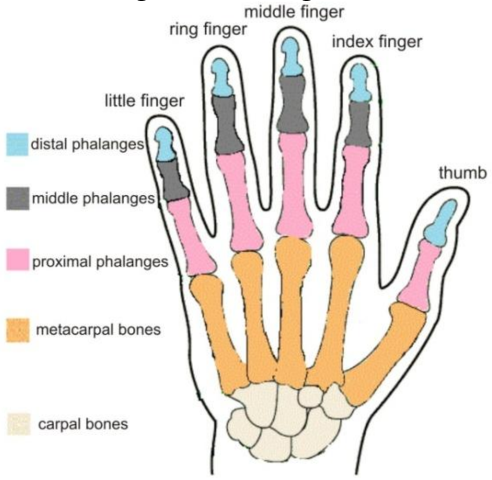

Figure 1: Simple Anatomical Scheme of a Hand Structure. [2]

Factors defining a hand's motion and grip activities, from the biomechanical point of view, are as follows:

- •Size and shape of a human hand.
- •Muscular flexibility.
- •Ranges of motion in joints and relative ratio of lengths of the muscles of antagonistic groups. [3]

Finger strength and motions are coordinated by the central nervous system. The strength is a result of the action of an elastic component of a muscle and a tendon. The muscular strength depends mainly on the amount of muscle fibres (the more fibres, the higher the strength) and on the amount of activated motor units. [4]

The maximum muscular strength is the force that an examined person is able to exert with the maximum effort performed by particular groups of muscles in a defined working position, in a dynamic or static form. [5]

The strength of the dominating hand, i.e. the one used for writing and performing majority of actions, is in 6.5% higher than in the other hand. As a result of a disease, injury, or older age, a person's strength values are significantly lower than the ones defined as the standard. At the age of 70 - 80 years, the grip strength decreases on average in 30%. A healthy person is able to perform short-lasting activities using 60% of their maximum possible strength. At the age of 20 - 30 years, a healthy person has the highest grip strength. [6]

The forces exerted by individual fingers during the gripping actions are varied. According to several trials, the strongest finger in griping actions is the middle finger, with the percentage value of 28.7%. The second strongest finger of a hand during a grip is the index finger with the value of 26.5%. They are followed by the ring finger, with 24.6%, and the lowest strength, 20.2%, is assigned to the little finger. [7]

Despite the differences in the resulting values reported by different authors, many of them state, based on their knowledge, that the middle finger and the index finger are the strongest fingers, excluding the thumb; they are followed by the ring finger, and the little finger is regarded as the weakest finger. As for the gripping actions, the thumb is the strongest one; however, thumb is not included in majority of trials. [8]

II. DESIGN OF THE EQUIPMENT FOR THE FINGER STRENGTH MEASUREMENT

During a grip, all fingers exert forces on the given equipment at the same time and other muscles of the hand are also engaged in the measurement. In order to identify intensity of the forces developed by each finger separately, it is necessary to limit the movements of the remaining fingers and the forearm so that they are not engaged in the motion during the measurement. The trial as such thus contains the design of the equipment facilitating the measurement not of the forces exerted by individual fingers during a grip, but the flexion strength of individual fingers and the thumb, when the unmeasured fingers and the forearm are fixed.

The design of the equipment for the measurement of the flexion strength of fingers contained several alternatives. The first design, as shown in Figure 2a, had a robust structure. The principle consisted in the finger strength measurement using a dynamometer attached from above to a movable rod. Using this rod, it was possible to adjust the dynamometer's position to the measured finger. This method, however, did not facilitate the measurement of the flexion strength of the thumb, as the thumb must be measured from the side. During the measurement, the strength of the mat under the hand would be insufficient and it did not provide the required support. This resulted in the risk of mat bending or even breaking under the hand's weight and the measurement would not be possible. The design's disadvantages include also the structure of an upright shape, which would hinder comfortable hand placement and fixation. With regard to the above mentioned circumstances, this alternative was abandoned.

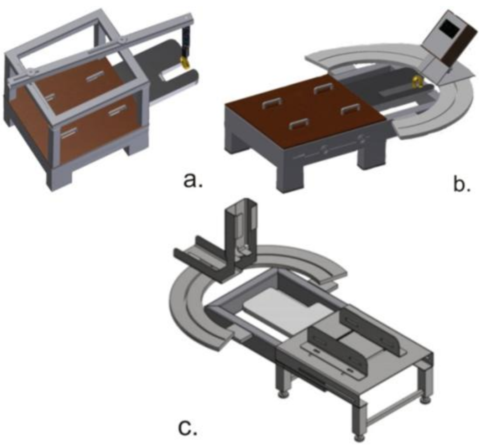

Figure 2: Design Alternatives of the Equipment for the Measurement of Flexion Strength of Fingers.

The second design is shown in Figure 2b. The structure, on which the dynamometer is expected to slide, was shifted forward from the upper section, which facilitated more comfortable hand placement onto the equipment. A semi-arch structure facilitated the dynamometer to be shifted aside, which solved the problem of measuring the strength in the thumb. The disadvantage, however, was the forearm fixation and the material planned to be used for the device manufacture, which was not resistant to corrosion - aluminium. The main requirement for the device manufacture was the compatibility with the human skin. Therefore, this design was abandoned as well. The final design of the equipment for the measurement of flexion strength is show in Figure 2c.

III. DESCRIPTION OF THE SELECTED ALTERNATIVE

The stainless steel structure consists of three separate parts, forming a functional unit. Additional, but also very important parts are five hand mats and two dynamometers.

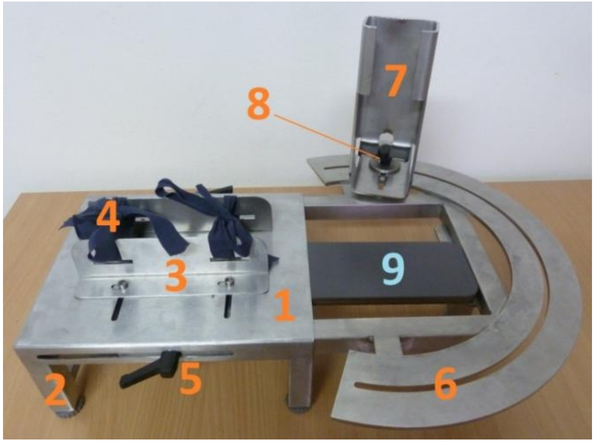

Figure 3: Parts of the Equipment for the Measurement of Flexion Strength in Fingers: 1- Equipment table; 2 - height-adjustable legs; 3 - fastening plates; 4 - straps; 5 - table screws; 6 - semi-arch rail serving for dynamometer sliding; 7 - dynamometer holder, 8 - fixing screw of the dynamometer holder; 9- hand mat.

Stainless steel structure of the measuring equipment consists of the following parts:

A. Equipment table - entire table consists of the following components:

- Upper table surface (forearm mat) - a place where the forearm is placed during the measurement. A forearm is positioned in the centre, between the plates.
- Fastening plates with the hook and loop fasteners/straps (forearm holder) - they serve for forearm positioning and fixation to limit its movement during the measurement. After proper forearm placement and adjustment of plates, the forearm is fixed using the hook and loop fasteners or straps.
- Threaded nut bolts - they are used to fix the plates to limit their movement during the measurement.
- Table screws - they ensure fixation of the table and the semi-arch structure to avoid undesired movements during the measurement. Their surface is plastic.
- Mat holder - located in the lower section of the table. Hand mats may be inserted, with their narrower end going inside, into this section of the equipment. Once they are inserted, the mat is in the same plane as the entire table. The holder secures the mat against the movement.
- Partition - a partition fills the space between the legs, connects them and ensures stability of the entire structure. It is located in the lower section of the table.
- Height-adjustable legs - they are used to adjust the table in the required height or to balance the equipment. Lower surface of legs is covered with felt to avoid damage to the surface onto which the equipment is placed and to facilitate better manipulation. Instead of felt, rubber material may be used to prevent from the undesired movement of the equipment; however, it is not necessary, as the equipment has the sufficient weight for preventing the movement during the measurement.

B. A semi-arch rail for the dynamometer - it is a separate removable structure, one part of which may be inserted into the equipment table, creating thus the connection between them, whereas the second part serves for sliding the dynamometer. For the stability purposes, a semi-arch rail also contains an adjustable leg in the front section. The rail's shape was designed as a semi-arch to enable proper positioning of the dynamometer for the measurement of all fingers, including the thumb. The structure also includes the holder for the front section of the hand mat. The weight and the dimensions of both parts, excluding the dynamometer holder, are as follows. Equipment weight = 9.7 kg; Total length of the equipment, excluding the holder = 52.2 cm. Table width = 25 cm. Table length = 28 cm. Semi-arch structure width = 43.3 cm.

C. Dynamometer Holder - it serves for the fixation of the dynamometer in the required position.

D. Acrylic polyurethane hand mats - intended for the limitation of the movement of the unmeasured fingers and as a place where a hand is placed during the measurement. Each mat consists of two sections; a thicker one, where the palm and the unmeasured fingers are placed, and a thinner one, which is inserted into the mat holder. Dimensions of the entire mat are unified, except for the thumb mat, which has a different width of the palm mat. The length of mats is 30 cm. The width of mats at the place where the palm is placed is 14 cm and the thickness of this part is 1.2 cm. The width of the mat section inserted inside the equipment table is 8 cm and the thickness of this section is 0.3 cm. The width of the thumb mat is 9 cm.

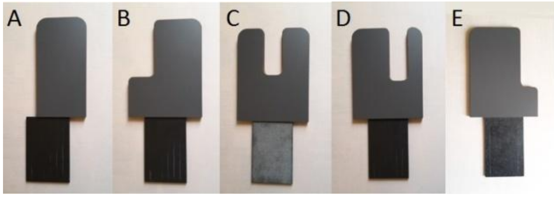

Figure 4: Hand Mats Used during the Measurement of: A) Thumb; B) Index Finger; C) Middle Finger; D) Ring Finger; E) Little Finger.

IV. PROPOSED METHODOLOGY FOR THE FINGER STRENGTH MEASUREMENT

The preparation of a measured subject may be divided into following phases:

1. Identification of the health condition - this information is collected through a questionnaire containing all the necessary questions regarding the health or physical condition of hands and fingers of the measured person.
2. Instructions - after the questionnaire is filled out and revised, the measured person confirms with their signature their agreement with the measurement execution. The measured person is then instructed on the use of the equipment to be used for the measurement and on the measurement procedure.
3. Warm-up exercises prior to the measurement - another important part, prior to the measurement, is the thorough warm-up exercise of fingers, so that the tissues are more flexible in the particular area.

Measurement of finger strength using a digital dynamometer

A digital dynamometer facilitates the conversion of the measured values into a computer, where the visualises them into a curve, transposed into a chart. On the left side of the screen, a table is displayed after the dynamometer is turned on. This table contains the data on the force exerted by the measured person on the dynamometer for certain period of time. Force values are shown in Newtons [N]. On the right side, there is a chart with the development curve. The lower horizontal line represents the x-axis, displaying the time data, whereas the vertical line, perpendicular to the x-axis, represents the y-axis. The y-axis displays the data on the forces exerted by individual fingers. After the measurement completion, the data are saved.

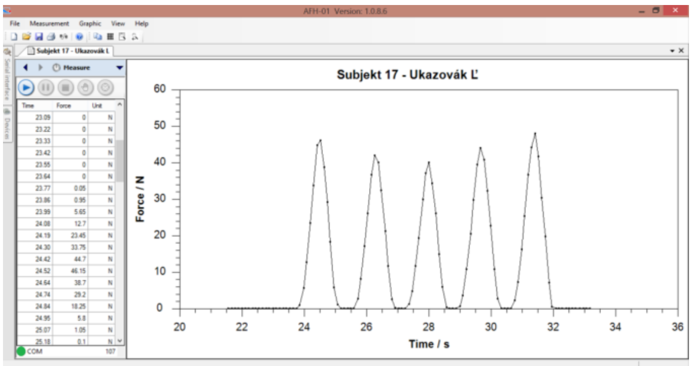

Figure 5: Software Displaying the Curve Course and the Measured Values.

The principle of the measurement using a digital dynamometer is that a measured person must make five consecutive smooth motions using the measured finger towards the flexion. During the measurement using a digital dynamometer, the measured finger is positioned so that the ring is located under the distal interphalangeal joint, on the palmar side, while other fingers stay stretched during the entire measurement and are in the full contact with the mat. The forearm is fixed using the plates and straps, having a similar function as a hand mat, i.e. to fix the forearm during the measurement and prevent thus the forearm elevation.

Figure 6: Measurement Process Using a Digital Dynamometer.

After five smooth motions with the measured finger, while exerting the highest possible force on the dynamometer without lifting the forearm and fingers on the mat, the measurement was completed. The data were saved in the software and the measurement could continue with the mat replacement, dynamometer adjustment, and measurement of the following finger. Entire process of the measurement using a digital dynamometer lasted approximately 15 minutes.

Finger strength measurement using a spring dynamometer

A spring dynamometer is based on a simple principle, i.e. the measured values are read visually, without the possibility of converting the data into a computer. Compared to a digital dynamometer, a spring dynamometer differs also by the fact that when the force is exerted on the ring, the measured person is able to make a motion into the flexion. The measurement process is basically the same as with a digital dynamometer, with the difference being that in this case a finger is put inside the ring so that the force is developed through the ball of the finger, i.e. distally from the distal interphalangeal joint.

Figure 7: Measurement Process Using a Spring Dynamometer.

Here again, five consecutive motions into flexion were carried out. The measured person was trying to overcome the resistance of the dynamometer by developing the strongest possible force, with the forearm and fingers in the full contact with the mat during the measurement. After the completion of five contractions, the mat was replaced, the dynamometer holder was adjusted to the following finger, and the measurement could start again. The entire process of measurement using a spring dynamometer lasted approximately 15 minutes.

V. CONCLUSION

Following various diseases, injuries, fractures, or operations on fingers and hands, the muscles are often weakened and a limb’s mobility is limited. Therefore, patients who have suffered from such damage, have weaker muscular strength in the damaged area than before the injury. Rehabilitation is applied in order to restore the strength and increase the mobility of fingers and hands.

An examining person will be able to obtain the information on the force produced by individual fingers in the beginning and at the end of the patient’s rehabilitation. Depending on that, the examining person will be able to assess the efficiency of the selected rehabilitation procedure.

As with majority of the designed and subsequently constructed initial equipments, also this device, being a prototype, possesses several deficiencies. The first disadvantage is represented by replaceable mats which must be replaced after each finger measurement. This causes prolongation of the measurement process. If the mats were substituted with the system measuring the fingers without the need to replace the mats, the measurement duration would be shorter and the patient's comfort would improve. Such system might contain a plate, to be placed where the mat is placed, with the function of opening only a section where a particular finger is supposed to be measured. A design of such system might represent the subject of a future trial.

During the measurement, particularly during the measurement using a spring dynamometer, it was observed that the problem consists also in the ring, in which a finger is inserted during the measurement. It is only a thin metal ring, not very comfortable, and also sliding off the finger during the measurement in majority of cases. There are two alternatives how to innovate this ring. Either by using the same ring, but a little wider, to increase the contact surface, and covered with a fabric to increase the comfort during the measurement, or, as the second option, by designing a system reminiscent of a thimble used in sewing. In such case, it would be necessary to manufacture several sizes to fit various finger dimensions.

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