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# Biomechanical analysis of grip strength in upper limb rehabilitation

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# Biomechanical analysis of grip strength in upper limb rehabilitation

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**Abstract.** This research is based on biomechanics as a science that involves concepts of engineering, mechanics, physic, anatomy, physiology, and many others, to study the human body with the desire to solve certain problems that may affect the performance of an individual in their work or personal level. This work is an investigative process in these areas of scientific and applied disciplines, in which the attention is focused on the hand as a valuable tool for the occupational performance of the human being, since through it is possible to touch, move, grasp, or manipulate objects. Injuries to this limb may be due to various causes, which require complex surgeries and long periods of rehabilitation to be reversed. This research highlights the importance of certain physical concepts that must be understood by the rehabilitation expert in order not to affect the surgery and thus guarantee the maximum functionality of the patient at the end of the recovery cycle.

## 1. Introduction

The hand is the element of the human body that interacts with the environment either to move, touch, manipulate or grasp objects, which makes it a necessary limb for daily life and work due to its functionality and ability to adapt to the shape of objects. As a factor that decreases work productivity or functionality, when it is affected by injuries, the maximum force that would be exerted under normal conditions is diminished.

However, the correct diagnosis and treatment of injuries has its own philosophy, since each injury compromises the biomechanics of the tendon, which motivates its in-depth study. The extensor tendon can be injured in different ways, generally the most common injuries are caused by lacerations, crushing, and forced flexion of the joint which, when extended, can cause laceration of the tendon insertion with or without fracture of the phalanx. Biomechanical analysis to characterize the force exerted by the hands is performed by means of readings obtained from dynamometers, either mechanical or hydraulic, where the results correspond to the force exerted by the whole hand.

Several previous clinical studies [1,2] have provided valuable information on this type of injury, for example it is known that: (a) extensor tendons in all areas tolerate controlled active mobility; (b) breaching and rupture are rarely a problem in carefully applied postoperative regimens where forces and excursion are controlled; (c) more digital joint mobility can probably be allowed than previously thought possible; (d) wrist position is critical in decreasing restrictive forces on the flexor system and is a factor in the true tendon excursion obtained with digital mobility; (e) those tendons have probably been actively moved, all within the confines of their dynamic splints; and (f) early referral to therapy with attention to splint geometry and applied stress are critical variables in achieving results [3].

Therefore, when designing a splint for the rehabilitation of the extensor tendons of the hand, the aim is to use mechanical means to allow the movement of the hand, generating faster and more effective treatment responses and thereby reducing the biomechanical, physiological, psychological, and socio-occupational impact.

Biomechanics studies the models, phenomena and laws governing the movement and balance of the human body. It is based on the biomedical sciences, which use knowledge of mechanics, anatomy, physiology, and other disciplines to study the behavior of the human body and to solve problems arising from the various conditions to which it may be subjected. Studies based on the human body and the human-machine relationship have achieved the restitution or replacement of damaged functions and structures, which has encouraged the construction of instruments for therapeutic and diagnostic purposes such as prostheses or devices that replace a biological function [4].

Most biomechanical studies focus on the hand, due to the importance it represents in mobility and the ability to manipulate and hold objects in daily tasks. For this reason, carrying out an in-depth study of this upper limb has become a necessary activity in research, either to replace it by means of prostheses or for rehabilitation in people with hand impairments. This study will serve as a support for health personnel. For this reason, a characteristic study of the forces generated by the hand and how it is affected after an injury after the rehabilitation process has been completed is proposed. The objective of any rehabilitation cycle is to guarantee the maximum functionality of the individual.

## 2. Method

To determine the degree of effectiveness and efficiency of rehabilitation treatments for extensor tendon injuries from zone IV to zone VIII, a descriptive comparative study was carried out to identify the most appropriate recovery protocol, considering the type of splint used in the recovery process as an independent variable and the intensity of the strength reached by the affected upper limb at the end of the rehabilitation process as a dependent variable.

The application of the protocols to determine the effectiveness and efficiency in the recovery process of the extensor tendons was carried out with patients who underwent surgery at the University Hospital in the city of San José de Cúcuta, Colombia, and who subsequently went to a rehabilitation center. The sample was non-probabilistic and intentional, since the inclusion criteria applied were the injury in the study zones and that they were able to complete the initial rehabilitation process (six weeks). A sample of six patients was selected, distributed equally between the traditional and early mobility controlled active movement (ICAM) treatment protocols.

For the pressure measurement, certain conditions were determined according to the American Association of Hand Therapists [5] emphasizing that the person should be in a seated posture, with spine aligned, shoulders adducted and without rotation, the elbow forming a 90° angle to the side of the body, together with the forearm and wrist in a non-influential position, *i.e.*, in a neutral position.

We had the support of a materials supply corporation, which provided the necessary resources to produce the splints, while the rehabilitation center has the Jamar dynamometer [6] and the Martin Vigorimeter [7], both instruments used to measure grip force and pressure.

## 3. Results and discussion

Regarding the demographic characteristics of the people who participated in the research, their ages range between 15 and 60 years, with an average age of 38.9 years. There is a predominance of men, whose daily activities are mainly concentrated in mining and agriculture, with a predominance in the municipalities of the Catatumbo region, Colombia. The patients to whom the traditional process was applied presented lesions in zones IV and V with a predominance of the third finger of the left hand, but predominantly on the right side; while the patients to whom the ICAM protocol was applied presented lesions in zone V, with 66.7% on the right side and the remaining percentage on the left hand.

### *3.1. Biomechanical analysis of grip force*

The hand corresponds to the final section in the mechanical line of levers starting with the shoulder, passing through the elbow, the wrist and ending with the wrist, characterized by operating in various planes, which allows the hand to move within a wide space and enables it to reach all parts of the body with great ease.

The grip strength of the hand corresponds to the force used to suspend objects in the air or to squeeze them. This requires the correct position of the wrist to avoid the development of so-called cumulative trauma disorders [8]. The grip force can be squeezing, clamping, and supporting. Then the biomechanical characterization of the grip involves the determination of the different kinematic and dynamic variables that affect the different phases of the grip: transport, grip formation and manipulation, as well as their relationship with the anthropometric characteristics of the subject and those of the manipulated object and the manipulation task [9].

Some key parameters that contribute to the characterization of the contact between an object and the hand are the areas of the hand in contact and the pressure experienced on it. This information is necessary as input data in the generation of biomechanical models of the hand to investigate the muscular efforts that act in this grip. Functional aspects of the physiology of the hand (muscles and tendons) are implicit in the hand's grip action or hand movement, among which the deep flexor of the fingers is the generator of pressure given its physical characteristics [10], in support of other muscles.

In the research of [9], an analysis of the forces generated internally with angles of 120° and 90° of flexion of a proximal interphalangeal joint is carried out and it is concluded that to generate an optimal grip where the forces generated will be maximum with respect to the tension in the flexor tendons, it is required that the fingers are as closed as possible (see Figure 1). It is in this scenario where the rehabilitation process plays a key role. The resultant forces in each force system are obtained from the application of Equation (1).

$$F_R = \sqrt{F_1^2 + F_2^2 + 2 * F_1 * F_2 * \text{Cos}\theta}. \quad (1)$$

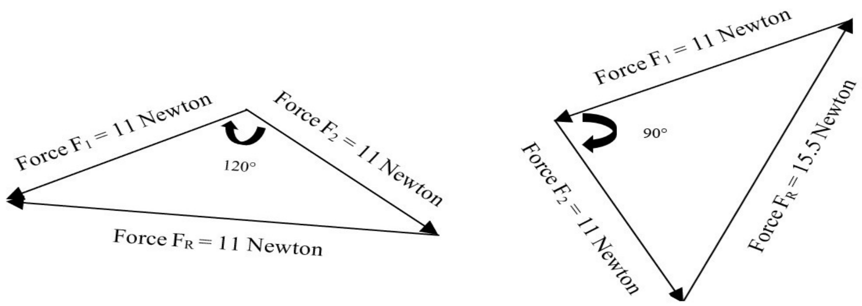


**Figure 1.** Magnitude of forces generated by the hand and their relation to the flexion position at the interphalangeal joint.

During the rehabilitation process, use was made of the dynamometer (cylindrical palm pressure) and the vigorimeter (spherical palm pressure) in order to consider, as a secondary objective, whether the shape influenced the measurement due to the comfort of the affected limb, as described by [7] where it is highlighted that the palm pressures are those in which the fingers and palm of the hand are involved, corresponding to a force pressure with the purpose of taking bulky and heavy objects [7], as shown in Figure 2.

Table 1 presents the measurements taken at the end of each week of treatment using the cylindrical palmar pressure measurement device (with force recording in kilograms) once the patient was able to start the rehabilitation process. Two measurements were taken for each patient with a five-minute recovery interval in between. In this way, six measurements per week were obtained, to report some pressure descriptions such as average, standard deviation (SD) and the lower and upper limits of the 95% confidence interval for each of the two treatments under evaluation.

The results offered by the patients who underwent the ICAM early mobility treatment show better results in terms of the recovery of their affected hand, compared to the traditional process, so the difference is statistically significant. Although it is worth clarifying that, in both cases, the strength measurements correspond to the measurements that would be reported by an infant of no more than 13 years of age [7].

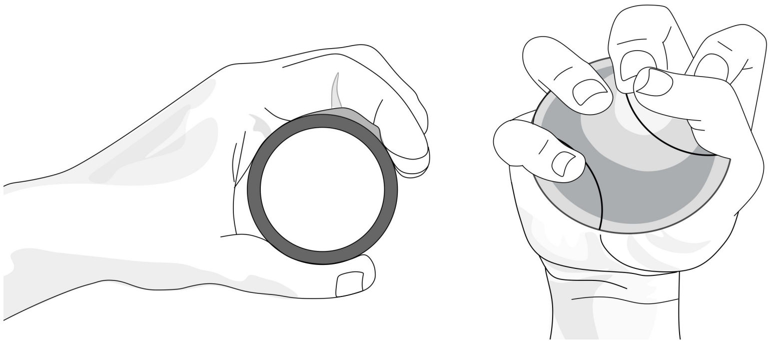
(a) (b)

**Figure 2.** Palmar pressure (a) cylindrical and (b) spherical. Adapted from [7].

**Table 1.** Comparative descriptive data according to rehabilitation treatment using the Jamar dynamometer.

| Week | Traditional method | | | | ICAM protocol | | | |
|---|---|---|---|---|---|---|---|---|
| | Average | SD | Lower limit | Upper limit | Average | SD | Lower limit | Upper limit |
| 1 | 9.83 | 1.24 | 8.84 | 10.82 | 12.52 | 1.13 | 11.62 | 13.42 |
| 2 | 10.99 | 1.78 | 9.57 | 12.41 | 13.24 | 1.68 | 11.90 | 14.58 |
| 3 | 12.84 | 1.94 | 11.29 | 14.39 | 15.46 | 2.11 | 13.77 | 17.15 |
| 4 | 14.86 | 2.33 | 13.00 | 16.72 | 16.77 | 2.25 | 14.97 | 18.57 |
| 5 | 15.65 | 2.97 | 13.27 | 18.03 | 17.48 | 2.78 | 15.26 | 19.70 |
| 6 | 17.23 | 3.11 | 14.74 | 19.72 | 21.23 | 3.31 | 18.58 | 23.88 |

Table 2 presents the measurements taken at the end of each week of treatment using the spherical palmar pressure measurement device (with force recording in bar) once the patient was able to start the rehabilitation process. Two measurements were taken for each patient with a five-minute recovery interval in between. Six measurements per week were obtained, to report some descriptive pressure data such as average, standard deviation (SD) and the lower and upper limits of the 95% confidence interval for each of the two treatments under evaluation.

The results obtained from the patient measurements show slightly higher values for those who received the ICAM early mobility treatment, but these are not statistically significant, *i.e.*, there are no differences in the evolution of the two treatments under this measurement tool. It continues to be highlighted that the measurements report values that would correspond to an infant of no more than 13 years of age without any type of affectation in their hand [11].

There are few works that report the parameters of grip strength in people according to their age, for example, in [11,12] fist strength parameters are reported in healthy people of working age, while in [13] parameters are defined between 6 and 18 years of age, but in the three investigations the use of the dynamometer alone is resorted to. While the characteristics of the research developed by [7] is more in line with the characteristics of this research in terms of the use of various instruments for the measurement of the pressure force that vary in the way the hand is gripped to perform the measurement, which becomes a relevant feature given the characteristics of affectation of the informants in this research.

It should be noted that for the purposes of this discussion of results, it is compared with the parameters provided in [7] who estimate the parameters of normal strength in children and young people. This situation becomes an obstacle that makes it more complex to determine both the degree of affectation of an injury and the level of effectiveness of the rehabilitation process.

The differences found between the rehabilitation treatments with the use of the Jamar dynamometer are based on the way in which the person performs the grip, favoring those patients who have been rehabilitated with the ICAM treatment, because, as concluded in [9], the optimal grip where maximum forces are reached with respect to the tension in the flexor tendons occurs when the fingers are as closed as possible.

**Table 2.** Comparative descriptive data according to rehabilitation treatment using the Martin Vigorimeter.

| Week | Traditional Method | | | | ICAM protocol | | | |
|---|---|---|---|---|---|---|---|---|
| | Average | SD | Lower limit | Upper limit | Average | SD | Lower limit | Upper limit |
| 1 | 0.273 | 0.045 | 0.24 | 0.31 | 0.368 | 0.051 | 0.33 | 0.41 |
| 2 | 0.347 | 0.073 | 0.29 | 0.41 | 0.375 | 0.057 | 0.33 | 0.42 |
| 3 | 0.389 | 0.074 | 0.33 | 0.45 | 0.392 | 0.063 | 0.34 | 0.44 |
| 4 | 0.396 | 0.077 | 0.33 | 0.46 | 0.406 | 0.063 | 0.36 | 0.46 |
| 5 | 0.413 | 0.078 | 0.35 | 0.48 | 0.421 | 0.065 | 0.37 | 0.47 |
| 6 | 0.422 | 0.081 | 0.36 | 0.49 | 0.448 | 0.069 | 0.39 | 0.50 |

## 4. Conclusions

After the execution of this research, several aspects can be highlighted: is evidence of the interdisciplinary knowledge that generates antecedents of work in science, technology, engineering, the arts, and mathematics, where the success of a rehabilitation process is clearly influenced by the therapist's knowledge of physics concepts, such as force, tension, pressure or pulleys that are immersed in the biomechanical functioning process of the hand; the evaluation of the effect of the rehabilitation process is clearly influenced by the instrument used for force measurement, given the particular connotation of this study, where the informants were people who had suffered hand injuries between zones IV to VIII, so the position of the fingers becomes a differentiating factor; finally, it is important to continue extending the results in this line of work, including people whose work activities are different from mining or agriculture, which correspond to the occupations of these participants, since clearly and after reviewing the literature, the patient's work activity influences their rehabilitation process; it is in this scenario where the concepts of Physics provide valuable guidance to the rehabilitation professional in order to guarantee intervention protocols that contribute to the functional recovery of the affected limb.

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