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# Simulation of the effect of displacement of tendon joints on knee joint forces and torques in people with cerebral palsy

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**Abstract:** Gait analysis is the study of the movement of body parts while walking using simple or advanced equipment to investigate the causes of movement problems in patients. Today, using special Motion Analysis laboratories and software such as Opensim and Tracker, it is easy to examine patient motion analysis and provide accurate engineering solutions to improve patients or increase capability. In this study, due to disorders caused by damage to the nervous system of a person with cerebral palsy and the output of the data obtained from the gait analysis of this person using motion analysis software and change the data obtained from Gait analysis and data simulation an attempt is made to simulate the best possible preoperative change to move the tendons and provide the surgeon with the information needed to optimize surgery. By considering a hypothetical marker between the two main markers ankle, toe and displacement of this marker, the approximate position of the tendon connection in the foot area is obtained.

**Keywords:** Motion analysis, joint angles, knee joint, cerebral palsy

## 1. Introduction

Special attention to human gait movement in recent decades with the advancement of imaging and motion analysis technologies has led to engineering treatment strategies along with physicians' treatment strategies to continuously improve the patient's mobility during clinical treatment. Patients with cerebral palsy have different movement disorders in the gait, which are manifested in different forms in the condition of their upper and lower limbs. Therefore, clinical gait analysis of these people is very important and has been considered by many researchers from the past until now. The issue of the usefulness of using gait analysis in the treatment decision of patients, including people with cerebral palsy, has always been criticized by doctors and specialists, and several studies have been conducted to prove this point. Therapeutic interventions for people with cerebral palsy are aimed at improving motor function and normalizing their gait (walking). The treatment plan at different stages can include occupational therapy, the use of braces, or surgery. Gait assessment of children with cerebral palsy is performed to assess the extent of muscle spasm, range of motion of the joints, muscle strength and skeletal structure of the individual. In some cases, this assessment is done only with the physician's experimental observations or filming the child's movement from different angles. More precisely, this evaluation is performed by advanced three-dimensional analysis systems. In 3D gait analysis, the kinematic information of body movement in three directions is recorded and analyzed by infrared cameras with high imaging rate. Also, forces on the joints (kinetic data) are calculated using force plates. The width of the right ankle is 69.79 cm and the width of the left ankle is 71.78 cm. The right and left offset holder is 35 cm and the thickness of the right hand is 28.01 cm and the thickness of the left hand is 29.26 cm, the width of the right hand is 83.84 cm and the width of the elbow the left hand is 29.26 cm, the width of the right wrist is 58.33 and the width of the left wrist is 61.69 cm.

The equipment used in this research is as follows:

- Tape meter to measure height with an accuracy of 1 mm

Caliper to measure the width of the wrist, knee, elbow with an accuracy of 0.02 mm

-Scale to measure weight with an accuracy of 1 gram

- Motion analyzer with 4 Vicon models, model 460, made in England, in order to systematically record three-dimensional movement with an average of 0.973 mm data

-Computer in order to receive kinematic motion data online

-44 infrared reflector markers

-Force plates made by Kistler company in Switzerland

First, a static trial was completed in an anatomically neutral position for model calibration and calculation of subject-specific joint axes. Subsequently, at least 15 dynamic walking trials in which the subject was cleanly striking the force plate were recorded while subjects were walking barefoot at self-selected speed across a 10-meter walkway [1]. Measurements required for analysis include height, weight, leg length, knee and wrist size. The correct leg length between the ASIS and the middle ankle bone was measured through the knee joint. Knee width is the distance between the inner and outer epicondyle of the thigh and wrist width is the distance between the middle and outer ankle. Measurements are made on the dominant foot of the person. The markers were placed on the bony prominences of the lower and upper limbs according to the Plug in Gait standard. The advantage of this system is the reduction in the number of markers used and thus the possibility of an error that the camera may have in detecting close markers. The location of the markers is shown in Figure1 and is described in Table1. In this study, only lower limb information was used. It should be noted that instead of left and right PSIS markers and left and right ASIS markers, HIP markers are used.

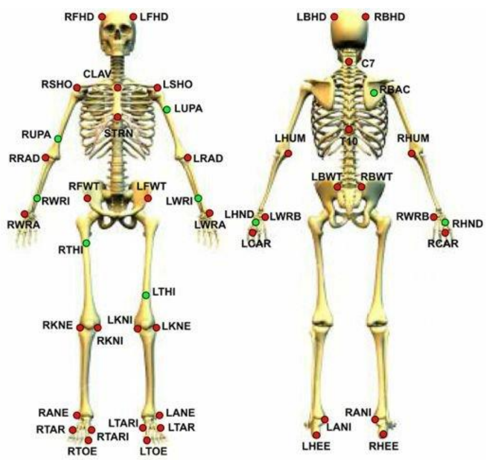


Figure1. Location of markers by Plug in Gait method

Table1. Abbreviations and location of markers

| Name Marker | Marker Abbreviation | Location |
|---|---|---|
| Right Asis | RASI | Upper anterior iliac spine |
| Right Knee | RKNE | On the flexion-extension axis of the right knee from the lateral side |
| Right Toe | RTOE | Head of the first metatarsal |
| Right Tibia | RTIB | On the upper 1/3 of the surface of the right leg |
| Right Ankle | RANK | On the outer ankle, along the hypothetical line passing through the axis between the two ankles |
| Right Heel | RHEE | Behind the heel, the same height as the TOE marker from the ground |
| Sacrum | SACR | On the middle surface of the left and right PSIS |

The three-dimensional coordinates of these markers were recorded using four calibrated cameras with an imaging frequency of 120 images per second when the person was walking on the specified path. Reconstruction of images and extraction of marker coordinates was performed by Vicon software.

Before the data was recorded by the cameras, the subject was given the opportunity to move on the path leading to the force plate to get acquainted with the path, then he was asked to move normally on the path to obtain the necessary data. Data on the position of individual markers were stored and used in Excel format. In the past, it could be demonstrated that individuals with CP display shorter fascicle lengths [2,3] and muscle weakness [2,4] in comparison to their TD peers indicating an altered torque-fascicle length/ankle angle relation as previously reported for adults with CP [2,5].

In this research, the human body is considered as a set of related rigid links, which is a standard approach in biomechanics. In order to follow the changes of kinematic variables, it is necessary to create a reference system to describe the movements and position of the components relative to each other. The reference system for expressing data can be absolute or relative. In anatomy, there are predefined descriptions for the relative expression of a member's condition. In order to ensure the accuracy of the received data, the patient's movement was repeated several times in this direction, considering that the patient had cerebral palsy and all the data could not be done completely, and in most of the data, only one foot movement on the force We had a plate, so the repetition of the data seems obvious. After testing and reviewing the data, due to the movement of the hand in the direction of movement and the alignment of the hands on some markers, we saw data loss in many frames. Therefore, we separated the more complete data and for We created a complete file on our calculations with the help of data interpolation and extrapolation. In the forces that lead to walking, 80% are external forces and 20% are internal forces. All three types of contractions produce internal forces in a coordinated and orderly manner, and each of them works positively or negatively according to the direction of displacement and the direction of the force, and produces or absorbs energy. The action, work and method of effect on the energy of contractions are as follows: Concentric contractions are the initiators of movement and produce energy, their work is positive and they produce energy (produce energy and transfer it to other parts of the body) Eccentric contractions absorb forces and energy and their work is negative.

Isometric contractions are used to stabilize the joints while walking.

This is a retrospective analysis performed on data collected as part of a strengthening study in person with spastic CP [6,7]. In the present study, the available data from the baseline measurements of this study was used for further analysis.

## 2.Methods

After obtaining the data and analyzing them completely, operations should be performed on the data to eliminate their shortcomings and prepare the data for calculations. in general, the forces that affect gait and lead to walking with the stated characteristics are divided into two categories:

1- (IGF) Internally Generated Force: which are the same internal forces and are the force produced by body structures, especially muscles.

2- (EGF) Externally Generated Force: which are the same as external forces and include inertia (Earth), gravity and ground reaction forces (GRF) Ground Reaction Force. First, we need to take a step away from the patient's data. To do this, we draw a diagram of the heel marker on the Z coordinate axis as we can see in Figure 2, in the time interval of 85 to 262 frames, we will have a complete movement step that we can separate these points in other coordinates of the markers and get the full coordinates of a step for all points of the foot.

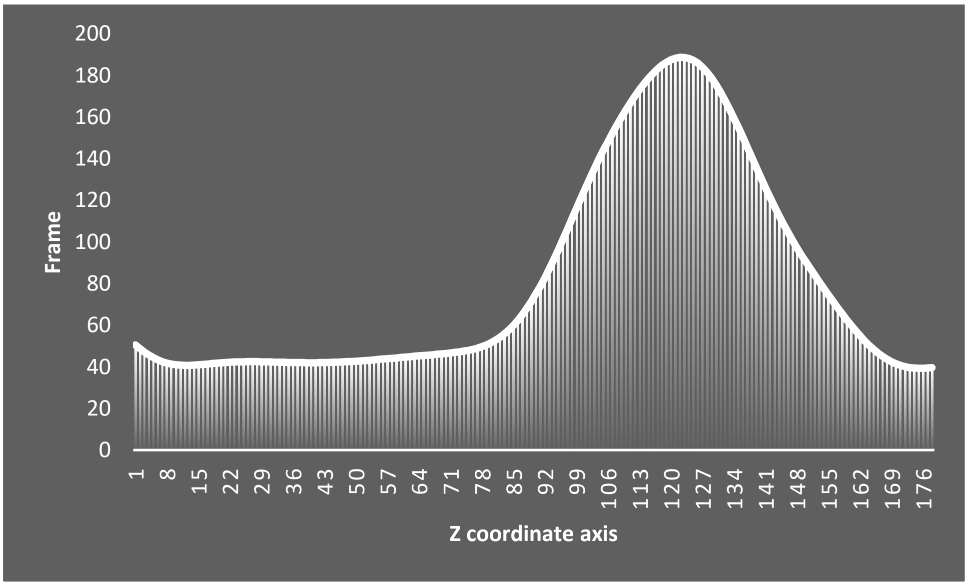


Figure2. Heel marker on the z coordinate axis

Now we can separate the coordinates of a complete step at the Ankle, Toe, Knee points and use these coordinates to obtain the foot torque around the Ankle axis.  We Follow this movement on the right foot and around this chart and perform our calculations. Given that the data related to the force plate is in the y direction and the main data of the gait analysis at a frequency of 120 cameras for every 10 frames we will have a series of data, so from the Resample command to synchronize the relevant data We will use GRF power.

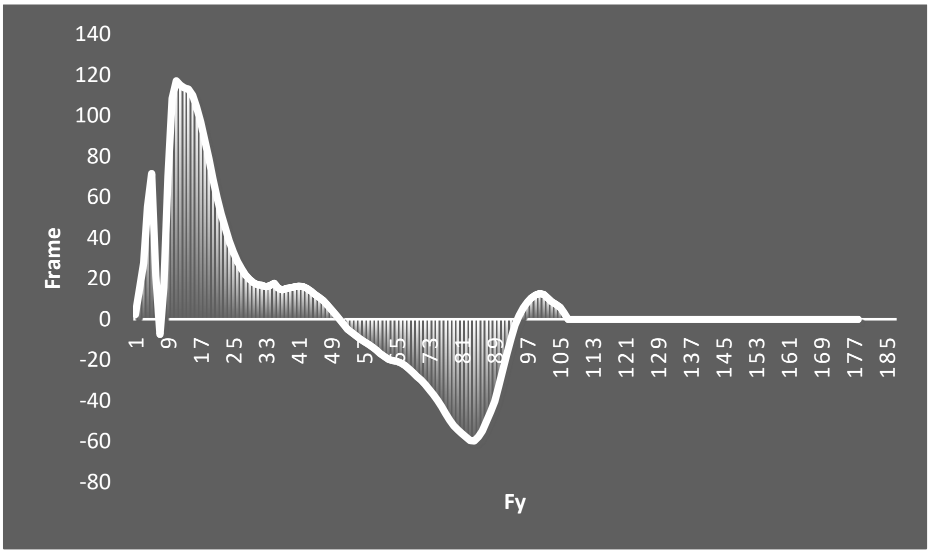


Figure3. Forces on Force Plate

Using laboratory data and manual calculations performed in Excel, angular velocity, acceleration, inertial torque, torque around the ankle axis and the distance between the toe and ankle markers can be calculated. The acronyms used in our figures and calculations are shown in Table 2. The hypothetical point P between the two markers A and T is shown in Figure 4.

Table 2 Abbreviations used in calculations:

| Title | Abbreviation |
|---|---|
| Cerebral Palsy | CP |
| Gluteus Soleus | GS |
| Gait Profile Score | GPS |
| Theta | ϴ |
| Omega | ω |
| Alpha | α |
| Dorsi Plantar Flection | DPF |
| Extension-flection | EF |
| Velocity | VT |
| Acceleration | AT |
| Tibia list Anterior | TA |
| Point | P |

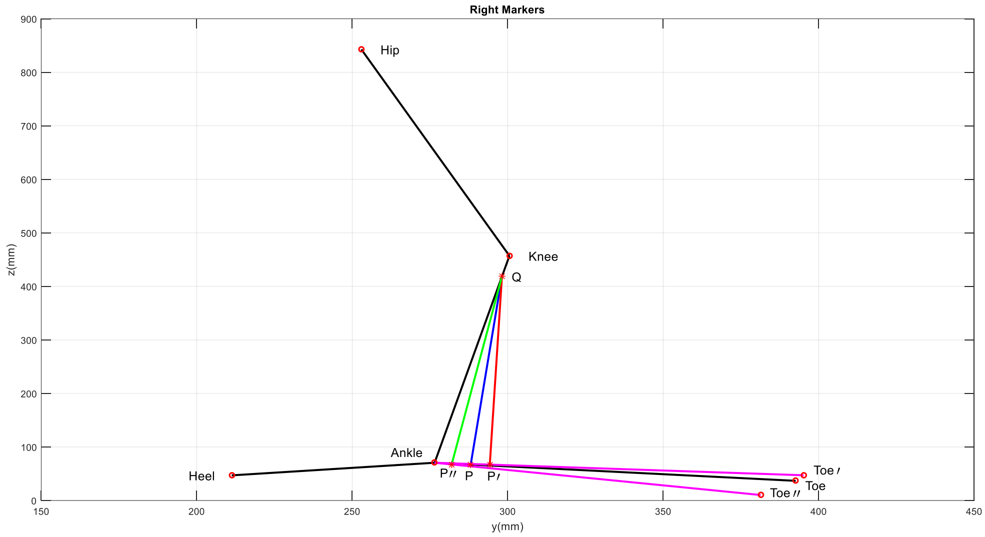


Figure4. Hypothetical position of P, P', P'' points between two markers ANKLE, TOE

The general shape of the connection of the two markers Ankle and Toe is shown in Figure 5. By calculating the length of the line segments shown in the figure, the torque around the Ankle axis can be calculated. Figure 6 Torque around the ankle axis in this person with cp Is displayed.

Equation1.Torque around the Ankle axis:

$$MA=-d3\boldsymbol{f_y}-d4\boldsymbol{f_z}+\boldsymbol{d_2 w_{foot}}-\boldsymbol{I_{A\alpha}}+\boldsymbol{M_{foot}.a_y d_1}+\boldsymbol{M_{foot}.a_z d_2} \quad (1)$$

Given the coordinates of the points Ankle, Toe, Knee, we can define points like P near Ankle on the Ankle-Toe line segment and a point like Q near Knee on the Knee-Ankle line segment and the line segment resulting from the connection of two points Q Consider P as the anterior tibialis muscle. By changing the coordinates of point P, the angle of connection of this segment at point Q changes. How to perform calculations and obtain kinematic parameters and angles of the joints and the method of determining the P index points on the diagrams were explained. In the following, the diagrams of kinematic parameters and joint angles are reviewed and introduced. Using the P index points on the graphs, we compare the walking of the right foot of a person with cerebral palsy according to the mean values of standard deviation, and finally show the description of the results of the comparison. To do this, we first show the general form of the presence of different coordinates at hypothetical points.

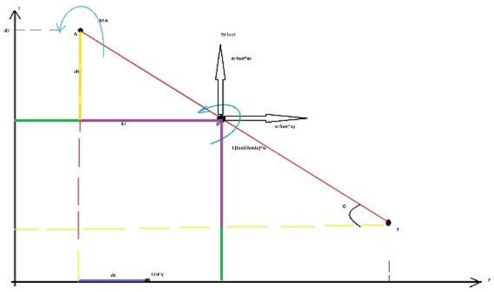

Figure5. Calculation of torque around the ANKLE axis

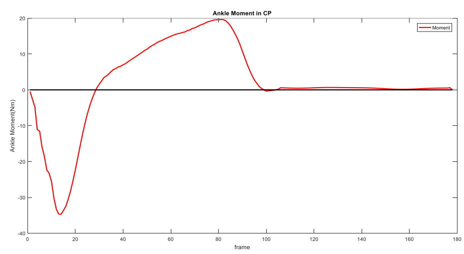

Figure6. Ankle Moment in cp

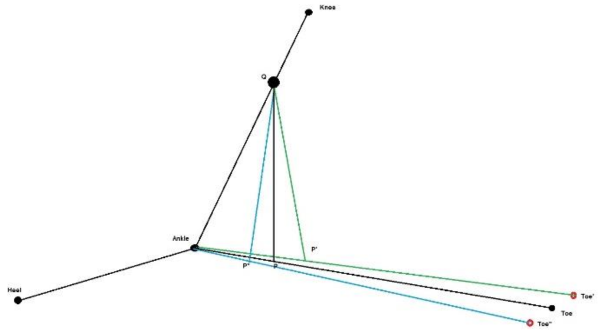


Figure7. Displays the P, Q coordinates and new coordinates in the Toe

## 3.Results

The results of comparing the angles obtained in the new tendon positions are as shown in Table 3:

Table 3. Comparison of angular points in displacement of the tibial tendon

| Title | Θ | Θ’ | Θ” |
|---|---|---|---|
| Frame 3 | 75.402058 | 79.46954 | 62.73844 |

Due to the change in the parameters of the new points, of course, new diagrams are obtained in the AT and torque diagrams around the ankle axis and acceleration diagrams, which will see below. You can also see the tendon transfer changes in Figures 11. Therefore, the preoperative surgeon can make a more appropriate decision for the new location of the tendon from the content in the program to optimize the surgery of the patient with cerebral palsy according to the parameters obtained from new points and modeling the movement of this person in MATLAB program.

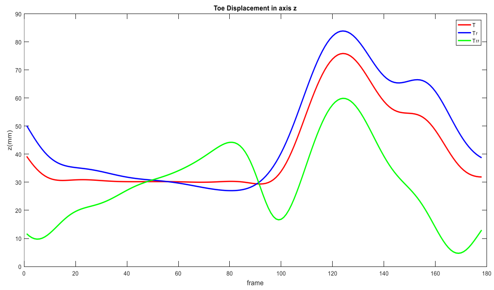


Figure 8. Coordinates T, T’, T” in the direction Z

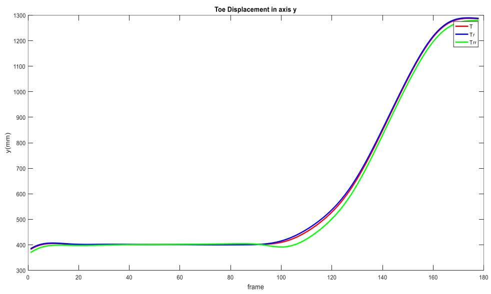


Figure9. Coordinates T, T’, T” in the direction Y

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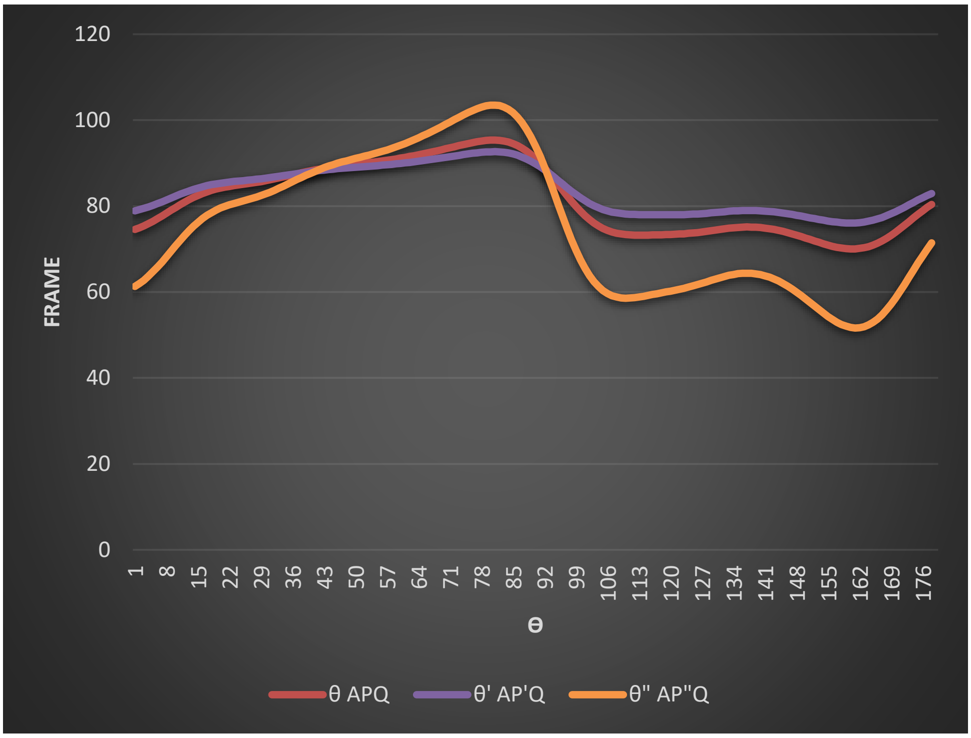


Figure 10. Show angles P, P ’, P”

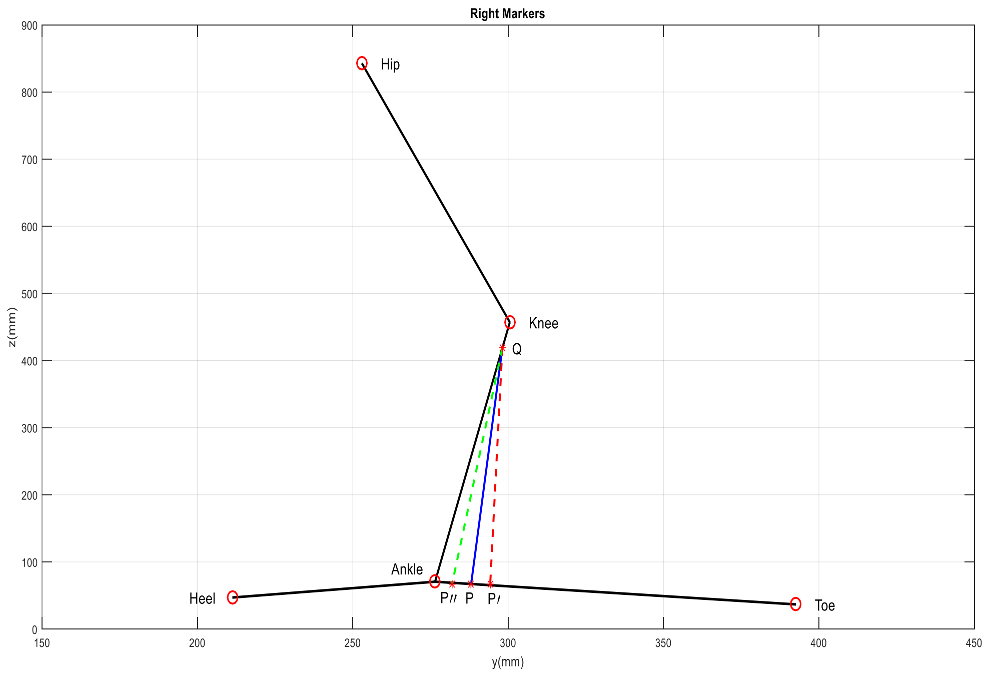


Figure 11.tendon location changes

## 4.Discussion

Due to the fact that the subject in this study is one person and can change the parameters with a high range due to the differences in people with cerebral palsy, so the subject of this study should be more people, but considering that in Calculations All formulas and positional calculations have been performed in Excel and MATLAB programs, so only by moving the basic data obtained from the motion analysis laboratory, all hypothetical points obtained from a suitable motion can be measured. In this way, by moving the hypothetical new points in the final data instead of the previous data, a suitable and new location of the tendon can be obtained. If these calculations are performed after the surgery, it can prove the correctness of this issue. If a similar test is performed with the help of an EMG device, it can help a lot in obtaining the definite points of the tendons.

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