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Adjustable Modular Spring Resistance Exercise Equipment For Lower Extremities

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Abstract

In sports traumatology, arthroscopic methods, which are the type of closed surgery, are applied in cases such as meniscus ruptures and anterior cruciate ligament injuries. In both types of surgery, it is important that the position and exercises of the lower extremities should be performed correctly in the postoperative period. Tools such as roll towels, pillows and sandbags are in solid form and can stretch to a limited extent during the movement of the leg. Especially in knee exercises, the pressure applied by the sub-knee towards the roll towel is met with resistance due to the structural form of the towel. In addition, the materials used can be lost during sleep or at the time of exercise because they cannot be fixed and can damage the surgical site by causing uncontrolled and unwanted movement of the leg. In this study an attempt to prevent problems that may occur during the position and exercise of the lower extremities after orthopedic surgery was taken. Developed modular spring resistance exercise equipment; resistance springs, lower extremity tables and the main body. Adjustable modular spring resistance fatigue analysis data were evaluated at various resistance values using the exercise equipment final element analysis method. Using the Ansys (v2018) package program, the system's tensile map values were drawn to identify critical areas of the design and the final form of modeling was given. Finally, it is targeted to perform the exercises that patients who have undergone orthopedic lower extremity surgery with modular spring resistance exercise equipment should perform in the postoperative period correctly and prevent errors that may develop due to the use of inappropriate materials.

Introduction:

Orthopedics is a medical science that works to treat musculoskeletal diseases and to ensure that the structures related to this system are carried out in a healthy way (Wiesel & Delahay, 2007). It has multiple subbranches including arthroplasty surgery, sports traumatology, hand surgery, arthroscopic surgery, oncology and pediatric orthopedics (Erdil & Elbas, 2012). Due to bone and joint diseases that develop with advancing age, loss of function of ligament and cartilage structures, there is limitation of movement and arthroplasty surgery is applied to restore function to the joint with reduced movement or lost mobility (Lee, 2016). Currently, knee and hip replacement operations are frequently performed in arthroplasty

surgery for the lower extremity (Price et al., 2018; Ferguson et al., 2018). On the other hand, arthroscopic methods which are a type of closed surgery are used in meniscus tears in sports traumatology (Günaydin, 2014; Oguz et al., 2004; Shiraev et al., 2012) and also anterior cruciate ligament injuries (Clark et al., 1998; Serbest et al., 2011; Schmieding, 2003). In both types of surgery, it is important to perform the position and exercises of the lower extremities in the postoperative period. After orthopedic surgeries performed on the lower extremities, materials such as rolled towels or pillows are placed under the knee and between the legs in order not to dislocate the prostheses and prevent contractures in the relevant joint (Eksioglu & Gürçay, 2013). Isometric exercises are suggested to the patient after knee

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surgeries in order to give the knee joint range of motion and increase muscle strength. During exercise, a rolled towel is placed under the knee and when the leg is extended, the lower part of the knee is asked to be pressed against the rolled towel (Bilik, 2017). After hip surgeries, in order to stabilize the prosthesis, the prosthetic leg must be kept in abduction in the lying position, while turning on the bed, sitting and exercising (Yaban & Karaöz, 2007). For this reason, a pillow is placed between the legs to prevent internal or external rotation of the leg after prosthetic surgeries and the outer part of the legs is supported with a sandbag (Basal & Duran, 2018). In the postoperative period, it is important to start the exercises effectively in the early period and to protect the operation area from traumatic movements in order to strengthen the muscles and joints and regain their former functionality (Akyüz, 2017). Materials such as rolled towels, pillows and sandbags are in solid form, so they can stretch to a limited extent during the movement of the leg. Especially in knee exercises, the pressure applied by the lower knee towards the rolled towel encounters resistance due to the structural form of the towel. In addition, since the materials used cannot be fixed, they can fall during sleep or during exercise, and cause uncontrolled and unwanted movement of the leg, causing damage to the operation area (Dauty *et al.*, 2007). On the other hand, contact of the support materials used with the floor outside the bed and the inability to disinfect due to workload creates a risk of infection for the patient with incomplete skin integrity due to surgical incision. At the same time, the size of the support materials occupies a lot of space in the bed and limits the movement area of the individual (Bandholm & Kehlet, 2012). For this reason, the patient and his relatives make an effort to control the materials and to be able to position them correctly. In addition to the current disease state of the patient, complications due to the use of unsuitable material result in late recovery and prolonged discharge (Akdağ & İzdes, 2018).

When the motion exercise mechanisms used today are examined, it is seen that spring resistance systems are common. These mechanically controlled systems are based on the force equivalent of the resistance coefficients of the springs and the displacement value of the spring. Force (F) = spring resistance coefficient (k) * displacement (ΔX = end spring length (X_1) - initial arc length (X_0)); It reveals the spring thrust force compressed according to the formula (ΔX sign -) or the extended spring (ΔX

Figure-1: Force-path diagram in arcs

sign +) pulling force. Spring resistance coefficients vary according to the elasticity modules and production methods of the materials they are manufactured (Fig.-1)

It is clear from the diagram above, the magnitude of the reaction forces occurring in the springs can be adjusted with the changes made in the lengths of the springs. In our study based on this principle and the aim is to design a mechanical exercise equipment with spring resistance mechanism that will increase the effectiveness of isometric exercises to be applied to shorten the recovery times of patients after lower extremity knee surgery.

Methodology:

Computer aided design (CAD) and analysis (CAA) programs were used in our study. The anatomical structure of the human knee region was designed using Solidworks (v2016) program (Fig.-2). Various constraints such as anthropometric values and joint area were taken into consideration in the design.

Figure-2: Human front, left side view and knee area detail drawing

In order to determine the boundary conditions of the designed spring resistance exercise equipment, it is necessary to transfer the anatomical constraints to the computer environment and to simulate these constraints (muscles, cartilage tissue, bone tissues, tendons, etc.) and their freedom of movement well defined. Here, 3D Organon Anatomy software was used (Fig.-3).

Figure-3: Knee region anatomical constraints (3D Organon, 2020)

The inner and outer sleeves in which the body components are bedded and the distance between the knees are adjusted in the CAD program. Distance adjustment pins are located between the outer surfaces of the inner and outer sleeves. The distance adjustment pins lock the system by adjusting the distance between the shells according to the width between the patient's knees (Fig.-4).

Figure-4: Modular spring resistance exercise equipment outer and inner sleeve.

Figure 5. The cross-section of the right and left shafts located in the bushings and within the resistance springs

Shafts in which the springs that provide resistance in horizontal exercise movements are guided are positioned on the shafts in the casings. Resistance springs on the shafts

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are replaceable and have different spring resistance coefficients according to the physical capacity of the patient. While the springs are limited by the inner support surfaces in the direction of the sleeve, the outer surfaces of the springs are fixed with the resistance adjustment nut. The spring length is adjusted by tightening and loosening the resistance adjustment nut (Fig.-5).

There is an elbow pin socket at the shaft ends to which the second spring-shaft mechanism is connected. A second shaft-spring mechanism mounted in this area is around the pin slot and can only make an upward angle of 90 degrees. With this structure, the patient can perform knee, upper leg and lower leg movements in a vertical direction (Fig.-6).

The critical regions of the mechanism were examined using the finite element method of modular spring resistance exercise equipment designed in the solid modeling program. In the finite element analysis, a force of 1200 N would applied to the plate area in the horizontal position. Stainless steel material (excluding spring components) is used in the system components. The finite element model is created under the effect of the applied force (Fig.-7). The number of elements of the system is 1 873 659 and the number of nodes is 2 893 087.

Fig.-6

Fig.-7

Fig.-8

Figure-6: Second shaft-spring mechanism and table assembly rotated 90 degrees

Figure-7: Finite element model of the system

Figure-8: Modular spring resistance exercise equipment assembly scheme

The final shape of the system was obtained by constructively redesigning the critical stress zones occurring in the connection areas of the system (Fig.-8).

Results and Discussion:

This study is intended to prevent problems that may occur during the position and exercise of the lower extremities after orthopedic surgery. For this purpose, adjustable modular spring resistance exercise equipment is designed for the lower extremities.

In order for the wounds that occur after joint surgery to heal quickly, it should not be immobilized. In this sense, when we examine the literature, a number of exercises are recommended to accelerate healing after surgical operations in order to ensure the mobility of the body joints and it is applied to people after surgery. However, various problems may occur due to the different materials used during these exercises (roll towels, pillows, sandbags, etc.). Especially in knee exercises, the pressure applied by the sub-knee towards the roll towel encounters more or less resistance due to the structural form of the towel. Because the materials used cannot be fixed, they can cause discomfort to people during sleep. At the time of exercise, such materials can slip and fall and cause uncontrolled and unwanted movement of the leg, damaging the surgical site. On the other hand, Continuous Passive Motion (CPM) is applied at the point of equipment that can replace such exercises or help with exercises (Sapling *et al.*, 2017). CPM is a method that can be applied in the first stage of rehabilitation after soft tissue surgery or trauma. It is especially used after joint surgery. The device that makes the application is called CPM. This process reduces inflammation and pain. Devices increase the rate of recovery because they passively move to the joints in a particular order. It is applied to patients who have undergone operations such as knee, wrist, ankle, shoulder or hip surgery with the recommendation of a physician. Parameters such as the speed and angle of the device are determined by the physician. It can be categorized as a physical therapy and rehabilitation device (Concise, 2020).

The CPM device is specifically designed to improve the joint openness of individuals after surgical surgeries. In this sense, adjustable modular spring resistance for lower extremities differs from exercise equipment. Because adjustable modular spring resistance exercise equipment for lower extremities is an equipment designed to increase and improve the muscle strength of individuals after surgical operations.

The system is a mechanical system that can be used in lower extremity surgical operations and knee area exercises with its basic components. According to the finite element method, the safety coefficient of the system against fatigue in 1200 N bearing and vertical axes to be applied to the mechanism is 2.7 and 2.1, respectively (Safety Coefficient > 1; system safe). The system, which consists of 20 subcomponents, has a modular structure and the resistance values applied according to the variable spring mechanism can be changed.

Conclusion:

The designed modular spring resistance exercise equipment includes seven basic parts and sub-components that can be adjusted according to the lower extremities. With the design, it will be ensured that the patient's muscle strength is strengthened by providing the individual with ease of movement by properly fixing the extremities in the lying position and during exercise and adapting the support materials to the patient in terms of structure and size. In addition, problems that may occur will be solved by preventing complications that may occur in the extremities due to the loss of support materials used. The final prototype studies of modular spring resistance exercise equipment are the next step of the research subject and the field studies of the obtained prototype should be developed by comparing the data obtained in the computer environment by reporting the user experiences.

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