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Full Length Article

Determination of contact position of fractured bones and the applied force in external fixator applications

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A B S T R A C T

In this article, we propose a new method for the estimation of the force, which is applied by two fractured parts of the bone on each other at the time of contact, while they are brought closer to each other, and the distance between these two bones.

The manual alignment operations being applied today in the alignment of fractured bones does not become successful as desired each time. The two fundamental reasons for this is the insufficiency of the force applied by the health personnel for stretching the muscles of the patient under anesthesia and the impossibility of keeping the applied force fixed for the desired period even if their force suffices. Furthermore, the small amounts of linear and rotation operations needed during alignment are very difficult. In this case, the alignment operation is performed not as it should be but as much as it can be performed. Another negative aspect of manual bone alignment is the great amount of exposure to radiation both for the patient and the health personnel since X-ray images are needed to see the new situation.

In this study, a new method is proposed for estimating the force applied by two fractured parts of the bone while they are brought closed to each other, and the distance between those two bones. With the new method that we propose, the distance between the bones and the pressure applied by them on each other are measured in the operations of alignment of fractured bones and this information is provided to the physician. Thanks to this method, the probability of applying a force on the bones in excess of the desired force is canceled out.

At the beginning of the operation, the stretching property of the muscles of the broken limb of the patient, who is under anesthesia, is learnt and in the continuation of the same process, the moment when the bones start touching each other and the force applied by them on each other are determined by using loadcells and encoders. Consequently, a method that aligns the fractured bones being independent from personal properties of the patient such as gender and age has been developed.

1. Introduction

In the therapy of fractured bones one of the popular methods used for keeping the fractured bones fixed is the use of an external fixator. Aalsma et al. used external fixator in their studies [2]. Wu et al. used external fixator to examine the behavior of fracture ends [3]. Sakai et al. used external fixator in their study on follow up of fracture healing using an ultrasound [4]. Lesniewska et al. used external fixator to examine the load distribution of the fractures in various sizes and at various distances in external fixator [5].

Bringing the fractured parts to the desired position is a problem that was tried to be solved. There are various methods and applications for this purpose. Although primitive applications performed with hand force are still very popular, there are also some robotic applications. Fu et al. constructed a robot – assisted system for fixing factures using an in-bone nail [6]. Kong et al. installed a robotic imaging system in order to understand the position of fracture ends [7]. Douke et al. applied the tension necessary to place the fracture with the help of a robot [8]. While keeping one of the bones fixed, the other one is made coherent with it being moved linear and/or rotate. The problem that we are interested in is the determination of the pressure applied by the bones on each other and the distance of them to each other after the bones are brought to the desired directions in external fixator applications.

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In this study, a robot that is capable of performing 3 linear and 3 rotate movements to bring the fractured parts to the necessary positions (6 degree of freedom) is developed. The robot that is operable with a remote control moves the bone that is far from the body by using the nails driven in the bones. The command is given to the robot through remote control. The positions of the bones are followed up being displayed using a C-Arm X-ray device. By this way, the health personnel does not have to be next to the patient during operation. Thus, the radiation amount for the health personnel is canceled out. A saving of time and manpower will be ensured thanks to the robot and the radiation amount applied on the patient will be reduced to a great extent. Furthermore, it will be possible to perform a very accurate positioning [1]. The application of the developed robot on the mannequin patient is shown in Fig. 1.

The distance between two fractured parts in excess of the needed distance is not a desired situation in terms of therapy and the excess amount of pressure applied by them on each other is not a desired situation as well. Excessive distance can delay healing and even make it impossible. The pressure that will occur in case of bringing the bones too close to each other can delay healing or can even result in fracture of the bone. Isaksson et al. researched the important role played by mechanical stimulations on bone healing [9]. Sigurdsen et al. examined the clinical results of the stimulations at the fracture ends [10]. The adjustment of the pressure and distance between two fractured parts is important in the therapy process and is a problem requiring solution.

The distance between two fractured bones can be displayed using an X-ray device. However, it will not always have the desired accuracy. It may even be impossible to obtain a good image in accordance with the fracture shape of the bone and imaging angle. Furthermore, the efforts for accurately adjusting the distance mean the use of more radiation.

Both for the complete and reliable alignment of the fractured bones and for saving the patient and health personnel from the problem of radiation exposure, a new external fixator application, the details of which are given in this study, is performed. This method is based on teaching the stretching forces of muscles to the system. Using loadcells and encoders, it is measured in which position and with what force the muscles are stretched. When the fractured bones start touching each other the force that we will read from the loadcells will change in accordance with the position. The difference between those forces is the force applied by the bones on each other. Thanks to this operation, the excessive pressure applied by the bones on each other as well as the excessive distance between them can be prevented.

There are robotic systems that measure the force and/or position related with the fractures. Zuniga et al. followed up the healing of the fracture by measuring the force applied by the fractured bones on each other and the load applied on the external fixator [11]. Wu et al. examined the distance between the fractured bones that are fixed by using an external fixator [3]. Wee et al. monitorized the change in force of the external fixator during stretching of the fractured bones [12]. Our method is a new study on the determination of the force applied by fractured bones on each other and the distance between those bones in external fixator applications.

Fig. 1. Application of robot on mannequin patient.

Hill proposed a three- member muscle model [13]. The use of this modeling method is very popular. The muscle is stimulated and various studies are performed on its movement, fatigue, etc. behaviors. Winters constructed the muscle model especially on multi-joint taking into consideration the behaviors of muscles [14]. Huijing showed that factors such as fatigue played roles in the reaction of muscles [15]. Martins et al. created a digital model for the active and passive behaviors of muscles [16]. Carol et al. studied on Hill Type model and the behavior of muscles according to this model [17].

In the alignment of bones using the robot the self movement of the muscle or its movement through stimulation are not necessary. External force is applied for aligning the bones. Therefore, the muscles are never active. What stands against external force is the passive properties of the muscles such as soft tissue and tendons. This is the part that we are interested in our calculations. Because, the patient will be under anesthesia and therefore will not be able to perform voluntary muscle movements.

McGinnis PM. showed active and passive forces and their resultant force in his study [18]. Their study describes the force relation in accordance with the amount of elongation of active and passive members. It is observed that the members causing the passive forces are linear up to 160% of their own lengths.

Wang in his study, gives the relationship between force and displacement in the application of fracture bone of a leg [19]. Here, it is seen that the data used in the simulation of the relation between the force and the distance is approximately linear; the graphic that is given experimentally is approximately linear if it is divided into two parts.

Many people used the mass spring system to model the muscles. In the modeling of the muscle surface the use of mass spring system is very popular [20].

For modeling and simulation of surface expressions, mass-spring system has a popular use. Zhang et al. used the mass- spring system in modeling the face muscles for the real-time simulation of face expressions [21]. In the study performed by Silva and Tabouillot on electromechanical models and working frequencies of muscles for robotic studies, the electromechanical model is established on the basis of mass- spring principle [22].

Hussain et al. performed studies on the changes in lengths of passive muscles in accordance with the torque applied on those muscles [23].

As can be seen, the use of mass –spring principle in muscle modeling is very popular in the literature. When the studies related with the muscles are examined, it is seen that the behavior of passive members of muscles are not exactly as a linear spring, but they exhibit a behavior that is close to it [17,18,23,24].

2. Material and method

In our experiments, assuming that the muscle will behave similar to a spring, a spring is used for modeling. Since the modeling is prepared with a spring, the force acting on the spring will be as,

$$F = k\,x \quad (1)$$

F: Force (N),
k: spring constant (N/m),
x: distance the spring is stretched or compressed away from its rest position (m)