A simulation model of FES for the treatment of shoulder subluxation

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Abstract

Purpose: To design a musculo-skeletal dynamic model for hemiplegic shoulder subluxation with which can perform FES effectively as well as the simulation of shoulder motion by FES on this dynamic model.

Method: The skeletal model was designed from the computed tomography (CT) data of an embalmed cadaveric shoulder. The muscle dynamics model was designed according to Hase’s model. The physical properties of muscles, which can be used to design the dynamics model, were obtained from the cadaver. We installed the muscle model into the skeletal model and controlled the musculo-skeletal model by using the numerical analysis software “MATLAB”.

Result: The shoulder subluxation was reduced on this model as a result of simulation.

Conclusion: We designed a musculo-skeletal model that can be used to simulate the role of FES.

1 Introduction

It was reported that shoulder pain was one of the most frequent complaints of hemiplegic patients after the stroke, with a prevalence of 34-84%, and that shoulder subluxation was recognized in 81% of the patients who suffered from shoulder pain [1]. Recently, functional electrical stimulation (FES) has been applied for the treatment of the shoulder subluxation [2].

The purpose of this study is to design a musculo-skeletal dynamic model for hemiplegic shoulder subluxation with which can perform FES effectively as well as the simulation of shoulder motion by FES.

2 Methods

2.1 Design of skeletal model

First, an embalmed cadaver was scanned with CT. After obtaining the CT data, we made three-dimensional model of scapula, humerus, and clavicle by using 3D design software “MIMICS” (Figure 1).

![Three-dimensional model of scapula, humerus, and clavicle by using “MIMICS”](image)

2.2 Design of muscle dynamics model

We designed muscle dynamics model, according to Hase’s [3] (Figure 2). This model demonstrates the dynamic characteristic of muscles in numerical formulas. It consists of a contractile element which can generate muscle tonus optionally, and three elastic elements: series elastic element, parallel elastic element, and tendon which can generate tonus passively.

When we input muscle activation “q” into contractile element, muscle tonus is generated. The muscle tonus changes muscle length and
contraction velocity, and this changes automatically feeds back to the model. Thereby new muscle tonus is generated again. Analysis numerical software “MATLAB” was used this control system. The muscle activation “q” set up to zero to one, in which zero means no contraction and one means maximum contraction.

**Figure 2:** Muscle dynamics model which was designed by Hase. It consists of a contractile element and three elastic elements: series elastic element, parallel elastic element, and tendon.

Contractile and three elastic elements have the physical properties which are different from muscle to muscle. In this study, we measured it according to the data obtained from the embalmed cadaver about deltoideus, coracobrachialis, subscapularis, supraspinatus, infraspinatus, teres minor, and teres major.

We made another muscle model by 3D analysis software “Visual Nastran”, which had the characteristics of the muscle dynamics model made by MATLAB. It can be install into the skeletal model. This muscle model consists of the actuator, which the muscle tonus is transmitted to, the strings, which cannot expand or contract and connect the origin with insertion, and the globules which express muscle curve and thickness (Figure 3). Because muscle tonus is transmitted to the actuator, thus this model can move.

**Figure 3:** Muscle model on Visual Nastran, which consists of the actuator, the strings and globules.

### 2.3 Control of musculo-skeletal model

When we input a muscle activation into the muscle model on MATLAB, a muscle tonus is generated. The muscle tonus is transmitted to the musculo-skeletal model on Visual Nastran. And, motion of the skeletal model occurs with contraction of the muscle model. The activation of musculo-skeletal model not only changes the length and contraction velocity of stimulated muscle, but also changes those of non-stimulated muscles. The changes feed back to the model on MATLAB, and new tonuses are generated (Figure 4). We control the musculo-skeletal model by turning this circuit.

**Figure 4:** The dynamic musculo-skeletal model was controlled by turning this circuit.

### 3 Results

We installed the muscle models into the skeletal model. In this model, scapula and clavicle are fixed, and only gleno-humeral joint can move.

We set up muscle activation with 0.5, and stimulate deltoideus and supraspinatus. As a result of simulation, we can confirm the reduction of shoulder subluxation.

### 4 Discussion

Clinically, the shoulder subluxation was frequently treated by means of stimulating the deltoideus and the supraspinatus, and yield good results [4]. Therefore, we also stimulated the deltoideus and the supraspinatus in our model, with which we were able to confirm the reduction of subluxation. This proves the availability and effectiveness of FES from the model side. Furthermore, using this model, we can do simulation of other muscles.

The shoulder forms shoulder complex consisting of three anatomical joints (gleno-humeral joint, acromio-clavicular joint, and sterno-clavicular joint) and one functional joint, called scapulo-thoracic articulation. In this study, we fixed scapula and clavicle, and simulated only gleno-humeral motion.
Actually, Scapulo-humeral rhythm means glenohumeral-scapulothoracic motion at a 2:1 ratio in arm elevation [5]. This shows other joints also participate for shoulder motion. Thus, if we connect this model to thoracic skeletal model with the muscles, we are able to do the simulation of whole shoulder complex. Now, making this shoulder complex model are on the way.

5 Conclusion

We designed a musculo-skeletal dynamic model which can be used to simulate the role of FES.

References


