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4D analysis of muscular dynamics using flexible 3D muscle models

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Abstract

We attempted to develop a system to visualize muscle dynamics with virtual muscle systems using quantitative 4D imaging. In the system, the skeletal and muscular model was reconstructed from MRI 3D data sets. The muscular models are composed of elements of muscle bundles. Each element is able to contract or relax while avoiding the bone or adjacent muscle bundles accounting for physical interference. In this system, it is possible to record and visualize the dynamics of each muscle and their relative interactions in space and time sequential domains.

1. Preface

The mutual interaction of muscles engaged in exercise is one of the most difficult images to visualize. Normally those interactions are only assessed by movements under the skin surface. We also apply electromyography to monitor muscle activity. However the data is one dimensional (1D) information which is unable to recognize the spatial activities of each muscles on a x,y,z axis. It is commonly held that that system which is able to analyze the mutual interaction of muscle groups both physiologically and clinically doesn't presently exist. We hoped to develop a system to visualize those muscle dynamics with quantitative 4D imaging. In our system, skeletal systems and muscle systems can be reconstructed from 3D data sets obtained from a subject by MRI. Each skeletal articular is able to move using the location data obtained by a motion capture system in 4D space. In the case of muscle models, the shape and size of each muscle is obtained from a 3D dataset. The skeletal and muscular models are manipulated according to the forementioned data. During this manipulation, the user can quantitatively record and visualize the dynamics of each muscle and their relative interaction in space and time sequential. This system will become a tool to analyze muscle dynamics anatomically and physiologically in 4D space.

2. Method

2.1 Muscle model formation

We aimed to create a human muscle model in a virtual space which act like real muscle tissue and we also wanted to manipulate a virtual human which possesses an entire body muscle structure. Simple 3D reconstruction of muscle structure using 3D data set of the MRI makes it possible to show the morphology of the muscle but it is still impossible to know its function. We need to create a muscle model which contracts and extends like a real muscle. The best way to create this kind of model is to construct the muscle model by combining muscle fibers. Muscle tissue is a component of muscle fibers and the direction and combination of muscle fibers determines the physical muscle's function. Each muscle was divided into a few groups according to different muscle fiber components. They are roughly divided into fusiform muscle, bipennate muscle and unipennate muscle according to the direction of muscle fiber components which show different characteristics of muscle functions. The best way to construct the virtual muscle model is to use the components of muscle fibers. However, one muscle is made by a few million muscle fibers and it is impossible to create a muscle model of a whole body in the virtual space using present computers. We decided to make a muscle model as a component of muscle bundles. In the real muscle tissue, the muscle fibers are gathered to a muscle bundle and the direction of the muscle bundle is almost same of that of muscle fibers. Each muscle is formed of 10 to 20 muscle bundles. First we made a virtual muscle bundle with some added features to incorporate a 3D model. Thus, muscle bundles are able to contract or relax as if exercising. At first, during contraction and relaxation the volume of the muscle bundles are kept stable in the system. With this feature of the model, the final muscle shape reflects the authentic shape and it is possible to perform a physiological analysis. Second, these muscle bundle models are able to contract and relax by counting for the physical interference with the bone or adjacent muscle bundles. These components of virtual muscle bundles are made into a 3D structure by matching the shape and volume to the reconstructed 3D muscle image of the subject. Fig.1 shows the fusiform muscle models and the direction of muscle bundles can be seen on the surface of the muscle model.

Fig.2 shows the biceps muscle model and Fig.3 shows the unipennate muscle model. Finally, each muscle is consecutively attached to the skeletal system according to its anatomical position.

2.2 Skeletal model formation

In the first step, we used CT and MRI to obtain the 3D data set of skeletal and muscular structures respectively. However it was very difficult to obtain two data sets from two modalities in the same condition. We decided to obtain both skeletal and muscular structures from a single 3D, MRI data set of by choosing the scanning condition. The entire body structure was measured by 4mm pitch 4mm slices using Spin Echo with 58 cm Field of view (FOV). The entire body was recorded in sequential sectioning planes from 400 to 450 axial slices. Generalized 3D information on skeletal structures and each muscle structure was read from this data set. The 3D skeletal model without the articular part was reconstructed with this data set. The muscular region on the MRI dataset was separated and each muscle was reconstructed into 3D image. Muscle size and volume could be adjusted as previously mentioned.

Then, we measured the principal articular structure with 1mm pitch 1mm slices using Spin Echo with 15 to 20 cm FOV to get the detailed 3D structure of the inner condition of each articular. We used small FOV with surface coils for scanning each articular to obtain their detailed

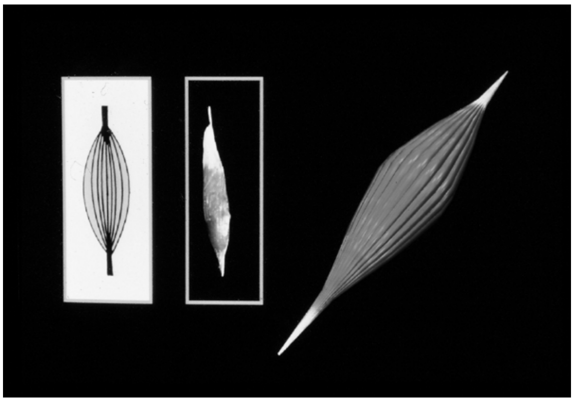

Fig.1 Model formation of the fusiform muscle. The left side is the direction of the muscle bandle in the fusiform muscle. The central part of the image is the muscle specimen while the right side is the muscle model composed of muscle bundle models.

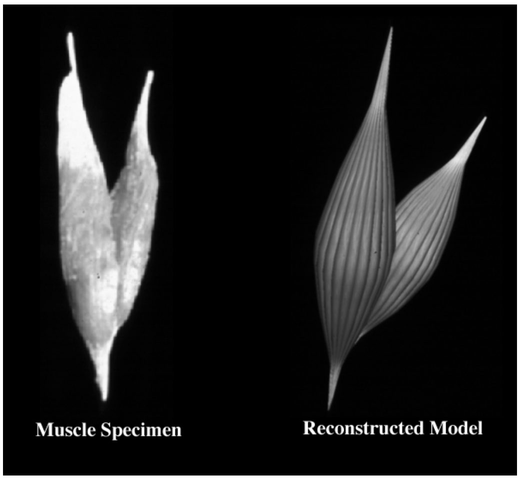

Fig.2 Model formation of a biceps. Muscle specimen (right side), Biceps model (left side)

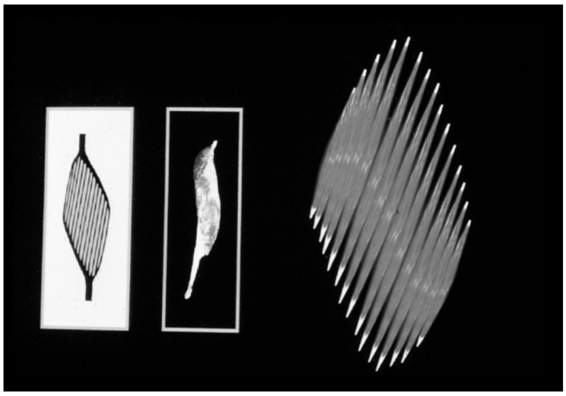

Fig.3 Model formation of the unipennate muscle. The direction of the muscle bundle contained in the muscle (left side). The muscle specimen (central part of the image) and the muscle composed of muscle bundle models (right side).

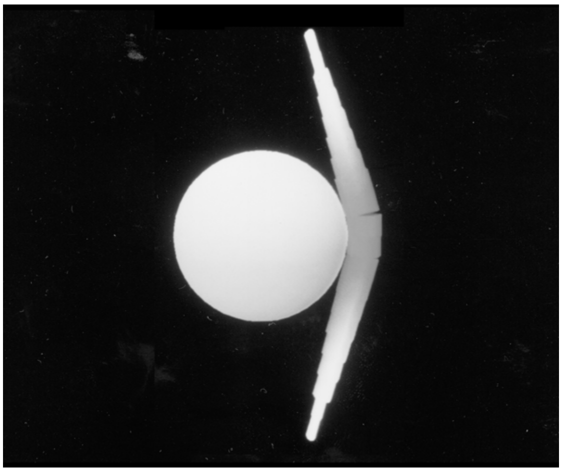

Fig.4 To create actual muscle actions the muscle bundle model can contract while accounting for physical interference with sphere.

structures. As a result, principal articulars such as articulatio humeri or articulatio cubiti etc. were recorded in sequential sectioning planes from 1200 to 1600 slices. 3D models of each articular were reconstructed and merged spatial according to their anatomical features.

2.3 Comprehensive model reconstruction

The size and volume of each muscle model is adjusted according to the reconstructed 3D muscle model which was attached to the skeletal models. Points of connection between muscles and bones are determined according to the sectioning plane of MRI images. We used the graphic work station, an Onyx reality engine 2 (SGI Co.,USA) and an Octane (SGI Co.,USA) for construction and manipulation of the skeletal and muscular models.

2.4 Movement measurement

We used two methods to capture the motion of the subject. The first employed a video camera for image recording while the second employed a position/orientation measuring device, Fastrak (Polhemus Co., USA).

The video camera recording was performed from two directions or stereo pairs to obtain the spatial movement of the upper limb. We used 4 polhemus sensors to capture the motion of the upper limb. The sensors were fixed by bands and surgical tape to the surface of the upper limb.

3. Results

In this section, we would like to focus on the results of the skeletal and muscle model construction for the upper limbs. Fig.4 shows the performance of a single muscle bundle

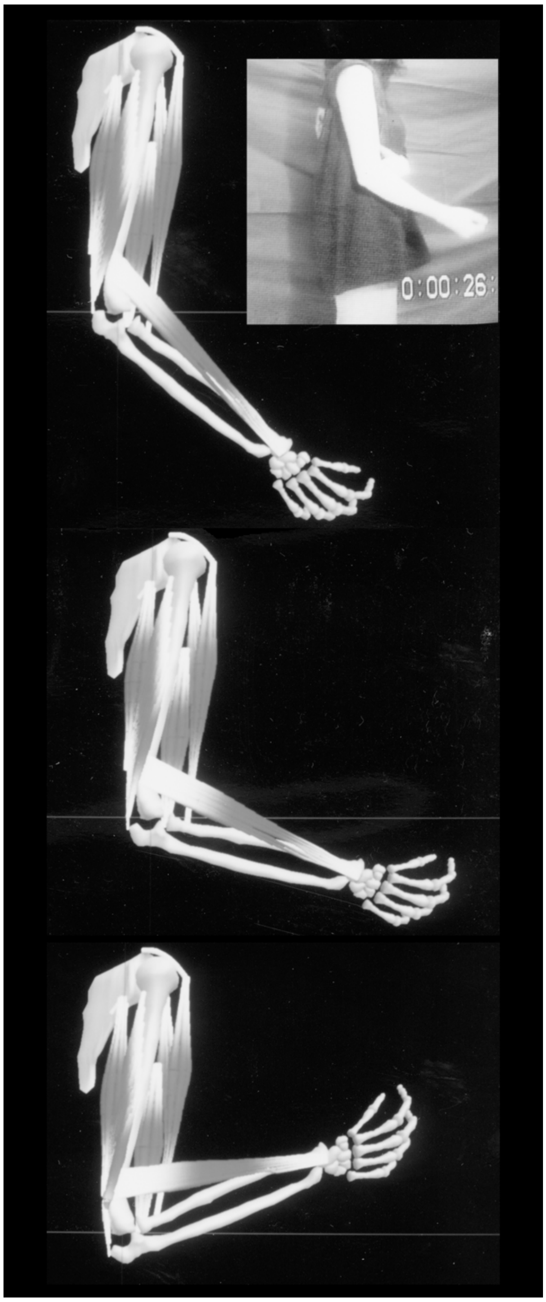

Fig.5 The skeletal and muscular model of the upper limb on the right side. Four principal flexor muscles and four extensive muscles are attached to the skeletal system. The limb model is manipulated into bending and stretching through motions recorded in the data.

model. In the image, the muscle bundle model shows that it is able to contract to account for the physical interference with a sphere. In this way the muscle model which is the component of a muscle bundle is able to contract and relax when in contact with adjacent bones and other muscle models. Fig.5 shows the right upper limb's model . The model includes scapula as well as all the wrist bones.

The bicepsbranchii in the model is composed of 40 muscle bundles. Four principal flexor muscles and four extensive

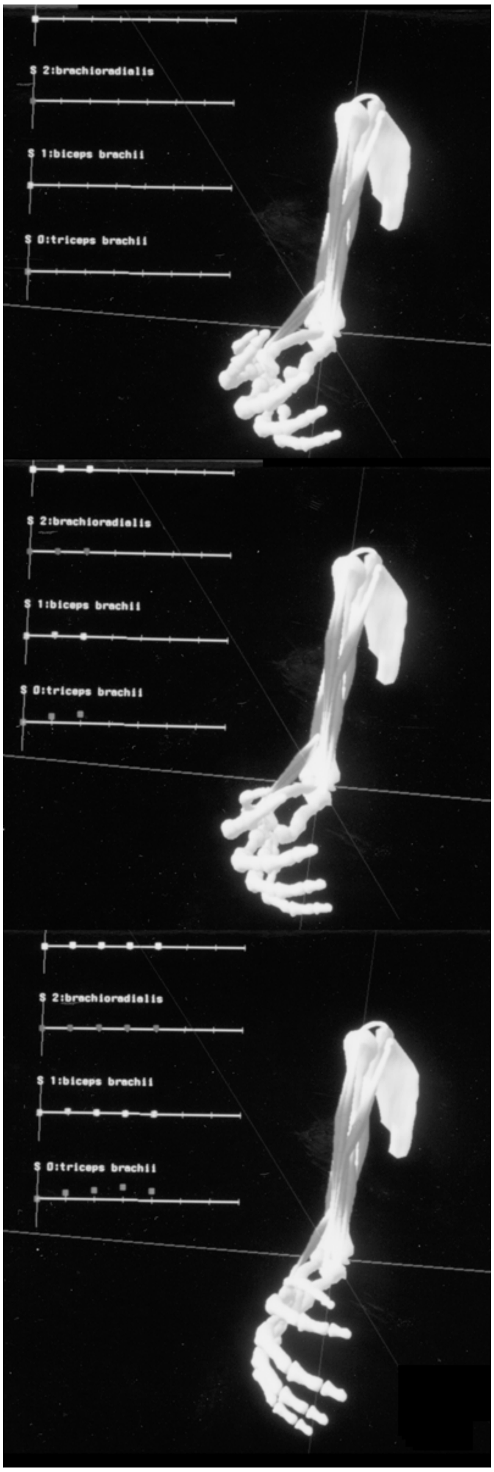

Fig.6 The model was manipulated to do pronation. Time sequential graphs at the upper left of the image show muscle reactions.

muscles are attached to the skeletal system. In the image, the limb model is manipulated into bending and stretching. In Fig.6, the model was manipulated to do pronation. The muscular reactions to the pronation were monitored by the time sequential graphs in the upper left part of the image. Muscular force and area sectioning could be observed.

4. Conclusion

We have constructed a 4D skeletal and muscular model system which is able to analyze and visualize muscular functions in a virtual space. In the system the 4D model can be customized for a particular patient by referring to the patient's 3D dataset and the motions captured in time sequential data. As a clinical application, it will be possible to diagnose the muscle injuries objectively and quantitatively in a 4D domain. For example, it will be possible to determine the consequences of partial muscle damage to overall mobility. It will be also possible to simulate the reinforce element of particular muscles to estimate the results of rehabilitation. As a physiological application, this system will help analyze the basic function and interdependance of each muscle. It will be also useful estimate training results for various kind of sports. At present muscle models can not be manipulated in real time with our system. In fact, it takes 20 seconds to create a one second motion of the upper limb. Therefore, we need a image animation technique to observe the movement of the image. In the near future, we are going to operate these muscle models in real time by improving the software and the model structure. In addition, we are going to construct skeletal and muscular model for the entire body in order ot observe walking movements and other physical activity.

References

[1] N. Suzuki, A. Takatsu, A. Hattori, T. Ezumi, S. Oda, T. Yanai, H. Tominaga: "3D and 4D atlas system of living human body structure", MMVR6, Eds: J. Westwood, H. Hoffman, D. Stredney, S Weghorst, IOS Press and Ohmsha, pp.131-136, 1998.

[2] N. Suzuki, A. Hattori, K. Yamasaki, A. Uchiyama, A. Takatsu: "4D analysis of muscular dynamics using flexible 3D muscle models", MMVR7, Eds: J. Westwood, H. Hoffman, D. Stredney, S Weghorst, IOS Press and Ohmsha, pp.131-136, 1999.