# A Musculotendon Model for Supporting Design and Analysis of Tendon Transfers in the Hand

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## ABSTRACT

This work has been directed at studying and developing a prototype Computer Aided Design (CAD) tool to be used for planning tendon paths in hand reconstructive surgery. The application of CAD to rehabilitative surgery of the hand is a new field of endeavor. There are currently no existing systems designed to assist the orthopedic surgeon in planning these complex procedures. Additionally, orthopedic surgeons are not trained in mechanics, kinematics, math modeling, or the use of computers. It was also our intent to study the mechanisms and the efficacy of the application of CAD techniques to this important aspect of hand surgery.

The following advances are reported here:

- Interactive 3D tendon path definition tools.
- Software to calculate tendon excursion from an arbitrary tendon path crossing any number of joints.
- A model to interactively compute and display the forces in muscle and tendon.
- A workstation environment to help surgeons evaluate the consequences of a simulated tendon transfer operation when a tendon is lengthened, rerouted, or reattached in a new location.

It also has been one of the primary concerns in this work that an interactive graphical surgical workstation must present a natural, user-friendly environment to the orthopedic surgeon user. The surgical workstation must ultimately aid the surgeon in helping his patient or in doing his work more efficiently or more reliably.

## I. INTRODUCTION

The tendon transmits a force to the structure that is generated by the muscle which in turn has been activated by the central nervous system (CNS). Patients with nerve damage due to a disease such as Hansen's Disease or an accident in daily life suffer from the lack of muscle force and the strength and balance of torques produced about joints.

Such a patient may regain the most elementary basic functions of the musculotendon through a tendon transfer operation. From time to time, however, the patient may become an unfortunate victim of an unsuccessful tendon transfer operation which could have been prevented if a surgeon had some mechanism to assess the efficacy of a procedure. This deficiency is exacerbated by the general lack of understanding of biomechanics and kinematics. This knowledge is certainly not a normal component of the academic training of surgeons.

It is true that, until now, most of the tendon transfer operations are performed by surgeons on the basis of experience and intuition gained through years of practice. With the help of an interactive graphical system programmed with the laws of mechanics, the less-experienced surgeon may use a computer model to plan and evaluate the best operation for their patients' hands.

## Ⅱ. RESEARCH ENVIRONMENT

As a hardware tool for this work, a 3D supergraphics workstation was used. Our system was capable of transforming and displaying 600,000 3D short vectors per second, and providing powerful integer and floating point performance, 20-25 MIPS and 40 MFLOPS respectively.

As software tools, the Application Visualization System (AVS) LUI, an X-Window system toolkit, and the Programmer's Hierarchical Interactive Graphics System (PHIGS), a 3D graphic standard, were used in this work as the interaction toolset for graphical model building and manipulation (Shuey *et al.*, 1986). This use of a standard graphical interface was chosen to permit using the software on other machines.

## Ⅲ. GRAPHICAL SIMULATION

Figures 4-7 show the graphical simulation of tendon path planning. Figure 4 shows two 3D displays of the hand in orthogonal viewing directions, along with a selection menu panel, virtual dials for manipulation of objects on the screen, and two orthogonal cursors that move in the $xy$ plane and $yz$ plane, respectively. Figure 5 shows the procedure of selecting tendon path points that will be connected with either a straight line or a curve to form a tendon path. A group of virtual dials indicates the values of the current rotation, translation, and scaling parameters. A small window at the bottom of the screen monitors and stores the coordinates of each tendon path point, the values of all joint axes and physiologically meaningful parameters that are generated from the graphical simulation.

Figure 6 shows an initial tendon path with the hand in the resting position. As shown in Figure 7, the initial tendon path changes dynamically and graphically as the joints of a finger are rotated by the user. The normalized force-length diagram of muscle and the stress-strain diagram of tendon are shown in small windows, along with slider bars for dynamic change of the parameters of the diagrams. Also shown is the muscle parameter editor for dynamic entry of the muscle parameters.

## IV. RESULTS

The experimental data provided by Brand (1985) were compared with the results of the simulation. Those data are:

- □ the moment arm for flexion of the FDP at the metacarpophalangeal (MP) joint of the middle finger with the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints in extension,
- □ the moment arm for flexion of the FDP at the PIP joint of the middle finger with the MP joint in extension, and
- □ the moment arm for flexion of the FDP at the DIP joint of the index finger with the MP and PIP joints in extension.

As shown in Figures 8 and 9, for the moment arm of the FDP at the MP and PIP joints of the middle finger, the experimental data and the simulation results are close. The quantitative accuracy of the simulation model is within 5% of actual tendon data. For the FDP at the DIP joint of the index finger as shown in Figure 10, the model predicts the moment arm 10% of the value derived from the experimental data. In addition, for each case the qualitative behavior is acceptable. The quantitative errors can significantly be reduced by placing the tendon path points based on anatomical data. The tendon excursions obtained from the simulation were not compared with experimental data at this writing. No statistical analysis was attempted because the workstation (theoretical) results were being compared to an average of several cadaver hand specimens.

A 1 kg load was placed in the plane of the FDP of the index finger at $60^o$ to the distal phalanx resulting in a joint torque of 1 kg-cm. A 0.5 cm moment arm was used based on the data of Brand (1985) and of this study (Figure 10). A moment balance resulted in a tendon force of 2 kg. A maximal isometric force potential of 13.5 kg was used (Table II, Brand (1981)) which yielded a normalized muscle force of 0.148. The muscle's central nervous system activation, $\xi$, was varied until this force was reached. This produced an estimate of $\xi = 0.234$. The data log for this operating point is shown in Table 1. The computed tendon and muscle lengths, forces, and strains from this model are also included in this table.

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