

THE INTERACTION OF MUSCULAR AND PASSIVE ELASTIC FORCES DURING UNLOADED
FINGER MOVEMENTS: A COMPUTER GRAPHICS MODEL.

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1. INTRODUCTION

The function of the hand has received much attention in the surgical and anatomical literature from the earliest anatomists until the present day. The hand, as a mechanical structure, exhibits a high degree of complexity which has tended to lead to descriptive studies of small functional components such as the lumbrical (1). The quantitative literature on the biomechanics of the hand, although relatively more recent, tends to exhibit the same characteristics. Although one needs to analyse and quantitatively describe each component of a complex system, the interaction of the component parts should not be overlooked.

The hand is interesting in that the passive elastic properties of the muscles and other soft tissues surrounding a joint can often be considered second order effects in many human activities. This is not true when considering the positioning of the fingers, especially when the hand is subject to nerve paralysis, soft tissue contracture or joint destruction. This paper presents a model that demonstrates the interaction of many complex structures during finger movement as well as the dramatic importance of the passive elasticities. The model has a dual purpose; as a pedagogical vehicle and as a means of distinguishing the structures of a major functional importance in unloaded finger motion.

2. MODEL

A planar four segment model of the index finger was implemented as a deterministic mathematical model on an IBM PC microcomputer. Although such a model has appeared in the literature before (2) the present model differs in that it incorporates experimentally determined passive muscle elasticities and joint stiffnesses as well as incorporating considerably more detail on the many ligamentous connections of finger, such as the sagittal and lateral bands, the oblique retinacular ligament and the

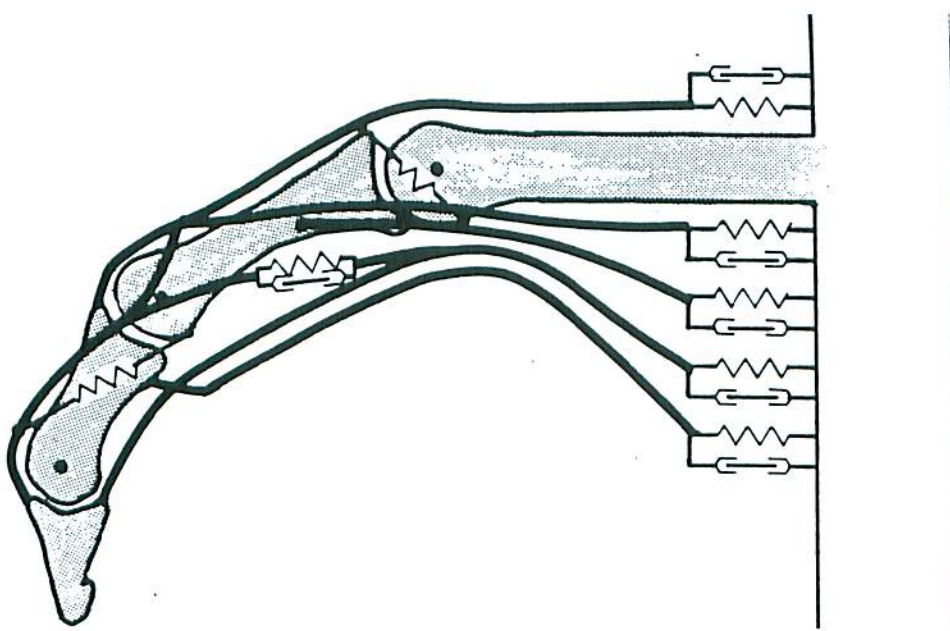


FIGURE 1. Model of the index finger

interosseous hood. Six muscles; flexor profundus and superficialis, extensor communis, lumbricalis, and the palmar and dorsal interossei are represented in the model. FIG. 1 shows the model used (the names of the structures modelled can be found in FIG. 2C). The input parameters of the model were taken from a number of sources. Moment arm lengths were taken from (3). Physiological cross-sectional areas of the extrinsic and intrinsic muscles were taken from (4). The passive muscle elasticities were determined on four fresh cadaver forearm and hand specimens within five hours of death (5). Static force/length curves for the six muscles above were produced for the musculature of the right index finger.

The model operates by entering the contraction level of the six muscles. These, as a first approximation, were obtained from EMG studies of unloaded finger movement (6). These values were expressed as a percentage of a maximum contraction (which was modified by muscle length). The model performs a quasi-static forward solution by iterating to find a position with zero net moment at each joint, taking into account all forces both active and passive. This is the equilibrium position of the finger. The program runs in compiled BASIC and includes a menu driven input and graphical and tabular output.

The model was developed and validated using two approaches; qualitatively, the behavior of the finger was compared to the published behavior presented in EMG studies (6). Quantitative comparisons were made by sub-

jecting three cadaver hands to simple and complex loading schemes and determining the resulting finger and tendon displacements (5). Deficiencies in the behavior of the finger model prompted the inclusion of additional structures or enhancements to existing structures.

3. RESULTS AND DISCUSSION

The form of the model input/output along with the type of information about the resulting finger position is illustrated in FIGS. 2A,B,C. A simple loading condition with an 80% maximum contraction of the extensor is shown; note the start of "clawing" of the finger under extensor alone as is commonly seen clinically. The contributions of the muscle tendons directly as well as the tendon displacements and passive joint stiffnesses are seen in FIG. 2B while FIG. 2C lists the forces in each of the modelled structures. FIG. 3 shows a sequence commonly described in the clinical literature; trying to achieve the straight finger position. FIG. 3A shows the starting "rest" position with flexion at all three joints. If the person attempts to straighten the finger by contraction of the extensor the situation already shown in FIG. 2 occurs. If the profundus is activated to try and straighten the metacarpophalangeal joint, a full claw position is reached; FIG. 3B. A "third force", other than that of the extrinsic musculature is required.

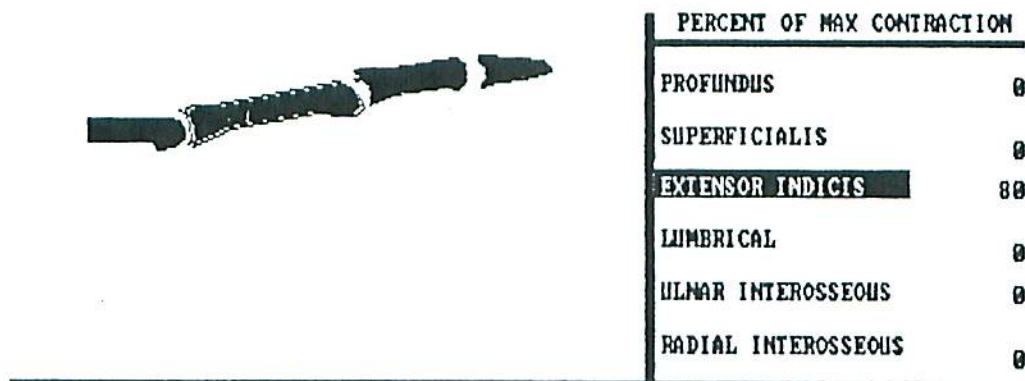


FIGURE 2(A). Typical graphic output showing the activation level of the musculature and the corresponding finger position.

FINGER SIMULATION MODEL

FINAL EQUILIBRIUM POSITION

| Muscle Name | * % Max * Active * Force * (%) | * Active * Force * (N) | * Passive * Elastic * Force * (N) | * Tendon * Length * Change * (mm) | * MP | * PIP | * DIP | Muscle-Joint Moment (Nmm) |
|------------------------|---|------------------------------|--|--|--------|--------|-------|------------------------------|
| Flexor Profundus | 0.0 | 0.0 | 4.5 | 2.5 | 54.4 | 53.7 | 22.4 | |
| Flexor Superficialis | 0.0 | 0.0 | 19.7 | 3.9 | 279.0 | 141.4 | 0.0 | |
| Extensor Indices | 80.0 | 31.5 | 0.0 | -3.1 | -377.4 | -201.1 | 0.0 | |
| Lumbrical | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 | |
| Radial (Dorsal) Inter. | 0.0 | 0.0 | 1.6 | 1.6 | 8.9 | 0.0 | 0.0 | |
| Ulnar (Palmar) Inter. | 0.0 | 0.0 | 4.3 | 2.4 | 34.6 | 0.0 | 0.0 | |
| ===== | | | | | | | | |
| Joint Angles (Deg) | | | | | -16.2 | 3.4 | 8.0 | |

| | | | |
|------------------------------------|-----|------|-----|
| Skin and Soft Tissue Moments (Nmm) | 0.0 | 26.7 | 0.0 |
|------------------------------------|-----|------|-----|

FIGURE 2B).

| STRUCTURE | TENSION (N) |
|---|-------------|
| 1 Flexor Superficialis | 19.79 |
| 2 Flexor Profundus | 4.43 |
| 3 Extensor | 31.44 |
| 4 Lumbrical | 0.00 |
| 5 Dorsal (Radial) Interosseous | 1.63 |
| 6 Palmar (Ulnar) Interosseous | 4.36 |
| 10 Sagittal Band | 0.00 |
| 11 Extensor Expansion | 31.44 |
| 12 Extensor Expansion | 32.83 |
| 13 Central Extensor Tendon | 28.02 |
| 14 Central Extensor Tendon | 28.02 |
| 15 Lateral Band (Proximal) | 4.81 |
| 17 Lateral Band (Distal) | 4.81 |
| 18 Terminal Extensor | 4.83 |
| 19 Oblique Retinacular Ligament | 0.00 |
| 20 Lumbrical Tendon | 0.00 |
| 21 Lumbrical Tendon (Spiral Fibres) | 0.00 |
| 22 Profundus Tendon Distal to Lumbrical | 4.43 |
| 23 Sagittal Bands | 0.00 |

FIGURE 2C).

FIGURE 2. B), C) Typical tabular output

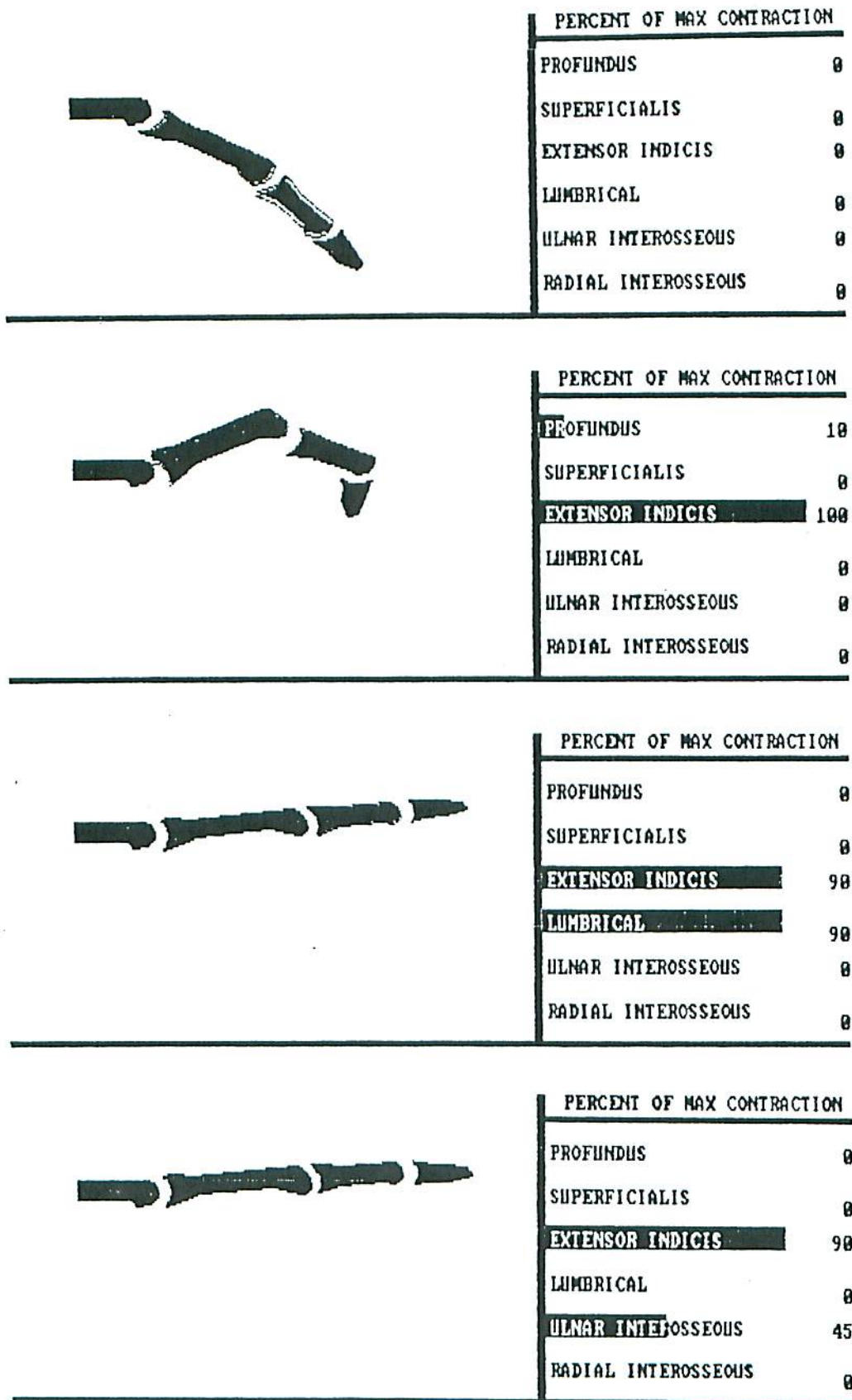


FIGURE 3. Sequence of muscle activations to achieve a straight finger position. See text for details.

FIGS. 3C,D show two alternative approaches using either the lumbrical or the interossei. It has been observed (6) that it is the lumbrical alone which performs this task. The model also mimics other manoeuvres such as the movement caused by lumbrical contraction alone (1).

4. CONCLUSIONS AND RECOMMENDATIONS

The model mimics the behavior of the normal finger and can be used to examine the complex relationships between the active muscle forces and the passive elasticities resident in the hand. Future work will involve refinement of the extensor expansion model and the ability to cut or shorten/lengthen any structure to simulate surgery or injury.

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