

Design of an Extremely Affordable and Zero Maintenance Mechanical Secondary Finger (S-finger) Prosthesis for Index Finger Amputees

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ABSTRACT: This paper describes the designing of an indigenously developed, extremely affordable prosthetic finger for index finger amputees. We discuss the simple mechanism that is used to attain functionality for the prosthetic finger (flexion & extension) which increases the efficiency of the design. This device can be used to perform basic functions such as grasping, holding and other vital day to day tasks. The device has been designed in accordance with the requirements arising in developing countries. We also show the results achieved using this device and discuss further improvising providing food for thought.

Keywords: Distal inter-phalangeal joint, Extension, Flexion, Index finger amputee, mechanical finger, Prosthetic finger, proximal inter-phalangeal joint.

I. INTRODUCTION

In developing countries, the vast majority of the people who are at the bottom of the pyramid are daily wage workers. They lack employability skills and are willing to work in hazardous environments so as to earn a living. Most of them work in factories or industrial establishments which require such manpower. Even a minor negligence in such conditions can cause life lasting trauma.

According to Erin Strait[1], in developing countries, an overwhelming number of prostheses are in requirement but the availability, accessibility and cost of prosthetics are very high and a major concern. Amputees without the assistance of a prosthetic device may not be able to function, succeed or be accepted by society. Individuals who become dependent on prosthetics in developing countries find multiple replacement limbs necessary over their lifetime. Obtaining single prosthesis, let alone subsequent replacement prosthesis, is in itself resource-and cost-prohibitive. A simple silicon replacement for a finger, can cost around \$10, but does not provide any functionality to the finger.

We believe that this serious problem faced by the amputees can be addressed by developing extremely low cost and maintenance-free prosthetic fingers which utilize a basic mechanism to allow flexion and extension and thereby provides the much desired near functionality that is lost. Thus we introduce the mechanical S-Finger (Secondary finger), shown in Fig.1 which would minimize the problem to a great degree and provide a cost effective and resource efficient solution.



Fig.1. Mechanical S-FINGER

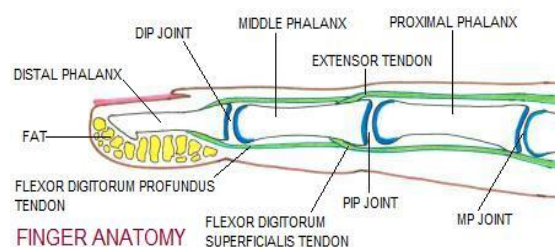


Fig.2: Anatomy of index finger

Anatomy of index finger:

Knowledge of the basic anatomy of the finger is crucial to understand the mechanism of the S-Finger. Fingers are constituted of ligaments (strong supportive tissue connecting bone to bone), tendons (attachment tissue from muscle to bone), and three phalanges (bones). There are no muscles in the fingers; and they move by the pull of the forearm muscles on the tendons. The three bones in the finger are named in relation to distance from the palm of the hand, as shown in fig. 2. The first bone, closest to the palm, is the proximal phalange; the second bone is the middle phalange; and the smallest and farthest from the hand is the distal phalange. The thumb does not have a middle phalange [3]-[4].

Each finger also has three joints which include the distal inter-phalangeal (DIP) joint between the distal phalanx and middle phalanx. The next joint is the proximal inter-phalangeal (PIP) joint between the middle phalanx and proximal phalanx. And the final joint is the metacarpo-phalangeal (MP) joint between the head of metacarpal and the proximal phalanx.

Movements occurring at the different joints are

flexion and extension at all the three joints

abduction and adduction (side to side movement) at the metacarpo-phalangeal joint

Flexion at the DIP joint is provided by flexor digitorum profundus muscle. Flexion at the PIP joint is produced by flexor digitorum superficialis muscle. Abduction and adduction (side to side movement) at the metacarpo-phalangeal joint are produced by the palmar and dorsal interossei muscles. This is illustrated in Fig.2.

II. DEVICE DESIGN

Based on the anatomy discussed in the previous section, we have made efforts to incorporate flexion and extension movements in a prosthetic device. The S-finger works based on the Concavo-convex Rule[5]. The rule states that 'When a convex articulating surface moves on a stable concave surface, the sliding of the convex articulating surface occurs in the direction opposite to the motion of the bony lever. When a concave articulating surface is moving on a stable convex surface, sliding occurs in the same direction as motion of the bony lever'. This is illustrated in Fig.3. Here the Convex surface is the male articulating surface and Concave surface is the female articulating surface.

If the proximal part (bone) is stable and the distal part is moving, then the movement of the articulating surface takes place in the opposite direction to that of the bony lever.

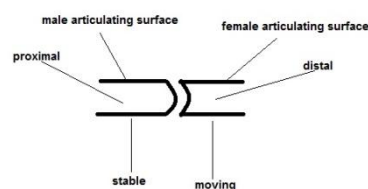


Fig.3: Movement of articulating surfaces in same direction

The prime functionality which we intend to provide with our device is flexion and extension. And for this we applied the concavo-convex rule. We realised that if the metacarpo-phalangeal (MP) joint can be taken to be the stable part then these movements can be achieved. With this in mind, we planned to design the device which follows the concavo-convex rule to achieve the desired functionality.

Our designing process began with the individual parts first, on which we throw some light further.

Parts of S-finger:

a) *Holder*: It is important to make sure that the device has to be mounted upon the palm. So we came up with a simple design to hold the device securely in place while it provides support to the mechanism. It is a moulded 'C' shape holder fig.4 which holds on to the palm of the hand. The holder has been designed keeping the user's comfort in mind and thereby attaches and detaches with ease. It can also be made secure using a Velcro strap.

b) *Ring*: A metallic/plastic ring, as shown in fig.5, is fixed onto the device in order to provide an interface between the proximal phalanx of the user and the device. The user inserts his proximal phalanx into the ring which can be secured by fastening its diameter. The position of the ring is designed in such a way that it acts as the articulation point where the required external force is transferred effectively to the device.

c) *Prosthetic Proximal Phalanx*: An augmentative part has been designed keeping in mind that the amputee doesn't have equal strength as before. This brings the need to augment the function of the proximal phalanx. One end of it is attached to the holder and other end to the prosthetic distal phalanx. The ring is fixed at its centre. The force from the stump of the amputee's finger is transferred to the rest of the device through this part. Prosthetic proximal phalanx is shown in fig.6.

d) *Prosthetic Distal Phalanx*: The distal part of the device is designed such that it is analogous to the distal phalanx of the index finger, as shown in fig.7. This is attached to both the connective lever and the prosthetic proximal phalanx at two different points. It is designed such that when force is applied from the proximal phalanx, a push-pull effect is reciprocated by the connective lever analogous to the flexion and extension.

e) Connective Lever: The connective lever in fig.8 is designed in a way so that its function is analogous to the flexor digitorum superficialis tendon. It provides a link between the prosthetic proximal phalanx and the prosthetic distal phalanx.



Fig.4: Holder proximal phalanx



Fig. 5: Ring



Fig. 6: Prosthetic



Fig.7: Prosthetic distal phalanx



Fig.8: Connective lever

An interesting point to observe is that in the classes of levers the S-finger occupies first-class lever category because its fulcrum is between the effort and the weight.

This has been effectively illustrated in the Fig.9 shown below.

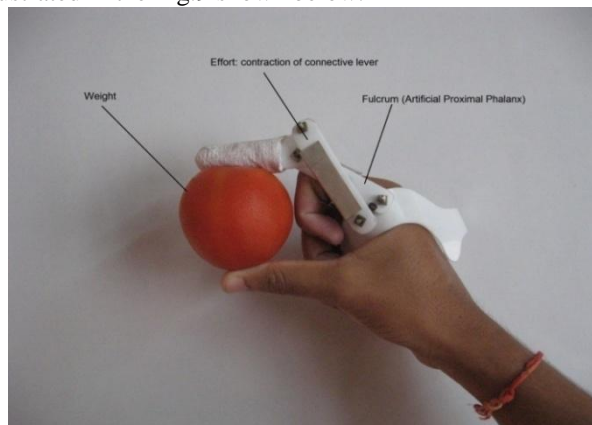


Fig. 9: S-finger as first-class lever

Here the Artificial Proximal Phalanx acts as the fulcrum while the effort refers to the contraction of the connective. It can be seen that a small amount of muscular contraction will be translated into much more extensive & rapid movement of the artificial distal phalanx.

Functionality achieved

The S-finger is designed to be able to achieve two directions of motions i.e. Flexion & Extension.

Flexion: Flexion is a position that is made possible when the joint angle decreases. The artificial proximal phalanx and connective lever systems work together to move the joint into a "flexed" position, as shown in fig.10.

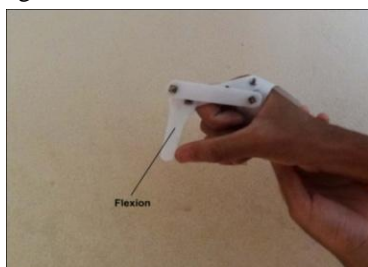


Fig.10: Flexion

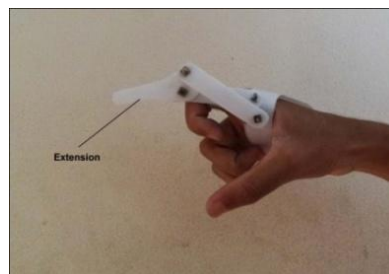


Fig.11: Extension

Extension: The counter-motion of flexion is extension, or straightening. Flexion decreases the angle between the bones of the limb at a joint, and extension increases it, which is shown in fig.11.

The ability of any force to cause rotation of the lever is known as torque or moment of force. Torque (T) is a product of the magnitude of the applied force (f) and its distance (d) from the axis of rotation. The distance (d) is the shortest distance between the action line of the applied force and the axis of the lever; it is the length of a line drawn perpendicular to the action line of the force and intersecting the axis.

$$T = (F) (\perp d)$$

Mechanical advantage (M Ad) is a measure of the efficiency of the lever. It is the ratio of the effort arm to the resistance arm.

III. RESULT

The S-finger provides functionality which is very similar to the natural index finger making it anthropomorphic in nature. The S-finger has been designed keeping in view the strength, mobility, flexibility & angular momentum (flexion and extension) required by an amputee. The material used is UHMWPE, which is used in various biomedical applications and its strength has been tested and proven [6]-[7]. An amputee can be able to perform basic functions such as grasping, holding objects, pressing or pushing buttons, opening the caps of objects, typing on a keyboard, riding bikes, cars, operating cellular phones and many other functions as illustrated in Figures 12-20.



Figure 12: S-Finger in different types of operations and motions

IV. CONCLUSION

At present, the S-finger has been designed in such a way that it is easy to put it on and pull it out. It synchronizes well with the motion of other fingers. It is compact & flexible and can be adjusted to any size. The parts are easily replaceable. The device is designed in a manner that it is very simple to control and at the same time possesses strength & durability. It is very light in weight and is extremely affordable and requires zero maintenance. Although the user might not be able to support heavy weights with this device, it is satisfactorily supports daily usage.

So far the S-finger has been designed keeping in mind only index finger amputees. We intend to extend this concept to other finger amputees as well, in order to restore near normal functions, in the upcoming versions. Another major area which we intend to improvise is to equip the prosthesis with pressure sensors and Shape Memory Alloys (SMA) so as to enable the sensation of touch to the amputee's finger and make the device even more robust.

Empowering the developing countries with such extremely affordable and zero maintenance prosthetic devices will surely be a boon to the lives of many people, many of who is the sole bread-winner of the family.

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