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A New Metacarpophalangeal Joint Prosthesis

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***Abstract*—The metacarpophalangeal (MCP) joint is crucial for hand function, but the joints are frequently affected by arthritis, leading to pain and disability. Joint replacement implants are used to replace the diseased MCP joint, but current and past designs have had varying success. This paper presents a new MCP joint prosthesis based around an idea of combining a single piece elastomer implant with a surface articulating implant.**

***Index Terms*—Design, implant, metacarpophalangeal joint, rheumatoid arthritis.**

I. Introduction

The metacarpophalangeal (MCP) joint (Fig. 1 and Fig. 2) is the articulation between the metacarpal and phalange bones of the hand and is critical for finger positioning and hand function [1]. The MCP joint is frequently affected by arthritis that leads to great pain and disability. Joint replacement implants are commonly used to replace the diseased MCP joint, but they have had varying success [2].

The MCP joint replacements can be categorized into three groups: the hinge joint replacements, the flexible one-piece joint replacements and the surface joint replacements [3]. The Swanson single piece elastomer implant is the most widely used MCP implant. Surface replacement prostheses include the Pyrocarbon, the Avanta SR, the Total Metacarpophalangeal Replacement (TMPR^{TM}) and the Elogenics [4]. These designs are based on the articulation of the metacarpal head and the proximal phalange socket by using wear resistant materials.

The aim of this paper is to present the design of a new metacarpophalangeal joint prosthesis based around the idea of combining the principle of a surface prosthesis with a single piece elastomer prosthesis.

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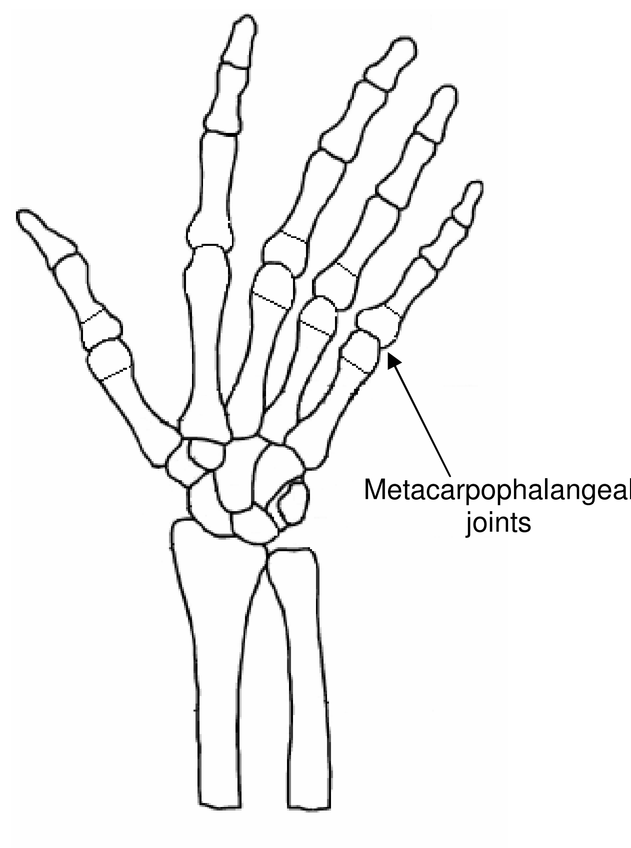

Fig.1 Metacarpophalangeal joints.

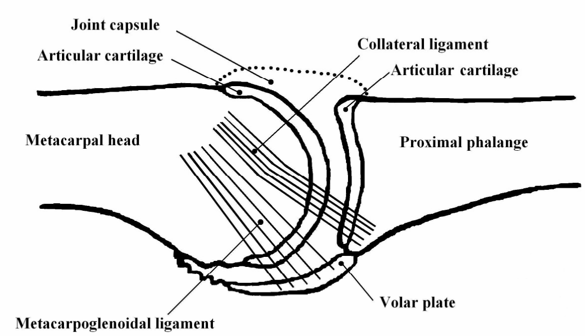

Fig.2 Anatomy of the metacarpophalangeal joint.

II. Design Considerations

A. *Biomechanics of the MCP joint*

The range of motion of the MCP joint is 90º of flexion and 20-30º of extension, 40º for abduction and adduction movement, together with a few degrees of axial rotation of

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the proximal phalanx towards the metacarpal head [3]. However, the functional range of motion required to undertake activities of daily living is less, typically 33º to 73º of flexion [5].

The grip strength for normal males has a wide range of values from 81-672 N [6]. Assuming an external pinch force of 70 N for males, it has been shown that the resultant internal joint force acting on the MCP joint to be 490 N for a static pinch grip and 980 N for a static power grip. For females, with a smaller external pinch force of 50 N, the calculated values for static pinch and power grips were 350 N and 700 N, respectively [7]. The resultant force acting on the MCP joint of patients with rheumatoid arthritis is 210 N and 420 N for pinch grip and power grip, respectively [7].

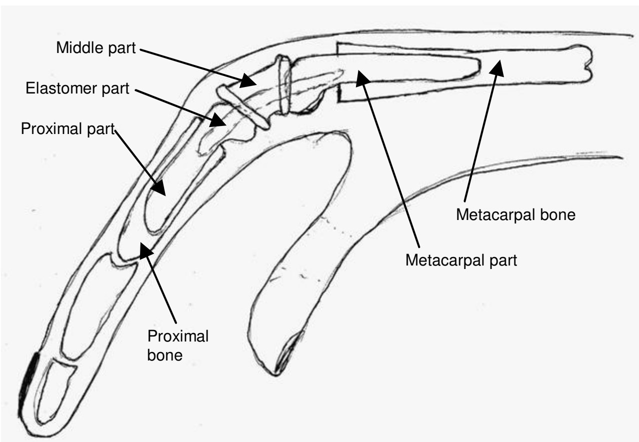

Fig.3 Concept design.

B. Design requirements

From the information on the biomechanics of the normal and diseased MCP joint the prosthesis design should have the following design requirements:

- Provide a functional range of motion instead of full range of motion
- Not required to withstand the high forces of the normal MCP joint as strength of the hand is limited after implant surgery
- Use wear resistant materials
- Provide internal support to the highly deteriorated diseased joint.

III. Design

A. Concept

The concept is based around the idea of combining the principles of an articulating surface implant with that of a flexible elastomer implant. A similar design has previously been proposed for the wrist [8].

The design (Fig.3) consists of a proximal part that fits into the proximal bone and a metacarpal part that fits into the metacarpal bone. The proximal and metacarpal parts each has a convex spherical bearing surface that articulates with the middle part, which has two concave spherical bearing surfaces. A flexible elastomer part is housed within holes in the proximal, metacarpal and middle parts.

B. Detail design

1) Sizing

The implant was designed for the index MCP joint and the dimensions were based on measurements made on human MCP joints [9].

2) Proximal and metacarpal parts

The proximal and metacarpal parts have stems to be made from ultra high molecular weight polyethylene, with a spherical bearing surface head to be made from cobalt chrome molybdenum alloy (Fig. 4).

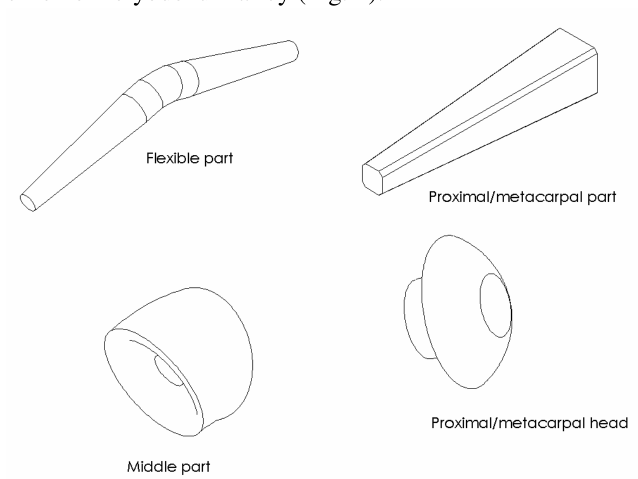

Fig.4 Parts of the prosthesis.

3) Middle part

The middle part (Fig. 4) has concave bearing surfaces to articulate with the proximal and metacarpal bearing surfaces. It is proposed that the middle part will be made from an elastomer, namely polyurethane. This is to enable the use of a soft layer concept for the design, where the metal bearing surfaces of the proximal and metacarpal parts articulate with the elastomer. The use of the soft layer concept has been previously shown to reduce contact stresses and potentially improve the lubrication regime in hip joints [10].

4) Flexible part

The flexible part (Fig. 4) acts as an internal support for the device to prevent dislocation of the implant parts. It is proposed that the flexible part will be made from medical grade silicone rubber.

5) Assembled prosthesis

The assembled prosthesis is shown in Fig. 5 and Fig. 6.

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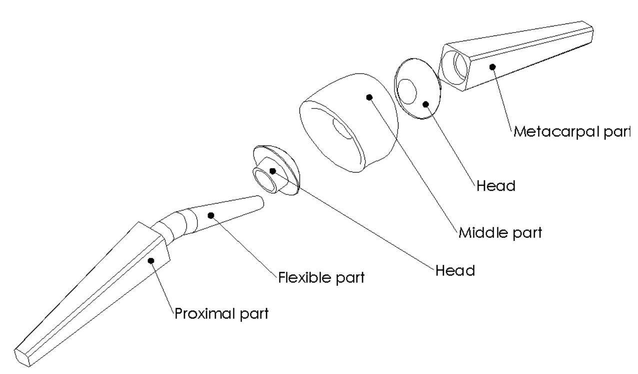

Fig.5 Exploded view of the prosthesis.

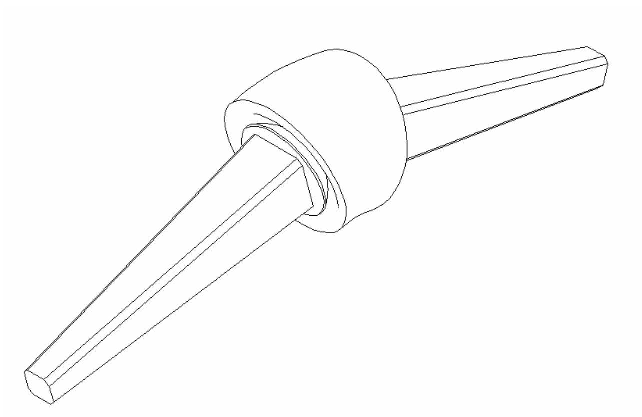

Fig.6 Assembled prosthesis.

IV. Discussion

This paper has presented a new concept for the design of a metacarpophalangeal joint replacement implant that combines the principles of a surface articulating implant with those of a flexible elastomer implant. It is hoped that this design will enable a longer lasting implant to be developed. At present the single-piece silicone elastomer finger joints are prone to fracture [11], while there have been reports of dislocation with the surface articulating implants [12]. By combining the principles of the two designs may overcome these reported problems.

The next stage in the development work is to manufacture the parts. Mechanical testing will then be undertaken. A proposed standard for testing finger joints has been published [13]

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