Differential Spring Stiffness Design for Finger Therapy Exercise Device: Bio-inspired from Stiff Pathological Finger Joints

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1 Background

Finger therapy exercises are important for maintaining hand mobility and preventing development of tendon adhesions in post-operative hand-injury and stroke patients [1]. Current continuous passive motion devices for finger rehabilitation are unable to recreate the therapy exercises that therapists performed on patients, namely table-top, proximal interphalangeal (PIP)-blocking, straight-fist, distal interphalangeal (DIP)-blocking, hook-fist and fist. The aim is to develop a rehabilitation device that utilized a differential spring stiffness design to recreate finger therapy exercises.

2 Methods

Stiff pathological finger joints require a larger external force to move into the desired flexion angle, compared to normal joints [2]. Using this concept, the finger can be moved into a target posture by dictating the sequence in which the joints flex, using a differential spring stiffness design. The approach is to allow DIP joint to flex first by making it least stiff, followed by PIP joint and finally metacarpophalangeal (MCP) joint as the stiffest. Extension springs of different stiffness were fixed on dorsal side of the three joints (Fig. 1), between interface attachments placed on distal, middle and proximal phalanges and metacarpus. Suitable spring stiffness for DIP, PIP and MCP joints are 180, 240 and 590N/m respectively. Cables are attached to palmar side of proximal, middle and distal phalanx interface attachments, and connected to spooling actuators. Each actuator pulls on one cable, linked to one phalanx interface attachment. The whole device was donned on the index finger of a model hand with range-of-motion similar to human finger [3]. Therapy exercises are performed by moving finger from resting extended posture into each therapy posture by actuating cables linking to distal, middle and proximal phalanges. Upon achieving desired posture, actuator was deactivated and the springs returned the finger to resting posture. Cable tension and joint angles were measured using load cell (9212, Kistler) and goniometer. Each exercise was repeated three times.

3 Results

By actuating the cable attached to proximal phalanx, the finger adopted a table-top posture. Actuation of cable attached to middle phalanx moved the finger into PIP-blocking, and subsequently straight-fist posture by progressively increasing cable force. When actuating the cable connected to distal phalanx, the finger attained DIP-blocking, followed by hook-fist and finally fist posture through increased cable force (Fig. 2). Peak applied cable force was 1.6-18.4N for all six therapy exercises. These forces were also different ($p<0.001$) between therapy exercises, with DIP-blocking exercise requiring least force, followed by PIP-blocking, hook-fist, fist, straight-fist and lastly table-top, with greatest cable force.

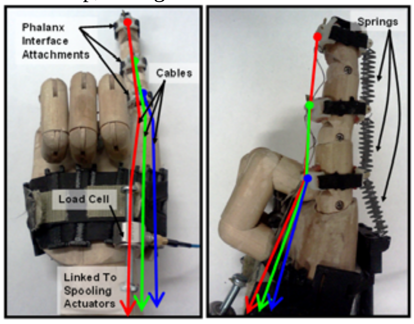

Fig. 1. Cable actuation-passive return design

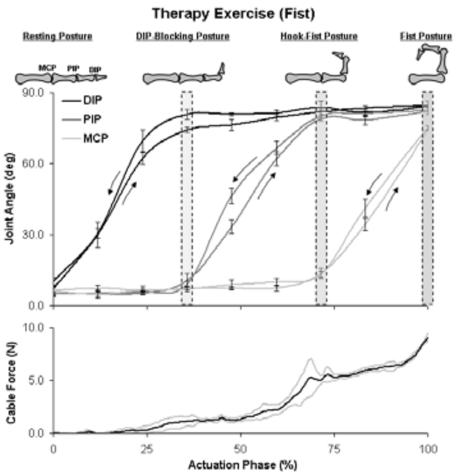

Fig. 2. Achieving three different postures during fist exercise

4 Interpretation

Cable actuation at distal, middle and proximal phalanges, coupled with differential spring stiffness design, allowed the finger achieve all six therapy exercises, depending on the magnitude of cable force applied from the actuator. Upon actuator deactivation, the springs returned the finger to initial resting posture. Altogether, the differential spring stiffness design eliminates the need for dorsal side actuators and is capable of recreating all six therapy exercises, which are beneficial for post-operative hand injury and stroke patients. Future tests would be performed on human subjects to examine the efficacy of the design on actual human fingers.

References

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