JOINT LOADING OF THE THUMB WHILE OPERATING A MECHNICAL PIPETTE – AN INVERSE DYNAMIC ANALYSIS

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INTRODUCTION

Thumb-push manual pipettes are commonly used tools in many medical, biological, and chemical laboratories. Epidemiological studies [1] indicate that the use of pipettes is strongly associated with musculoskeletal disorders (MSDs) in the hand and shoulder. Almost 90% of pipette users, who continuously used the pipettes for more than an hour on a daily basis, reported hand and/or elbow disorders [2]. Despite the strong evidence that operation of the thumb-push manual pipette is related to MSDs in the thumb, the biomechanics of the thumb during pipetting have not been quantified. It is not known if the operation of the thumb-push pipette would induce excessive joint torque in the CMC joint, a factor that may potentially cause degeneration of the articulation [3]. The purpose of the current study was to analyze the kinematics and loading in the joints of the thumb during pipetting.

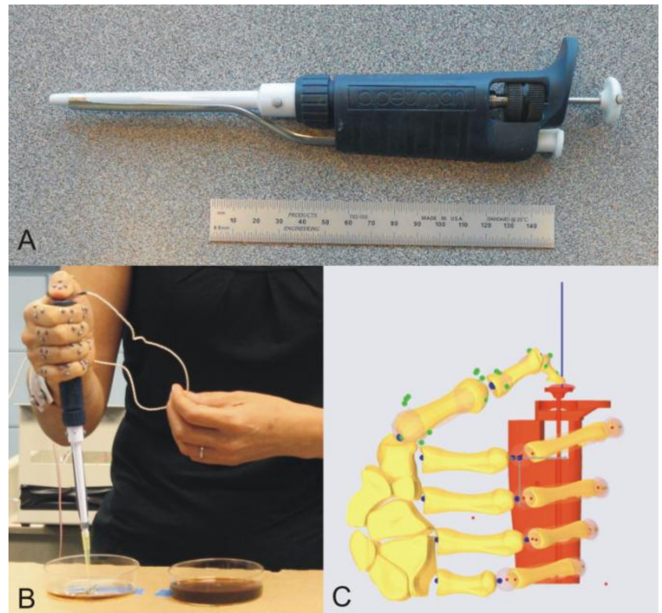

Figure 1. Experimental set-up and model. A: The pipette used in the study. B: The subject operating the pipette during the testing. C: The model of pipetting.

METHODS

A typical thumb-activated pipette (P300, Pipetman, Gilson, Inc, Middleton, WI, USA) was used in the study (Fig.1A). This type of pipette is actuated by a thumb-push button to extract and to dispense fluid, whereas there is a separate button to eject the disposable tip. One female participant was recruited in the study. The subject first pressed the plunger to the first stop, extracted the sample fluid from the container by releasing the plunger, pointed the tip to a second container, and dispensed the fluid by depressing the plunger to the second stop (Fig. 2B). The subject was instructed to repeat the same procedure 15-20 times in a test session.

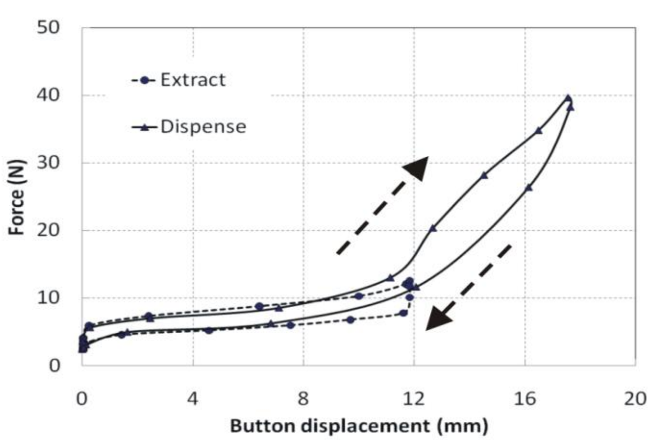

Figure 2. Variation in the button displacement and push force during the extraction and dispensing cycles.

In order to measure the plunger press force, a film force sensor (Type C500, Pressure Profile Systems, Inc., Los Angeles, CA) was placed on the top of the plunger button. The relative displacement of the plunger button was measured via two motion markers placed on the plunger press button and the pipette handle. Kinematics for the fingers, hand, and forearm were determined using methods previously described [4]. Retro-reflective markers (4 mm diameter hemispheres) were applied individually on the finger/thumb/hand segments using a thin self-adhesive tape (Fig. 1B). The measurement model consists of 12 finger segments (three segments for each of the four fingers), three thumb segments, a hand, and a forearm, with a total of 55 tracking markers being used to obtain pipetting kinematics. A 14-camera Vicon Nexus system (Oxford Metrics Ltd., Oxford England) provided marker trajectories at 100 Hz, with calibration residuals less than 0.5

mm for a control volume approximately 3 m (wide) x 3 m (long) x 2 m (high).

The hand was modeled as a multi-body linkage system and includes four fingers (index, long, ring, and little finger), thumb, and a palm segment (Fig. 1C). Each of the fingers is comprised of a distal, an intermediate, and a proximal phalange and a metacarpal. The thumb is comprised of a distal and a proximal phalanx, a metacarpal bone, and a trapezium. The metacarpals of the four fingers and the trapezium of the thumb were considered to be fixed to the palm segment. Although the model includes the entire hand, we have analyzed only the biomechanics of the thumb because it is the focus of the current study. The model was developed using the commercial software package AnyBody (v4.0, AnyBody Technology, Aalborg, Denmark). There is only one DOF (degree-of-freedom) for the IP (interphalangeal) joint, i.e., in flexion/extension motion. The MP (metacarpophalangeal) and CMC (carpometacarpal) joints are modeled as spherical joints and have three DOFs.

RESULTS

Since the extraction and dispensing actions are cyclic in nature, we have summarized all calculation results in terms of task cycle, as researchers traditionally do with gait analysis [5]. An entire work cycle is divided into extraction and dispensing phases. The plunger button stiffness during the extraction and dispensing actions is represented in the slope of the curves of push force versus displacement (Fig. 2). The IP joint moment as a function of the joint angle is shown in Fig. 3A. The joint angle for the extraction is similar to that for the dispensing action; however, the peak joint moment for the dispensing action is about three times that for the extraction. For the MP and CMC joints, the moment in flexion/extension is predominant (Fig. 3B-C). The peak MP joint moment in flexion/extension is approximately 5-7 times of those in adduction-abduction and internal-external rotation (not shown). The peak CMC joint moment in flexion/extension is close to that in adduction-abduction, while approximately four times that in internal-external rotation (not shown).

DISCUSSION AND CONCLUSIONS

Our results show that the force-displacement curves of the pipette plunger button in loading differ from those in the un-loading process (Fig. 2), which is consistent with a previous study [6]. During the loading process, work is done by the musculoskeletal system to push the plunger, whereas the potential energy stored in the pipette spring mechanism is given back to the hand system during the unloading process. The joint power absorption during the unloading is mainly caused by the CMC joint that produces resistant flexion moment in the presence of extension; this action controls the speed of the compressed spring returning to its resting length.

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DISCLAIMER

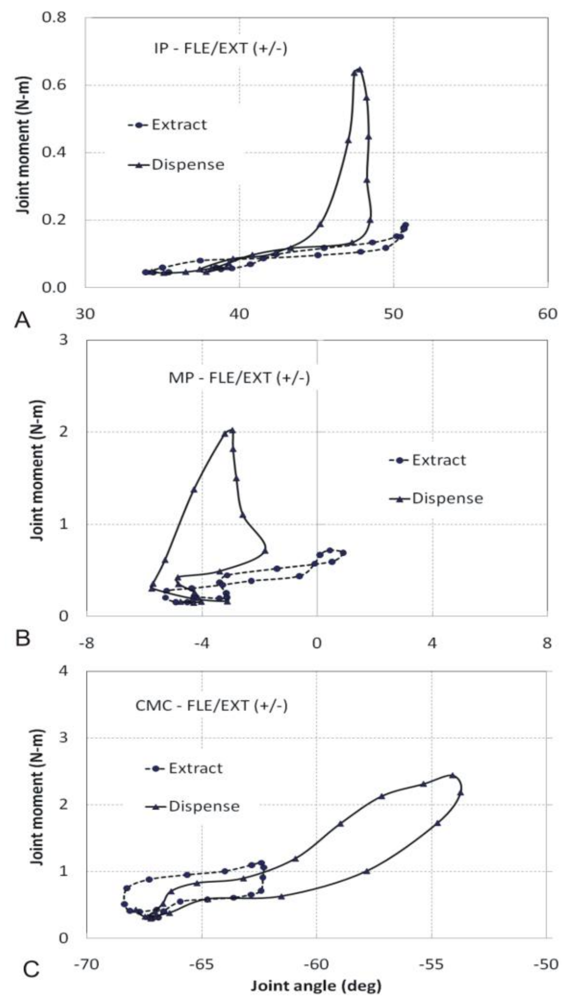

Figure 3: Joint moments as a function of joint angles in flexion/extension (+/-) motions during pipetting.