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CASE STUDY

Kinematic comparison of the wrist movements that are possible with a biomechatronics wrist prosthesis and a body-powered prosthesis: a preliminary study

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***Purpose:* This study examined the kinematic differences between a body-powered prosthesis and a biomechatronics prosthesis as a transradial amputee performed activities that involve flexion/extension and supination/pronation of the wrist. *Method:* The subject's wrist movements were calculated and compared as he completed a wrist range of motion test involving simulated flexion/extension and supination/pronation. *Results:* The results revealed that, under the test conditions, the body-powered prosthesis limits an individual's ability to complete four different tasks of wrist movement especially when it comes to complete the supination/pronation movement. Conversely, while using biomechatronics wrist prosthesis, the user was able to compensate for limited wrist motion through an ability to achieve a greater range of wrist movement. *Conclusions:* The biomechatronics wrist prosthesis provides a greater degree of freedom of wrist flexion/extension and supination/pronation movements.**

Keywords: Motion analysis, transradial prostheses, upper extremity

Implications for Rehabilitation

- Body powered prosthesis for transradial amputees involved the wrist movement that focus on flexion/extension and supination/pronation.
- The biomechatronics wrist prosthesis is a combination of controller that controlled the servo motor at the wrist.
- The biomechatronics wrist prosthesis provides a greater degree of freedom of wrist flexion/extension and supination/pronation movements compare to the body powered prosthesis.

Introduction

Previous studies have compared the function and capability of electrically-powered prosthetic devices with body-powered prostetic devices while amputees performed general wrist activities [1–7]. Among the electrically-powered devices that have been investigated, are the myoelectric [8–13], BCI (Brain Computer Interface) [14] and the Pneumatic Glove [15], all of which apply mechanical and electrical engineering technologies within a prosthetic device. The majority of existing studies have been based on timed functional tests and surveys. Although a few devices and techniques for transradial prosthetics movement can be found in the literature, none have previously focused on the wrist movement through the use of a servo biomechatronics system that applied to the amputee. The purpose of this study was to compare the wrist movements of an amputee subject as he used two different devices, a biomechatronics wrist prosthesis and a body-powered prosthesis, to perform common rehabilitative tasks that focused on flexion/extension and supination/pronation.

Case description

Currently there is only one transradial amputee in University of Malaya Medical Centre (UMMC), Kuala Lumpur that is still undergoing rehab training. Even though there are many transradial amputees who registered to use the prosthetic hands, the majority of them had never completed the full rehabilitation training and some of them did not turn up at all. The UMMC informed that most of them did not show up because they no longer used the body-powered prosthetic hand due to the limitation of motion of the prosthetic hand. The subject who participated in the study did so voluntarily and was given prior written consent letter.

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The subject of the study was a 57-year-old who suffered from a congenital defect on the left arm. The transradial part only covered 40% of the length of his transradial hand (Figure 1). His limb was moderately scarred with graft coverage presented with active ulna radii bones. He had already worn the body-powered prosthetic device for approximately 12 years and changed it twice as a result of changes in his body size and weight.

Information provided by the subject revealed that he lived alone and could independently perform the majority of day-to-day activities, including holding a cup, dressing and eating. He reported that he would regularly remove his prosthetic device after two hours of constant wear due to discomfort. At the time of data collection, the subject reported that he experienced some difficulties with supination/pronation of the wrist for some daily tasks.

The subject was fitted with a body-powered prosthesis one hour before the data collection activity began. After the test for the body-powered prosthesis had been performed, the subject was fitted with the biomechatronics wrist prosthesis and also wore this device for one hour before the data collection activity began. The body-powered prosthesis consisted of a hard socket, a bowden cable and a cosmetic hand, while the biomechatronics wrist prosthesis consisted of a sensor, servo, and hard socket. Figure 2 shows the subject with the body-powered (Figure 2a) and biomechatronics wrist prostheses (Figure 2b).

Methods

The study was approved by the Central Office for Research Ethics Committees of the University Malaya Medical Centre (UMMC). The experiment was conducted at the Motion Analysis Laboratory and Brace & Limb Laboratory, Department of Biomedical Engineering, University of Malaya. The experiment was conducted using motion analysis system where six MX-F20 infrared cameras were placed in a room to capture any kind of reflection motion from the markers. Thirty-two markers were positioned at key points all over the subject's body, including on the prosthetic hand itself. The markers placement of the full body and details of the placement can be referred to Figure 3 and Table I. The MX-F20 infrared cameras were calibrated using the Vicon Nexus software to provide full measurements and dimensions of the room. Static and dynamic calibrations which involves the subject to stand and move randomly inside the room were carried out before the trials begin. Each and every time the subject moved, this gave an orientation to the cameras to capture the motion. This procedure was necessary in order to ensure that all of the cameras were in full working order and that the data that was transferred was accurate and reliable. Details regarding the kinematics, kinetics model and analysis of the range of motions and pressure analysis are described in previous work by the authors [16–18].

Figure 1. Anterior view of the subject's residual limbs.

The subject was asked to complete the following tasks:

1. Wrist Extension and Flexion: With a starting position of 90° of elbow flexion, the subject was asked to flex the wrist as far as possible and pause before returning to the initial position. The subject was then asked to extend the wrist as far as possible and pause.
2. Wrist Supination and Pronation: With a starting position of 90° of elbow flexion, the subject was required to rotate the forearm as far as possible so that the palm faced anteriorly (supination) and pause. After returning to the initial position, the subject was asked to rotate the forearm as far as possible so that the palm faced down (pronation) and pause.

The subject completed these tasks twice, first with the body-powered prosthesis fitted and then with the biomechatronics prosthesis.

Results

Table II shows the average maximum, average minimum and total difference of average range of wrist motion while wearing the body-powered prosthesis and biomechatronics wrist prosthesis during the range of motion task. The biomechatronics wrist prosthesis permitted a much greater range of motion of the wrist.

While wearing the body-powered prosthesis, the subject held his wrist flexed at an average of 20.6° and extended at an average of 57°. The subject needed to apply full strength to the body-powered prosthesis in order to flex and extend the wrist to the maximum range of motion. Conversely, while using the biomechatronics wrist prosthesis, the wrist was flexed at an average of 84.4° and extended at an average of 81°.

During the supination and pronation motion tests, the body-powered prosthesis held the wrist supinated at an average of 50°, and pronated at an average of 55.7°. Conversely, while using the biomechatronics wrist prosthesis, the wrist was supinated at an average of 89.3° and pronated at an average of 80.4°.

Discussion

According to a number of existing studies, wrist flexion and extension are mainly used when an individual wants to open a door or pick up an object [1–5]. The majority of humans are

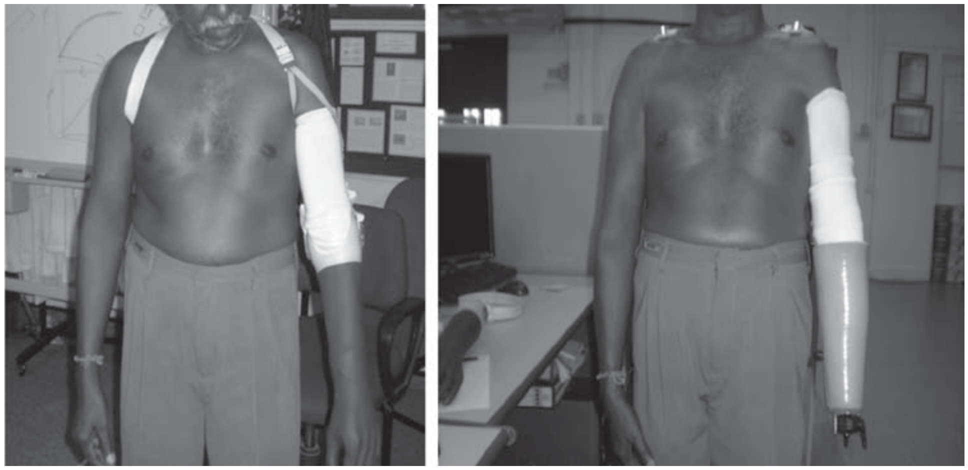

Figure 2. Anterior view of subject with prostheses. (a) Body-powered prosthesis; (b) Biomechatronics prosthesis.

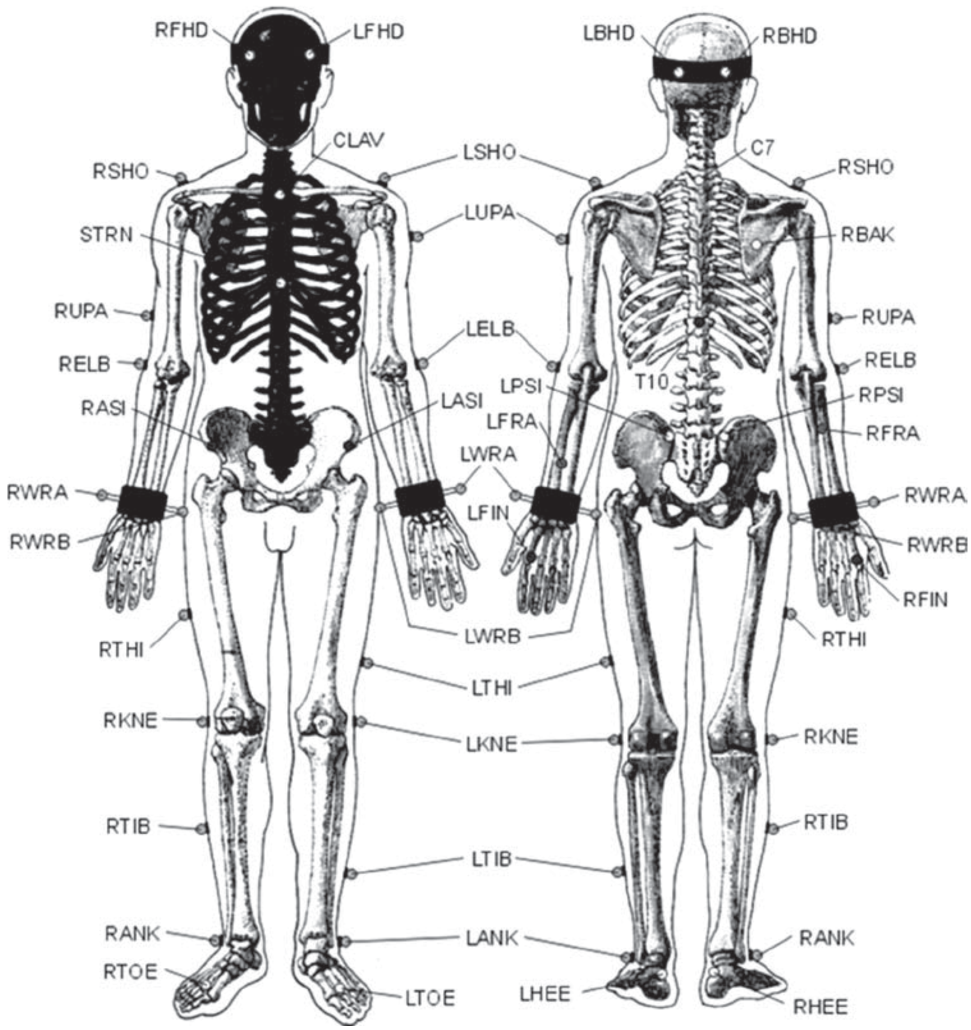

Figure 3. Placement of reflection body markers for MX-F20 infrared cameras to capture.

capable of a maximum flexion between 80° and 90° and can extend the wrist between 70° and 90° [1–7,16,17]. The body-powered prosthesis tested in this case allowed for 20.6°of flexion and 57° of extension. The biomechatronics wrist prosthesis allowed for a much greater range of motion of the wrist that flexed with an average of 84.4° and extended with an average of 81°, which is closer to the anatomic range of a healthy biological human hand.

In order to eliminate a harness suspension system for a self-suspending transradial prosthesis, which arguably enhances

Table I. Marker labels, definitions and positions reference for placement of the reflection markers.

Marker labels	Definitions	Positions reference
LFHD	Left front head	Located approximately over the left temple
RFHD	Right front head	Located approximately over the right temple
LBHD	Left back head	Placed on the back of the head
RBHD	Right back head	Placed on the back of the head
FORE	Forehead	Middle anterior aspect of forehead
LEAR	Left ear	Left ear canal
REAR	Right ear	Right ear canal
C7	7th Cervical vertebrae	Spinous process of the 7th cervical vertebrae
T10	10th thoracic vertebrae	Spinous Process of the 10th thoracic vertebrae
CLAV	Clavicle	Jugular notch where the clavicles meet the sternum
STRN	Sternum	Xiphoid process of the sternum
RBAK	Right back	Place in the middle of the right scapula
LSHO	Left shoulder	Placed on the acromioclavicular joint
LUPA	Left upper arm marker	Place on the upper arm between elbow and shoulder
LELB	Left elbow	Place on lateral epicondyle approximating elbow joint
LMEL	Left medial elbow	Place on medial epicondyle approximating elbow
LFRA	Left forearm	Place on the lower arm between the wrist and elbow
LWRA	Left wrist marker A	Left wrist bar thumb side
LWRB	Left wrist marker B	Left wrist bar pinkie side
LFIN	Left fingers	Actually placed on the dorsum of the hand
LASI	Left ASIS	Place directly over the left anterior superior iliac spine
RASI	Right ASIS	Place directly over right anterior superior iliac spine
LPSI	Left PSIS	Place directly over left posterior superior iliac spine
RPSI	Right PSIS	Place directly over right posterior superior iliac spine
SACR	Sacral wand	Place on the skin mid-way (PSIS)
LILC	Left iliac crest	Place on the mid-superior aspect of the left iliac crest
RILC	Right iliac crest	Place on the mid-superior aspect of right iliac crest
LKNE	Left knee	Place on the lateral epicondyle of the left knee
LMKN	Left medial knee	Place on the medial epicondyle of the left knee
LTHI	Left thigh	Place over the lower lateral 1/3 surface of the thigh.
LHIP	Left hip	Superior aspect of greater trochanter
LANK	Left ankle	Place on the lateral
LMAN	Left medial ankle	Place on the medial malleolus
LTIB	Left tibial wand marker	Similar to the thigh markers
LTOE	Left toe	Place over the second metatarsal head
LHEE	Left heel	Place on the calcaneus
LHAL	Left hallux	Anterior surface of left hallux (big toe)
LMT1	Left metatarsal 1	Medial aspect of head of left metatarsal one
LMT5	Left metatarsal 5	Lateral aspect of head of left metatarsal five

Table II. Maximum and minimum wrist flexion/extension and supination/pronation while wearing two different prostheses.

	Average flexion	Average extension	Average supination	Average pronation
Biomechatronics wrist	84.4°	81°	89.3°	80.4°
Body-powered	20.7°	57°	50°	55.7°
Total different of range	63.7°	24°	38.7°	34.7°

cosmesis, higher, more proximal trimlines are required. The biomechatronics wrist prosthesis gave a less value of rotation due to the servo rotation inside the wrist part. The inertia of the servo motor played a major role in determining the rotation of the motor. Frequently, each and every time the motor rotated, there would be a delay due to the inertia before the motor moved. However, this problem did not interrupt the motion system since the maximum human daily task that involves the flexion and extension of the wrist is only about 70–85° [1–5], and this range of movement had already been achieved.

A normal human hand usually rotates both the pronation and the supination between 85° and 90°, depending upon the task that it is trying to fulfil [1–5]. The biomechatronics wrist prosthesis in this case achieved an average of 80.4° of pronation and 89.3° of supination. Conversely, the body-powered prosthesis was only capable of rotating the wrist an average of 55.7° pronation and 50° supination. As such, a transradial body-powered prosthesis is only capable of completing a pick and place motion and is not fully concentrated on the wrist motion.

Previous researchers have reported that the compensatory movements required for extension/flexion while completing daily tasks is between 24° and 88° [9,11]. A study by Carey et al. investigated the kinematics of one bilateral subject as he used a body-powered prosthesis and their results revealed a lack of forearm and wrist movement. In addition, the prosthetic user was only capable of twisting a doorknob with assistance from the glenohumeral and elbow joints. John S. Landry simulated a model of a body-powered prosthesis that was capable of achieving a maximum average of only 63° of flexion/extension [19]. Landry further reported that the body-powered prosthesis has a limited capability in completing several tasks as a result of the lack of wrist movement that it was capable of achieving, especially with regards to pronation and supination.

The subject of this current study, while using the body-powered prosthesis to simulate flexion/extension, held his wrist at approximately 60% of the maximum 90°, and used a very limited range of motion to complete the sample tasks. The subject compensated for these limitations by increasing the shoulder power that was delivered through the tension cable that controls the wrist part of the body-powered prosthesis. The subject in this case utilized his shoulder directly between the prosthesis. Additionally, his ability to achieve the maximum angle of wrist rotation depended on the force of strength he could produce using his shoulder power in order to perform the action. The subject spent an equal amount of time wearing both prosthetic devices and reported equal efficiency for both system. However, he also indicated a preference for the body-powered prosthesis system for the flexion/extension task. The direct force that applied for the flexion/extension of the body-powered prosthesis gave him more self-control over the movements that were necessary for the completion of functional tasks.

The greater range of wrist rotation achievable by the biomechatronics wrist prosthesis in this case was present during both the pronation and supination movements. The subject also utilized more wrist pronation/supination degree of rotation with his biomechatronics wrist prosthesis then he did while using the body-powered prosthesis. While completing the task, it seemed that a certain range of motion in the sagittal plane was required to complete the task and that if the elbow's motion in static condition, making up the difference necessary to complete the task. This was not a technique considering the elbow rotation. Although, the elbow's movement helped the wrist to complete some abnormal movements, it is possible that the subject can reluctant any movement to his elbow as completing the task causing interrupt the result of exactly wrist degree of rotation. It may be a benefit in the future to investigate the interconnection of elbow condition while completing the wrist movements.

A case study does not allow for generalizations to be made pertaining to the use of body-powered prostheses and biomechatronics wrist prostheses. Further limitations of the current study relate to the fact that a laboratory setting was utilized that could only allow for the simulation of limited tasks. The study of internal kinetics factors such as pressure and force also need to be considered. The body-powered prosthesis required the distribution of a lot of force to the shoulder and this could also interrupt the movements. There is also a need to broaden the comparisons between existing products, such as myoelectric and bebionic hands, as opposed to focussing only on body-powered prostheses. No measurements were taken during the passive range of the transradial part while the subject was wearing and not wearing his prosthesis. Future work should incorporate everyday tasks, such as holding a cup, opening a door, etc. since the general requirement of the wrist is to complete such tasks on a daily basis. The condition of pressure at the transradial when applying a load should also be examined.

Conclusion

In this study, the subject's body-powered prosthesis limited his range of wrist motion, especially while engaged in pronation/supination motion. Additionally, the subject needed to strengthen the shoulder force that he applied to the tension cable that was integrated into the body-powered prosthesis in order to achieve the maximum flexion/extension motion. While using the biomechatronics wrist prosthesis, a greater range of wrist motion was measured for all four main wrist movement activities that were studied. Greater maximal wrist flexion/extension and pronation/supination was also utilized with the biomechatronics wrist prosthesis. Future studies should consider the performance of the biomechatronics wrist prosthesis while completing daily life activities such as opening a door, drinking from a cup, etc. Further comparative studies between the biomechatronics wrist prosthesis and the myoelectric prosthesis and biological human hand should also be implemented in order to understand the kinetics application of different types of devices.

Declaration of interest

All authors were fully involved in the study and preparation of the manuscript and that the material within has not been and will not be submitted for publication elsewhere. This study was supported by the UM/MOHE/HIR grant (Project Number: D000014–16001).

References

1. Anglin C, Wyss UP. Review of arm motion analyses. Proc Inst Mech Eng H 2000;214:541–555.
2. Buckley MA, Yardley A, Johnson GR, Carus DA. Dynamics of the upper limb during performance of the tasks of everyday living–a review of the current knowledge base. Proc Inst Mech Eng H 1996;210:241–247.
3. Chadwick EK, Nicol AC. Elbow and wrist joint contact forces during occupational pick and place activities. J Biomech 2000;33:591–600.
4. Ramanathan R, Eberhardt SP, Rahman T, Sample W, Seliktar R, Alexander M. Analysis of arm trajectories of everyday tasks for the development of an upper-limb orthosis. IEEE Trans Rehabil Eng 2000;8:60–70.
5. Romily DP, Anglin C, Gosine RG, Hershler C, Raschke SU. A functional task analysis and motion simulation for the development of a powered upper-limb orthosis. Rehabil Eng 1994;2:119–129.
6. Safaee-Rad R, Shwedyk E, Quanbury AO, Cooper JE. Normal functional range of motion of upper limb joints during performance of three feeding activities. Arch Phys Med Rehabil 1990;71:505–509.

7. Schmidt R, Disselhorst-Klug C, Silny J, Rau G. A marker-based measurement procedure for unconstrained wrist and elbow motions. J Biomech 1999;32:615–621.
8. Highsmith MJ. Kinematic evaluation of terminal devices for kayaking with upper extremity amputation. J Prosthet Orthot 2007;19:84–90.
9. Carey SL, Dubey RV, Bauer GS, Highsmith MJ. Kinematic comparison of myoelectric and body powered prostheses while performing common activities. Prosthet Orthot Int 2009;33:179–186.
10. Millstein SG, Heger H, Hunter GA. Prosthetic use in adult upper limb amputees: a comparison of the body powered and electrically powered prostheses. Prosthet Orthot Int 1986;10:27–34.
11. Carey SL, Jason Highsmith M, Maitland ME, Dubey RV. Compensatory movements of transradial prosthesis users during common tasks. Clin Biomech (Bristol, Avon) 2008;23:1128–1135.
12. Schabowsky CN, Dromerick AW, Holley RJ, Monroe B, Lum PS. Transradial upper extremity amputees are capable of adapting to a novel dynamic environment. Exp Brain Res 2008;188:589–601.
13. Agnew PJ. Functional effectiveness of a myo-electric prosthesis compared with a functional split-hook prosthesis: a single subject experiment. Prosthet Orthot Int 1981;5:92–96.
14. Abu Osman NA, Yahud S, Goh SY. Development of mechanical prosthetic hand system for BCI Application. Eur J Sci Res 2008;20:863–870.
15. Lauri C, Stoykov ME, Jia Y, Toro ML, Kenyon RV, Kamper DG. Use of a pneumatic glove for hand rehabilitation following stroke. IEEE 31st Annual International Conference 2009 Sep 2–6; Minnesota, USA; 2009;2434–2437.
16. Abd Razak NA, Abu Osman NA, Wan Abas WAB, Ahmad Fu'ad AN. Comparison study of the transradial prosthetics and biological hand using motion analysis approach. International MultiConference of Engineers and Computer Scientists 2011 March 16–18; Hong Kong: IEANG; 2011;1327–1330.
17. Abd Razak NA, Abu Osman NA. Comparison study of the transradial prosthetics and body powered prosthetics using pressure distribution approach. Kuala Lumpur International Conference in Biomedical Engineering 2011 June 21–23; Kuala Lumpur: Malaysia: IFMBE; 2011;35:743–746.
18. Abu Osman NA, Spence WD, Solomonidis SE, Paul JP, Weir AM. Transducers for the determination of the pressure and shear stress distribution at the stump socket interface of trans-tibial amputees. J Eng Manufac 2010;224:1239–1250.
19. Landry JS. Optimal fixed wrist alignment for below-elbow, powered prosthetic hands. Mech Eng 2000;113.