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Test rig design for upper-limb socket prosthetics at transradial amputation level

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Abstract. Statistics show that the transradial level is the most common level of upper-limb amputation seen by the prosthetist. Amputee needs an intermediate part to wear and fit the prosthetic device with the residual limb firmly. The socket is the only channel between residual limb and prosthetic components and is the crucial part of the prosthesis influencing the amputee's acceptance considerably. The purpose of this design is making a test rig that can assess the socket while simulating arm movements that are common during activities of daily living such as:(Abduction, Adduction, Flexion, Extension, Supination and Pronation) in Euler angles: Yaw, Pitch and Roll. This test rig allows to predict when dislocation between the residual limb and the socket will be happened with any weight and at any plane.

1. Introduction

The study published in 1996 of the medical records of Korean amputees showed that the ratio of upper amputation to lower amputation was approximately 1:2.2. Upper amputees have an enormous sense of frustration and problems in the rehabilitation process because of technical difficulties in reproducing delicate and complex movements and the tactile and proprioceptive sensory functions [1].

Based on information from National Center for Health Statistics in USA that showed 70% of all persons with upper limb amputations have amputations distal to the elbow. Transradial amputation level occurs in the forearm, from the elbow to the wrist [2]. Amputee needs intermediate part to wear and fit the prosthetic device firmly with the residual limb. So the socket is the only channel between residual limb and prosthetic components and is the critical part of the prosthesis affecting the amputee's acceptance considerably [3].

Assessment of transradial socket prosthetic is very important for measurement how amputees are satisfied about prosthetic interface. A survey showed that 20% of upper-limb amputees had abandoned prosthesis use. The critical factor is the comfort and functionality [4].The comfort-related problems are such as weight, fit, and heat [5].

Wayne K. Daly presented system that is adaptable to many amputation levels that maintains contact of electrode for patients who have volume changes or suffers from difficulty with the traditional suspension methods. Electrodes in roll-on sleeves have been tested to provide improved suspension. It showed that Roll-on sleeve is an excellent way to accomplish superior suspension and greater range of motion [6].

MatthewWernke used the motion capture model and Slip Detection Sensor. The 3D motion capture model allows for measurement of the movement that occurs at interface of the prosthetic socket. The Slip Detection Sensor measures the amount of socket slip which occurs between the socket wall and surface of the residual limb skin. Kinematic data was collected for each participant during the reiteration of a series of range of motion included shoulder flexion/extension, shoulder rotation, and elbow flexion, shoulder abduction/adduction, and activities of daily living included a modified box and blocks test, bilateral and unilateral lifting task at various weight increments, walk and carry a gallon jug of water, and folding a towel. The effect of donning the prosthesis on the range of motion of participant and the amount of socket movement during the activities of daily living tasks was analyzed[7].

On the contrary of the previous studies, Michael D. Paskett designed a modular upper-limb bypass socket allows to perform tests of prosthetic systems from the prosthetic user's perception. Bypass socket accesses to forearm musculature and the hand that are necessary to provide substituted sensory feedback and allows a sufficient range of motion to accomplish tasks in the frontal working area. Tests are performed by non-amputee participants [8].

Liz Haverkate also depended on able-bodied subjects in his assessment of body-powered upper limb prostheses to assess and compare the functional performance three body-powered upper limb terminal devices which commonly used in this work, two functional tests; the Nine Hole Peg Test and the Box and Blocks Test are performed by able-bodied subjects [9].

Upper-Limb Socket Prosthetic needs different tests to be assessed such as Pull-off force test, Practical Activities Test, Live-lift test, Axial-load test, and positioning control test [6][8][10].

The goal of this study is to objectively designing and fabricating a Test Rig to assess the upper - limb socket prosthetic in Euler angles: pitch, yaw and roll while simulating the arm movements during activities of daily living such as: Abduction and Adduction, Flexion and Extension, Supination and Pronation. Also, it allows predicting when dislocation between residual limb and the socket will happen with any weight and at any plane.

2. Methods

In this work, theSolidWorks CAD software is used to build the model of the test rig. This design allows testing the upper-limb prosthetic socket in Euler angles: Yaw, Pitch and Roll as shown in figure 1.It is used to find out when the socket will be dislocated from the residual limb by the effect of different weights in different plane.The authors introduce the test rig that has ability to move universally at any plane.

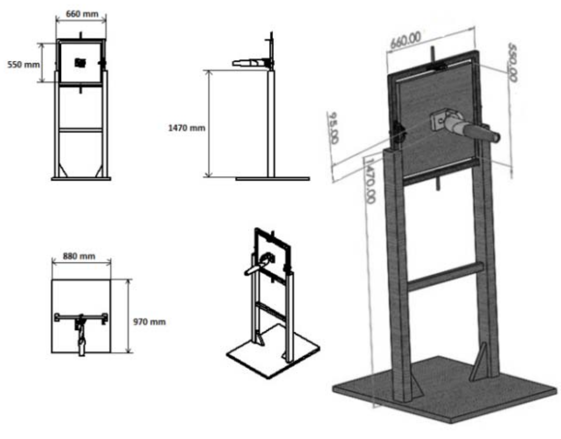

Figure 1. Test rig design on SolidWorks CAD software (Dimensions in mm).

This study is based on assessment of below - elbow socket prosthetic. The socket has been assessed was for a patient that has abandoned because of changes that happened in the volume of his residual limb. SolidWorks CAD software also was used to draw the socket with real dimensions as shown in figure 2.

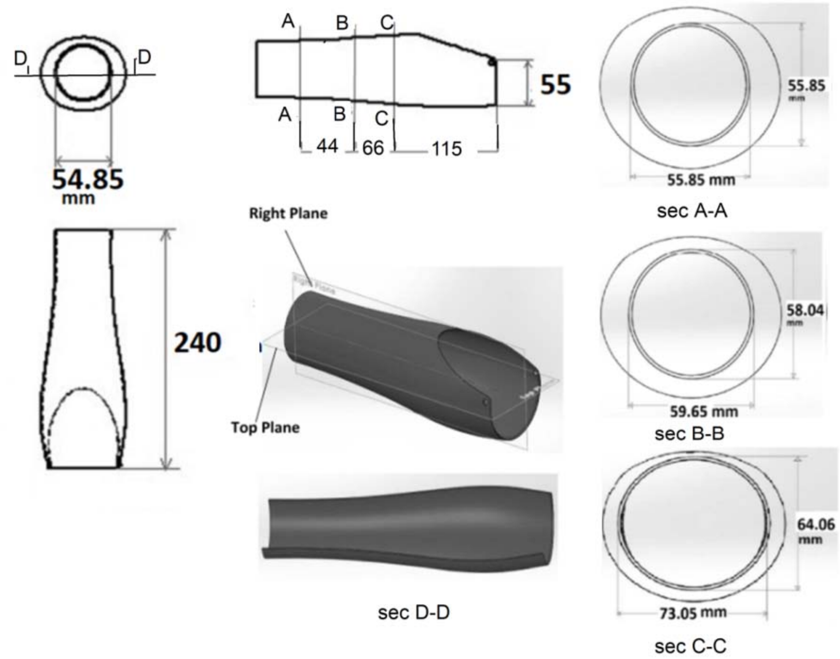

Figure 2. The Socket CAD model with sections at (C-C), (B-B), (X-X), and (D-D).

Figure 2 illustrates sections of the socket at different positions. Sections X-X and B-B have an elliptical cross section. The elliptical cross section decreases gradually to become a circular cross section at section C-C finally.

2.1. Design and manufacturing process for the test rig

Wood is the material used to build the test rig in this work. The design consists of : square plate 55 cm * 55 cm and square frame 66 cm * 66 cm, both of them are 3 cm in thickness, plat form with 1470 mm in height (Item no.3), connection part between plate and arm (Item no. 9), four wooden pins (Item no.4), two protractors (Item no.5), and two Indicators (Item no.6) as shown in figure 3 and table 1.

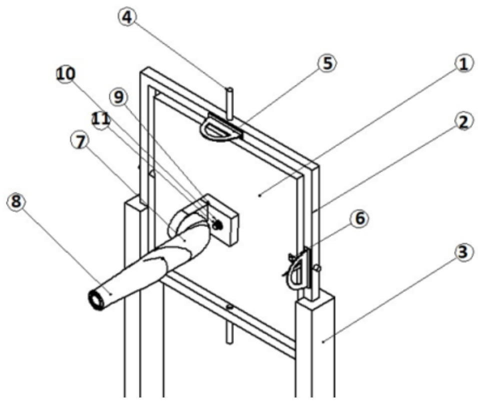

Figure 3. Parts of the test rig.

Table 1. Parts of test rig.

Name of parts	Number of parts
1 plate	1
2 Frame	1
3 Plate form	1
4 Wooden pin	4
5 Protractor	2
6 Indicator	2
7 Arm	1
8 Socket	1
9 Connection part	1
10 Nut	1
11 Pin stud	1

The purpose of this design is building a test rig that can assess the socket while simulating the common arm movements during the daily activities such as: Abduction and Adduction, Flexion and Extension, Supination and Pronation. All of these movements can be represented in Euler angles: pitch, yaw and roll as shown infigure4.

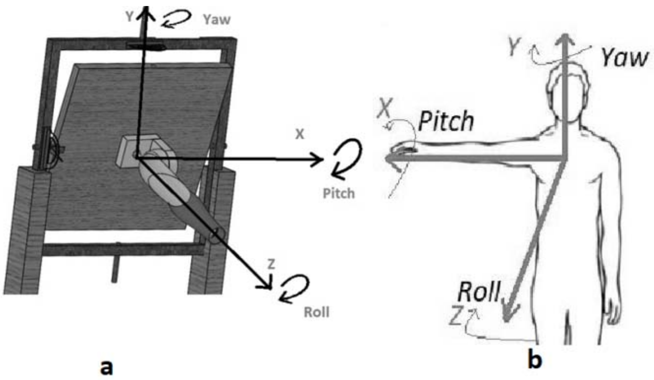

Figure 4(a) Representation of (Pitch, Yaw and Roll angles) on the Test rig. (b) Representation of (Pitch, Yaw and Roll angles) on the body human.

The test righ as been designed to simulate the movements of Euler angles by using four wooden pins and connection part between plate and arm. The four pins make the socket to rotate by alternating in X and Y axis to simulate pitch and yaw movement and connection part between plate and arm make the socket to simulate roll movement as shown in figure 5.

Abduction and Adduction are used to describe the movements that are towards or away from the midline of the body. Horizontal abduction: at the start position, arm is lifted in front of the body. The action occurs when arm moves out to the side. Horizontal adduction: at the start position, when arm is lifted out to the side of the body. The actions occur when arm moves in front of the body as shown in figure 6(a).

Flexion and Extension movements are used to describe increasing and decreasing the angle between two body parts and occurred in the sagittal plane. Flexion occurs when the angle is decreased between two body parts. Extension occurs when the angle is increased between two body parts as shown in figure 6(b).

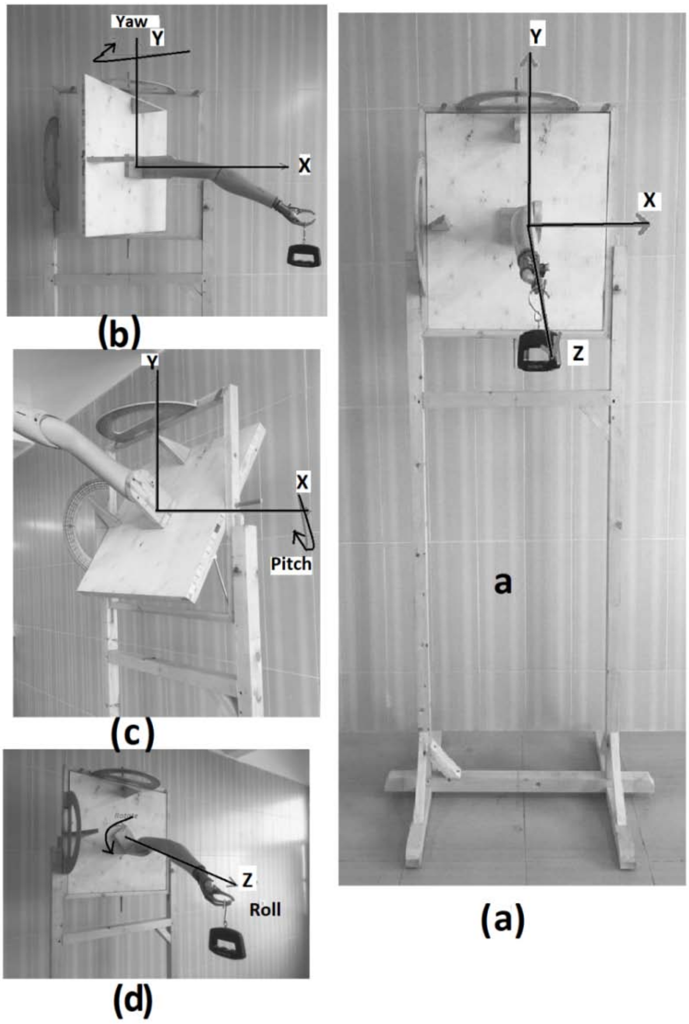

Figure 5.(a) Design and fabricating (The Test rig), (b) pitch angle by rotation about the Y axis Y-axis, (c) Yaw angle by rotation about the X-axis, and (d) Roll angle by rotation about the Z-axis.

Pronation and Supination is a pair of movements that occurs at the proximal radioulnar joint. The two unique movements allow the human body to flip the palm. Supination is occurred when palm is facing upwards and Pronation when palm is facing downwards as shown in figure 6(c).

2.2. Experimental work

Two tests were done by this test rig, Live-Lift Test, and Axial Load Test in Euler angles simulated common arm movements such as: Abduction and Adduction, Flexion and Extension, Supination and Pronation.

2.2.1. Experiment 1 (Live-lift test). Live-lift test measures the amount of vertical downward force applied to the socket that amputee can resist without occurring dislocation between the residual limb and the socket while maintaining his arm at 90ºas shown in figure 7(a)[10].

2.2.2. Experiment 2 (Axial load test). Axial load test measures the amount of vertical downward force applied to the socket that amputee can resist without occurring dislocation between the residual limb and the socket while maintaining his arm in an extended position as shown in figure 7(b)[10].

Digital luggage scale is used to measure the maximum force the socket can endure as shown in figure7 (c). It has 50kg capacity and accuracy of 0.05 Kg as shown in figure 7 (c).

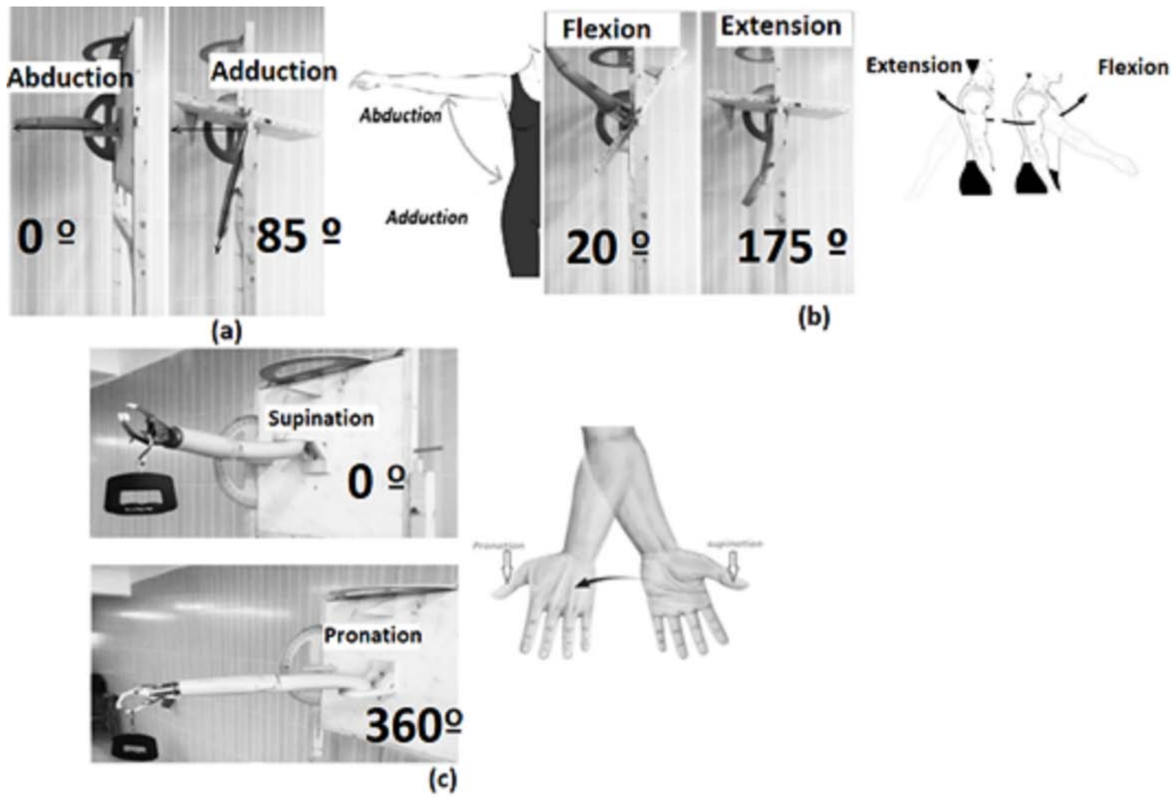

Figure 6.(a)Abduction and Adduction movements, (b) Flexionand Extension movements, and (c) Supination Pronation movements by test rig design and body human.

2.3. Special consideration

Female mannequin' arm is used to simulate arm's anatomy of human body. Female mannequin residual limb model is fitted firmly with the socket and both were suspended from a wooden connection part as shown in figure 7(c).

Revision should be considered that the socket must be donned firmly with a good level of accuracy. A mark on the stump of the arm was made where the maximum fitted position is reached it and the socket to be a guide for every time the position of the arm was made as shown in figure 7(d).

3. Results

In table 2, shows the live-lift force is larger than axial-load force at abduction case. In adduction case with an angle of 85º, live-lift force is larger than axial-load force.

In table 3, shows the live- lift force is larger than the axial-load force at flexion case with an angle of 20º. In Extension case when angle was 175 º, live- lift force was larger than axial-load force.

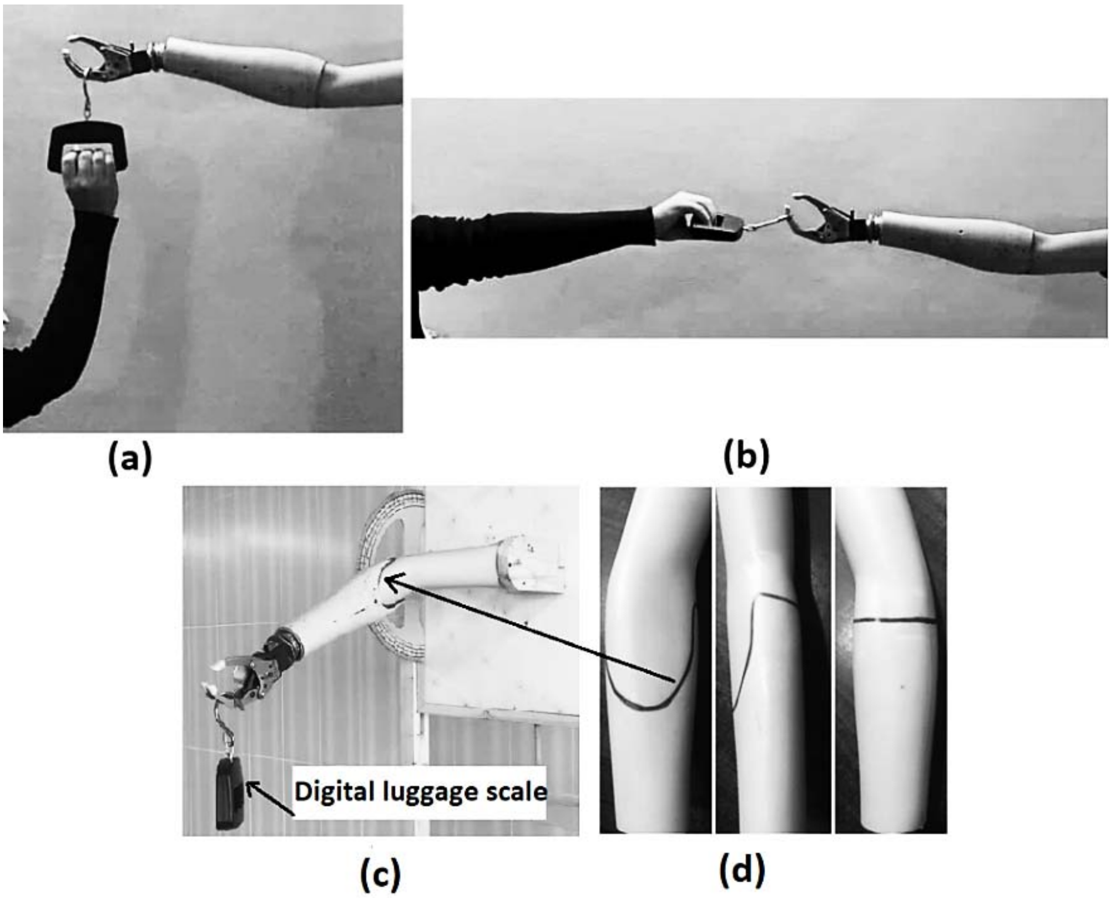

Figure 7.(a)Live-Lift Test, (b) Axial-Load Test, (c)Female Mannequin' arm simulating arm's anatomy of body human, and (d) Mark on the female mannequin' arm.

Table 2. Live-Lift and Axial-Load test Pronation and Supination movements.

	Abduction	Adduction
Angle (degree)	0 º	85 º
Live-Lift force (g)	6325	2330
Axial-Load force (g)	2330	523

Table 3. Live-Lift and Axial-Load test for Flexion and Extension movements.

	Flexion	Extension
Angle (degree)	20 º	175 º
Live-Lift force (g)	6577	875
Axial-Load force (g)	3620	523

In table 4, in pronation case, live-lift force was larger than axial-load force. In supination case, live-lift force was larger than axial-load force.

Table 4. Live-Lift and Axial-Load test for Flexion and Extension movements.

	Pronation	Supination
Angle (degree)	0 º	360 º
Live-Lift force (g)	6325	5425
Axial-Load force (g)	3620	2752

4. Discussion

The test rig was designed to simulate the human arm movement. All the parts of this test rig are made from wood. It is supplied with special parts to allow movements in Euler planes or angles. Four pins are used to allow movements in pitch and yaw angle. When two pins are connected with plate on the Y-axis and be free with X-axis, plate can rotate about the Y-axis (making yaw angle). Opposite to this, plate rotates about X-axis (making pitch angle) when pins are connected only with plate on the X-axis. Wooden connection part is responsible for rotation the arm about Z-axis (making roll angle).

The purpose of this test rig is the aid for assessment on the used commercial socket experimentally. The shape of the socket and cross sections at different locations are elliptical with different diameters. The study implemented two setup tests for the socket (Live-Lift Test and Axial-Load Test). Two tests were done at different positions as the human arm movements (Abduction, Adduction, Flexion, Extension, Supination and Pronation). The socket was suspended on Female mannequin arm without considering material used to simulate the soft tissues of the human body.

Referring to the experimental work, live-lift force is larger than axial-load force in all cases (Abduction, Adduction, Flexion, Extension, Supination and Pronation). In pronation and supination case, the variation of the measured forces was affected by the ending shape of the socket. In adduction, abduction, flexion, and extension cases, the experimental tests restricted by the edge of plate form of the test rig. Therefore, the tested socket didn't reach to 90 º and 180 º.

5. Conclusion

The study introduced a test rig design to test the commercial socket at different positions and planes that simulate the arm movements. The experimental work covers two main tests to assess the dislocation of the socket for Guarantee the safety for amputee. In the future, the study could use special materials to resemble the soft tissues of the human body.

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