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Manufacture of a mechanical test rig to simulate the movements of forces within the shoulder

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ABSTRACT

The shoulder complex, also known as the glenohumeral joint is the most manoeuvrable and one of the most well used joints of the human body. Over time problems can occur with the glenohumeral joint and surrounding muscles, cartilage, tendons and ligaments caused by ageing or by over stressing the shoulder complex. This work examines the design of a new innovative glenohumeral test rig. The test rig was required to imitate the movement of the humerus in the human body and replicate all the ranges of motion, which it can move in when combined with the relevant bones, muscles, ligaments and tendons in the shoulder complex. A variable force also had to be applied to the glenoid in all ranges of motion. Research had to be undertaken in the ranges of motion of the shoulder complex and the forces acting on the glenoid. Concept designs were initially created to mimic specific ranges of motion; adduction, flexion, internal (medial) and external (lateral) rotation for example. The concepts were evolved and combined to develop a test rig that would replicate any axial movement of the shoulder. Research determined the most appropriate manufacturing processes and materials so that the test rig could be manufactured in the material laboratories.

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1. Introduction

The Glenohumeral joint is the most manoeuvrable and one of the most well used joints in the body. It can become damaged due to sporting activities or through general wear and tear which can result in serious problems for the person with the injury. Surgeons, engineers and researchers are continually investigating methods of improving the quality of life of patients with shoulder problems and are developing methods of replacing, repairing and reducing the problems that may occur to the shoulder joint [1–12]. This research was carried out so that further developments into shoulder injury prevention, replacement and repair can take place via the design of a new and innovative glenohumeral test rig. The test rig will allow researchers to carry out tests on prosthetic humerus bones and allow them to add prosthetic muscles and apply forces to glenohumeral joint and make advances in the technology and knowledge in this field [13,14].

Fig. 1 above shows the major bones and muscles that make up the shoulder complex. The humerus is the main bone of the shoulder of which the shoulder test rig is designed around. As people age the humerus can become worn and prone to osteoarthritis. This causes the cartilage, used to distribute stress and loads on the shoulder, to deteriorate. In severe cases the humeral head must be replaced with a prosthetic device [15]. This test rig is designed to simulate the forces acting on the glenoid in any range of motion so that new prosthetic devices can be designed and tested.

2. The shoulder complex and ranges of motion

There are six main motions that the shoulder can perform these are known as adduction, abduction, extension, flexion, internal (medial) and external (lateral) rotation. Each of these movements is restricted by ligaments and moved by the muscles of the shoulder complex. The shoulder has the greatest range of motion of any joint in the human body [17–19] (Fig. 2).

Adduction—absolute adduction is mechanically impossible because of the presence of the trunk. Starting from a reference point position, adduction is only possible when combined with extension; this allows a trace of adduction and flexion: which allows adduction to reach 30–45° [17,18]. Transverse adduction is the medial movement toward the midline of the body in a horizontal plane; moving the upper arm toward and across the chest with the back of the arm facing down.

True *abduction* of the GH joint (referred to as true Glenohumeral motion) is limited to only 90°. Beyond 90°, it is a combined effort between both the GH and ST joints. In fact, at 180° abduction (arm straight up overhead), only two-thirds of the

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movement occurred at the GH joint (30° on its own, 90° combined with the ST joint and the remaining 60° exclusively occurring at the ST joint). This seamless combination of movements between the humerous and the scapula is referred to as the scapulohumeral rhythm [19].

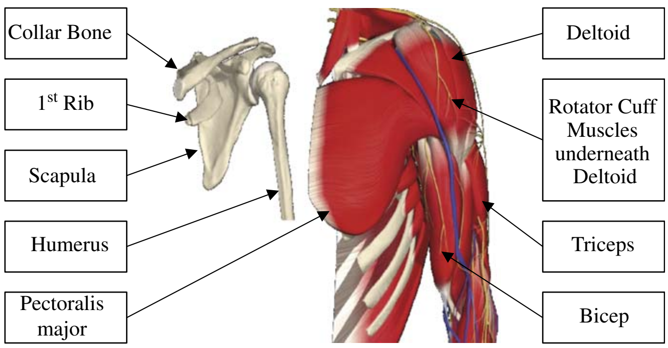

Fig. 1. Some of the major bones and muscles that make up the shoulder complex [13–16].

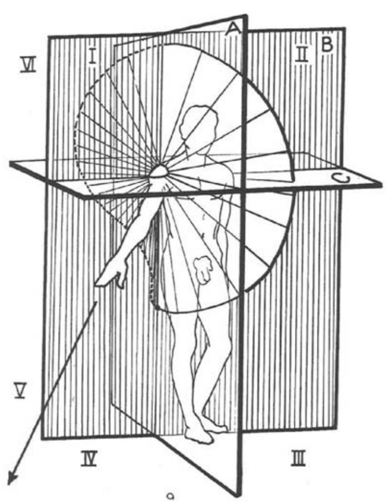

Fig. 2. The range of motion that the shoulder complex possesses [17].

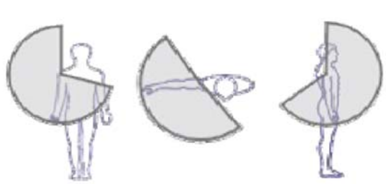

Fig. 3. The range of motion of the shoulder.

Extension is straightening the joint resulting in an increase of angle; moving the upper arm down to the rear. The movement capable of producing the next greatest level of strength second to the adduction strength is the extension movement. Extension uses the same muscle groups as the movement of adduction. Extension is slightly stronger than its opposite movement flexion. Extension, is closely associated with adduction, it has a limited range of between 30° and 50° [17–19].

True forward *flexion* at the GH joint ranges from 0° to 90°, with the movement itself separated into three distinct phases [19].

Internal (Medial) rotation is the rotary movement around the longitudinal axis of the bone toward the centre of the body; turning the upper arm inward. In internal medial rotation the shoulder can rotate 90° [17].

External (lateral) rotation involves the rotary movement around the longitudinal axis of the bone away from the centre of the body; turning the upper arm outward. In external lateral rotation the shoulder can rotate 90° [18] (Fig. 3).

3. Design

The initial stage involved brain storming and the generation of hand drawn concepts of the different test rigs. The designs evolved from a test rig concept that simply covered rotation of the shoulder to a concept test rig that covered extension, then extension and rotation, and finally a concept test rig was designed that could cover all the ranges of motion in the shoulder. Fig. 4 shows the initial concept design modelled in CAD [18–21].

The head of the humerus mounts to the front plate of the mounting module which has the freedom to turn 360° and also the ability to move around the semi circular track. The distal end of the humerus bone would be fixed to the distal end holder. The track will be mounted to two columns, inside the columns there will be large motors used to turn the track. Therefore the test rig is able to recreate the movement of the shoulder complex.

The major components of the concept test rig shown above in Fig. 4 were then evaluated and re-designed in detail. The authors could not presume that this initial design would perform correctly but by examining each component individually and creating concepts designs and evaluating those concept designs it could be ensured that the component would be fit for purpose. The figures below in Table 1 show the concept designs which were created for each of the major components.

4. Concept designs

The concept designs were all evaluated using a number of methods for example the track would be stressed when the actuators mounted to the mounting module are used to apply

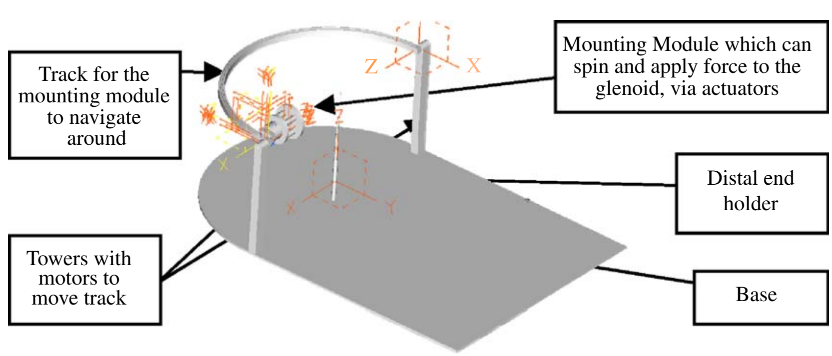

Fig. 4. The initial concept design of the Glenohumeral test rig.

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