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A quantitative method for evaluating inferior glenohumeral joint stiffness using ultrasonography

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ABSTRACT

Subluxation of the affected shoulder in post-stroke patients is associated with nerve disorders and muscle fatigue. Clinicians must be able to accurately and reliably measure inferior glenohumeral subluxation in patients to provide appropriate treatment. However, quantitative methods for evaluating the laxity and stiffness of the glenohumeral joint (GHJ) are still being developed. The aim of this study was to develop a new protocol for evaluating the laxity and stiffness of the inferior GHJ using ultrasonography under optimal testing conditions and to investigate changes in the GHJ from a commercially available humerus brace and shoulder brace. Multistage inferior displacement forces were applied to create a glide between the most cephalad point on the visible anterosuperior surface of the humeral head and coracoid process in seven healthy volunteers. GHJ stiffness was defined as the slope of the linear regression line between the glides and different testing loads. The testing conditions were defined by different test loading mechanisms ($n = 2$), shoulder constraining conditions ($n = 2$), and loading modes ($n = 4$). The optimal testing condition was defined as the condition with the least residual variance of measured laxity to the calculated stiffness under different testing loads. A paired t-test was used to compare the laxity and stiffness of the inferior GHJ using different braces. No significant difference was identified between the two test loading mechanisms ($t = 0.218$, $p = 0.831$) and two shoulder constraining conditions ($t = -0.235$, $p = 0.818$). We concluded that ultrasonographic laxity measurements performed using a pulley set loading mechanism was as reliable as direct loading. Additionally, constraining the unloaded shoulder was proposed due to the lower mean residual variance value. Moreover, pulling the elbow downward with loading on the upper arm was suggested, as pulling the elbow downward with the elbow flexed and loading on the forearm may overestimate stiffness and pain in the inferior GHJ at the loading point due to friction between the wide belt and skin. Furthermore, subjects wearing a humerus brace with a belt, which creates the effect of lifting the humerus toward the acromion, had greater GHJ stiffness compared to subjects wearing a shoulder brace without a belt to lift the humerus under the proposed testing conditions. This study provides experimental evidence that shoulder braces may reduce GHJ laxity under an external load, implying that the use of a humeral brace can prevent subluxation in post-stroke patients. The resulting optimal testing conditions for measuring the laxity and stiffness of the GHJ is to constrain the unloaded shoulder and bend the loaded arm at the elbow with loading on the upper arm using a pulley system.

1. Introduction

The shoulder joint is the most complex and unstable joint in the human body. The shoulder, which can assume more than 1600 different positions in its three-dimensional (3D) space [1], consists of three bones: the humerus, scapula, and clavicle. The glenohumeral joint (GHJ), which consists of the humeral head and glenoid, is a ball-and-socket mechanism stabilized by the labrum, glenohumeral ligaments, rotator cuff, and other muscles. The GHJ allows great mobility, but is also prone to instability.

The reported incidence of shoulder subluxation in hemiplegic patients after a stroke is between 17 and 84% [2–5]. Shoulder subluxation is a pathologic condition manifesting as pain and excessive translation of the humeral head on the glenoid during active motion

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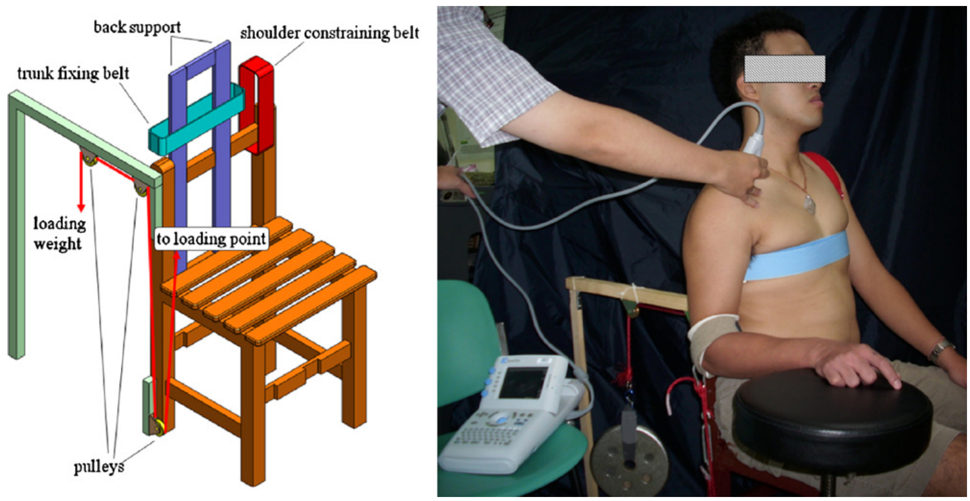

Fig. 1. Design of the custom-made chair. The chair was used to position the subject with back support and straps stabilizing the trunk and shoulder. Multistage inferior displacement forces of 30, 60, 90, and 120 N were applied using a counterweight and pulley set.

of the shoulder. Inferior glenohumeral subluxation (GHS) is the most common complication, and is a major cause of pain in stroke patients, accounting for 17–75% of all cases [6]. In this study, the laxity and stiffness of the GHJ were used to represent asymptomatic movement between the humeral head and glenoid with a displacement force to the humerus.

It is difficult to measure the internal force acting in the GHJ without artificially implanting instruments into the GHJ of patients undergoing shoulder replacement [7]. A mathematical approach, using a 3D model of the GHJ can be used to predict the relationship between the external load and humeral head translation [8–10] and to evaluate the laxity and stiffness of the GHJ; however, the construction of individual GHJ models is not feasible for a clinician or therapist.

Stress radiology has been used as a standard measurement to evaluate GHJ stiffness [11]. Several studies have demonstrated the reliability [12,13] and validity [13] of radiographic approaches. In recent years, ultrasonography has been recognized as a convenient and economical method for measuring real-time joint characteristics and movements. Additionally, good agreement has been demonstrated between ultrasonography and stress radiology with good reproducibility and validity [14,15] in assessing the laxity of the GHJ.

Several studies have reported the use of ultrasonography to investigate different characteristics of the GHJ [14–17], but none have addressed the issue of a standard procedure for measuring the laxity and stiffness of the inferior GHJ. The purpose of this study was to identify optimal testing conditions for measuring the laxity and stiffness of the inferior GHJ, and to quantitatively compare two types of commercial braces.

2. Methods

In this study, a custom-made chair for positioning the subject was developed in-house; the conceptual design is shown in Fig. 1. It had a vertical back to allow the subject to sit upright. Wide belts were used to stabilize the subject's trunk and shoulder. To prevent experimental variation, loading was performed using a set of pulleys and adjusted by the examiners behind the participant. The chair was used to execute two series of tests, which involved two types of loading mechanisms, two shoulder constraint conditions, four loading modes, three brace wearing conditions, and a multistage test with loads varying from 0 to 120 N.

2.1. Experimental design and measures

To evaluate the optimal conditions for measuring the laxity and stiffness of the inferior GHJ, three test parameters (test loading mechanism, shoulder constraint condition, and loading mode) were considered. Two types of test loading mechanisms, direct loading (DL) and indirect loading (IDL) conducted via a pulley system, were designed. Two conditions for restricting shoulder movement during testing were considered, the first using a wide belt to stabilize the unloaded shoulder (CS) and the second without restricting the unloaded shoulder (NCS). Additionally, four loading modes were adopted: (1) pulling the elbow downward with loading on the wrist (SW); (2) pulling the elbow downward with loading on the upper arm (SU); (3) pulling the upper arm downward with loading on the upper arm with the elbow flexed (FU); and (4) pulling the upper arm downward with loading on the forearm with the elbow flexed (FF) (Fig. 2).

To demonstrate the effect of braces on the stiffness of the GHJ, two types of braces were evaluated in a second series of tests. Additionally, the experimental results for subjects wearing braces were compared with subjects without braces. The evaluation procedures for those wearing braces were the same as for those without braces. The relative glide between the most cephalad point on the visible anterosuperior surface of the humeral head and coracoid process was measured under five test loads (0, 30, 60, 90, and 120 N).

2.2. Participants

Fourteen healthy participants were recruited from the general population at a university through an advertisement. The participants were randomly divided into two groups for two series of tests. In the first series, seven healthy participants (age = 24.6 ± 3.6 years, height = 172.3 ± 3.9 cm, weight = 69.0 ± 12.1 kg) were recruited to determine the optimal testing conditions for measuring the laxity and stiffness of the inferior GHJ using ultrasonography. In the second series, seven participants (age = 24.7 ± 3.5 years, height = 172.4 ± 4.0 cm, weight = 69.9 ± 12.9 kg) were recruited to evaluate the effects of two types of braces under our optimized testing conditions. Subjects were excluded if they had a history of shoulder surgery or injury within the last two years.