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Volumetric definition of shoulder range of motion and its correlation with clinical signs of shoulder hyperlaxity. A motion capture study

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Background: Shoulder hyperlaxity (SHL) is assessed with clinical signs. Quantification of SHL remains difficult, however, because no quantitative definition has yet been described. With use of a motion capture system (MCS), the aim of this study was to categorize SHL through a volumetric MCS-based definition and to compare this volume with clinical signs used for SHL diagnosis.
Method: Twenty-three subjects were examined with passive and active measurement of their shoulder range of motion (SROM) and then with an MCS protocol, allowing computation of the shoulder configuration space volume (SCSV). Clinical data of SHL were assessed by the sulcus sign, external rotation with the arm at the side (ER1) >85° in a standing position, external rotation >90° in a lying position, and Beighton score for general joint laxity. Active and passive ER1, EIR2 (sum of external and internal rotation at 90° of abduction), flexion-extension, and abduction were also measured and correlated to SCSV.
Results: Except for the sulcus sign, SCSV was significantly correlated with all clinical signs used for SHL. Passive examination of the different SROMs was better correlated to SCSV than active examination. In passive examination, the worst SROM was ER1 ($R = 0.36$; $P = .09$), whereas EIR2, flexion, and abduction were highly correlated to SCSV ($P < .01$).
Conclusion: SCSV appears to be an appealing tool for evaluation of SHL regarding its correlation with clinical signs used for SHL diagnosis. The sulcus sign and ER1 >85° in a standing position appear less discriminating and should be replaced by EIR2 measurement for SHL diagnosis.
Level of evidence: Basic Science, Kinematics.

Keywords: Shoulder; shoulder kinematics; shoulder laxity; hyperlaxity: shoulder instability

Shoulder hyperlaxity (SHL) is considered a main risk factor for shoulder instability[2] and can be associated with different clinical shoulder instability presentations, such as multidirectional instability or unstable painful shoulder.[15] Interestingly, quantification of shoulder laxity and hyperlaxity, particularly during physical examination, still remains an unsolved problem.[8,20,21,26] Increased shoulder

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laxity, so-called hyperlaxity, can be defined as an increased amount of manual glenohumeral translation of the shoulder[11] or a global increased range of joint movement.[9] Currently, no shoulder laxity clinical test appears completely reliable[13,17] because of the spectral distribution of shoulder laxity in the population. Furthermore, only a few studies have described SHL from a biomechanical or a motion capture analysis point of view[7,15,16] but confirmed the possible use of a motion capture system (MCS) as an appropriate tool for quantitative assessment of multiaxial shoulder motion.

The lack of shoulder laxity quantification motivated this study. We hypothesized that the total volume of shoulder range of motion (SROM) is correlated to SHL. The aim of our study was to assess the 3-dimensional (3D) shoulder motion analysis in an asymptomatic population to know whether range of motion and, above all, external rotation are correlated to SHL. Finally, we tried to correlate actual clinical signs used for SHL diagnosis to this volumetric definition of SROM.

Materials and methods

This is an observational motion capture study.

Subjects

Twenty-three healthy female volunteers (medical or sports students; age, 24.5 ± 2.5 years [range, 20.2-29.9 years]; height, 165 ± 6 cm [range, 157-175 cm]; body mass index, 18.5 kg/m^2 ± 1) were selected for study. All subjects were right-hand dominant. Exclusion criteria were a positive apprehension test result or symptoms of instability, positive Neer test result or pathologic rotator cuff test result (Jobe, Yocum, palm-up, and lift-off tests), previous history of shoulder surgery or complaint, shoulder trauma (including acromioclavicular joint), sensitivity to adhesive tape, pregnancy, Marfan syndrome, psychological voluntary subluxation, and neck pain (complaint or surgery). Written informed consent was obtained from all subjects before participation.

Clinical examination

Before MCS analysis of SROM, SHL was searched for in every subject by different clinical criteria. Each clinical sign was elicited and assessed jointly by 2 shoulder senior orthopedic surgeons (M.R. and H.T.). Before examination and experimentation, all subjects sustained upper limb preparatory movements realizing complete circular movements of their dominant right arm in maximal SROM.

Signs considered for SHL diagnosis were the following:

- Passive hyperrotation with external rotation with the arm at the side (ER1) >85° in a standing position.[2]
- Passive hyperrotation with ER1 >90° in a lying position.[18]
- Sulcus sign >2 cm (yes or no).
- Sulcus sign grades (0, +, ++, +++).[9]
- Beighton scale for general joint laxity >5 points: passive metacarpophalangeal joint hyperextension of small finger > 90° (2 points); passive thumb apposition to forearm (2 points); elbow hyperextension >10° (2 points); knee hyperextension >10° (2 points); trunk flexion, knee extension, and palms to the floor (1 point).[3]

Figure 1 Overview of marker placement with rigid purpose-built splint at 90° of elbow flexion in neutral prone supination.

Active and passive ER1 measurements in a standing position were performed with a physiotherapist goniometer.

Instrumentation: motion analysis protocol

A 12-camera MCS (Vicon MX40; Oxford Metrics Ltd, Oxford, UK) was used to track the 3D displacements of markers of the whole upper limb to obtain 3D kinematics data. The upper limb and thoracic markers were positioned on the subjects by the same experienced physician for all the procedures and placed by the recommendations of the International Society of Biomechanics.[25] All measurements were realized with a purpose-built splint at 90° of flexion in a neutral forearm position (supination = 0°) (Fig. 1) to avoid coupling between elbow flexion/extension and shoulder motion analysis. The splint was designed with windows allowing shoulder examination and positioning of anatomic landmarks used for positioning markers tracked during motion capture analysis.

During MCS recording, subjects were first examined with measurement of ER1, EIR2 (external plus internal rotation at 90° of abduction), flexion, extension, and abduction. All measurements were performed in a standing position. First, the same senior shoulder orthopedic surgeon performed a passive examination. After this passive examination, subjects performed the same set of measures actively. Finally, the subject (active measure) or the examiner (passive measure) was asked to perform combined rotations in extreme SROM to explore all the shoulder joint reachable space, allowing determination of the passive and active shoulder configuration space volume (SCSV) (Fig. 2), expressed in 10^6 deg^3. This volume was defined as the smallest convex hull of a polyhedron including all measures in the 3D angular space proposed by the International Society of