J Shoulder Elbow Surg (2016) ■■, ■■–■■

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Procedure to describe clavicular motion

Guivey Gutierrez Delgado, ING[a,*], Matthieu De Beule, PhD[b], Dolgis R. Ortega Cardentey, ING[a], Patrick Segers, PhD[b], Arsenio M. Iznaga Benítez, PhD[a], Tania Rodríguez Moliner, PhD[a], Benedict Verhegghe, PhD[b], Tanneke Palmans, MSc[c], Tom Van Hoof, PhD[d], Alexander Van Tongel, PhD[e]

[a]*Departamento de Gráfica de Ingeniería, Instituto Superior Politécnico José Antonio Echeverría (ISPJAE), Havana, Cuba*
[b]*IBiTech-bioMMeda, iMinds Medical IT, Ghent University, Ghent, Belgium*
[c]*Department of Rehabilitation Sciences and Physiotherapy, Ghent University, Ghent, Belgium*
[d]*Department of Basic Medical Sciences, Ghent University, Ghent, Belgium*
[e]*Department of Orthopaedic Surgery and Traumatology, Ghent University, Ghent, Belgium*

Background: For many years, researchers have attempted to describe shoulder motions by using different mathematical methods. The aim of this study was to describe a procedure to quantify clavicular motion.
Methods: The procedure proposed for the kinematic analysis consists of 4 main processes: 3 transcortical pins in the clavicle, motion capture, obtaining 3-dimensional bone models, and data processing.
Results: Clavicular motion by abduction (30° to 150°) and flexion (55° to 165°) were characterized by an increment of retraction of 27° to 33°, elevation of 25° to 28°, and posterior rotation of 14° to 15°, respectively. In circumduction, clavicular movement described an ellipse, which was reflected by retraction and elevation. Kinematic analysis shows that the articular surfaces move by simultaneously rolling and sliding on the convex surface of the sternum for the 3 movements of abduction, flexion, and circumduction.
Conclusion: The use of 3 body landmarks in the clavicle and the direct measurement of bone allowed description of the osteokinematic and arthrokinematic movement of the clavicle.
Level of evidence: Basic Science Study; Kinetics

Keywords: clavicular motion; sternoclavicular joint; shoulder kinematics; 3D kinematics; biomechanics; local coordinate systems; clavicle

For many years, researchers have attempted to describe shoulder motion[7-9] by using different mathematical methods for their analysis, including Euler/Cardan angles, helical angles,[11,17] and matrix rotation.[3,20] The most highly recommended method according to specialized literature is the use of Euler/Cardan angles[18,19] because they facilitate calculating and interpreting joint positions from a clinical point of view.[17] Euler/Cardan angles define the joint position as a set of sequential rotations around the 3 axes.[11,15,19] However, there are 12 possible combinations for each movement, providing different descriptions for the same position.[16,17]

Because of this, the Standardization and Terminology Committee of the International Society of Biomechanics (ISB)

The Ghent University Ethics Committee authorized this study.

* Reprint requests: Guivey Gutierrez Delgado, ING, Instituto Superior Politécnico José Antonio Echeverría, Departamento de Gráfica de Ingeniería, Calle 114 #11901 e/ Ciclovía y Rotonda, 19390, Ciudad de la Habana, Cuba.

E-mail address: guivey11@yahoo.es (G. Gutierrez Delgado).

1058-2746/$ - see front matter © 2017 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
http://dx.doi.org/10.1016/j.jse.2016.09.009

proposed a set of recommendations for selecting the sequence that best describes the position of a human joint. The recommended sequence is based on the cancellation of positions, aligning the coordinate axes with anatomy.[5,19] However, Senk and Chèze[12] reported that there are 2 disadvantages when such a rotation sequence is used. The first is a mathematical determination of values near 0° or 180° that is called "gimbal lock." The second problem is that the described motion depends on the rotation axis sequence used for the analysis.[1,2,13] This can cause inconsistencies between the kinematic representation of movement and clinical interpretation. Senk and Chèze[12] showed that the coordinate system proposed by the ISB does not allow a clinical description of all possible movements of the arm.[12]

The sternoclavicular joint and the motion of the clavicle are the least studied movements in the human body. This joint is treated by some researchers as a ball-and-socket type joint,[6,7] with the main movements being elevation, retraction, and axial rotation. However, the axial rotation of the clavicle cannot be determined using the method proposed by the ISB because only 2 relevant points are identified in the collarbone. Wu et al[19] suggest that this can be estimated using the optimization technique shown by Van der Helm and Pronk.[14] The aim of this study was to propose a procedure to describe clavicular motion in 3 dimensions (3D) using direct measurements of bone and 3 transcortical pins in the clavicle.

Materials and methods

This is an invasive study of 3D movement of the clavicle in a cadaver. The deceased donor was a 45-year-old woman provided by the Anatomy Department of Ghent University Hospital. She had no known history of trauma, fractures, or dislocations, and had no abnormalities of the shoulder joint.

Sample preparation

We placed passive reflective markers in the clavicle, sternum, humerus, and scapula, keeping in mind the recommendations given by the ISB.[19] These markers were placed on transcortical pins (Fig. 1). Three pins were placed in the clavicle: the first was placed in the most ventral point near the sternoclavicular joint, a second pin was placed in the most dorsal point near the acromioclavicular point, and the last pin was placed at the midclavicular (MC) point between the first 2 described pins (Fig. 1, *A*). The third pin was placed to assist in calculating the motion. Two extra pins were added, one at the tuberosity deltoid point, and a second at the scapular spine.

The pins were drilled into position (Fig. 1), and markers were placed on them to identify the pin position during data collection. We verified that the markers did not hinder displacement or rotation of the arm during the experiments and checked that the markers remained rigidly fixed throughout the tests.

Motion capture

The body was in a seated position to avoid slipping during the experiments. Six cameras captured the trajectory of the markers. All series of motions were performed by the same technician, who tried to keep a constant speed of the trajectories to reduce error. The technician rested between each series of motion so that fatigue would not affect the results. Three different motions of the arm—abduction, flexion, and circumduction—were performed, and each experiment was repeated at least 5 times. The capture process resulted in a database with the positions of all markers as a function of time.

Obtaining 3D bone models

The cadaveric skeleton was then reconstructed in 3D. This was done for 3 main reasons: to simulate joint motion, to measure precise pin location, and to analyze the geometric anatomy. This process began with computed tomography images (Somatom Volume Zoom CT Scanner; Siemens, Erlangen, Germany) of the cadaver. The pixel size and the slice increments were standardized at a maximum of 0.977 mm and 1.5 mm, respectively. We captured the images with the previously placed markers.

The 3D models of the bones were reconstructed using a new segmentation module implemented via pyFormex (http://pyformex.org) open source software. The method uses a combination of global and adaptive thresholds to determine the geometric bony anatomy and

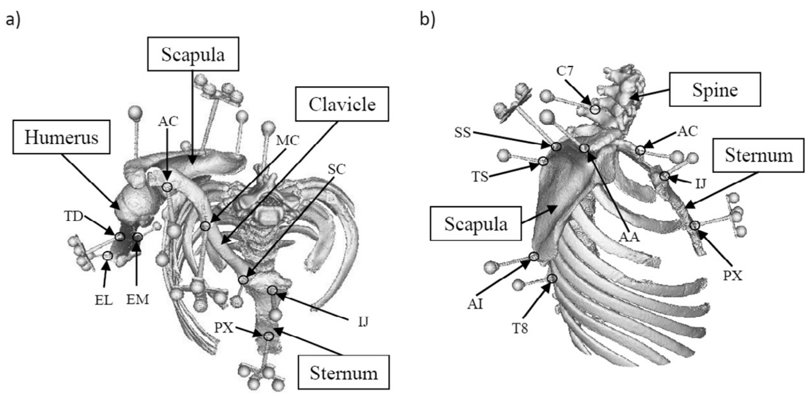

Figure 1 Shoulder markers. (**A**) Marker locations in clavicle (sternoclavicular [*SC*], acromioclavicular [*AC*], and midclavicular [*MC*]), humerus (most caudal point on lateral epicondyle [*EL*], most caudal point on medial epicondyle [*EM*], and tuberosity deltoid [*TD*]), sternum (suprasternal notch [*IJ*] and xiphoid process [*PX*]). (**B**) Markers in the spine (seventh cervical vertebra [*C7*] and eighth thoracic vertebra [*T8*]) and scapula (root of the spine [*TS*], acromial angle [*AA*], inferior angle [*AI*], and scapular spine [*SS*]) and sternum (IJ and PX).