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Letter to the editor

Recent advances in kinematics of the shoulder complex in healthy people

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Dear Editor,

The shoulder is the human's most mobile articular complex and is composed of 3 bones (clavicle, scapula, humerus) linked by 3 anatomical joints (sternoclavicular joint [SC], acromioclavicular joint [AC] and glenohumeral joint [GH]) and by the scapulo-thoracic joint (ST), considered a functional joint [1]. The global elevation range of motion (RoM) of the arm is mainly the result of a coordinated motion between the movements of the GH and ST joints, which contribute 30% to 40% of the total movement of the arm [2,3]. ST motion includes both rotation and translation and involves simultaneous rotations of the clavicle at SC and AC joints [4]. The efficiency of the "upper limb kinematic chain" is based on the coordinated and combined movements of the different shoulder joints; therefore, any clinical modification of one element of the shoulder complex will affect the global function of the "kinematic chain", requiring the development of appropriate methods of investigating the shoulder joint complex.

The shoulder joint complex was first assessed clinically (inclinometers) and with classical 2-D radiography, which showed that the scapula lateral rotation contributed to about one-third of the total arm elevation ("scapulohumeral rhythm"). However, 2-D measurement techniques do not allow for measuring the movements of a rigid body in space, defined by 6 degrees of freedom (DoF). Recently, 3D methods for analyzing the shoulder complex were derived from medical imaging (biplane, radiography, CT, fluoroscopy, MRI, low-dose biplane radiography EOS). The methods are based on the projection of 3D anatomical models of the bones on the radiography images and provide accurate access to the position and orientation of the bones. Nevertheless, most are irradiating methods and/or allow only static measurements.

The development of 3D kinematic analysis techniques (mainly electromagnetic or optoelectronic devices, Fig. 1), has allowed for precise and simultaneous kinematic measurements of the humerus, scapula and clavicle. To homogenize the description of movements, the International Society of Biomechanics (ISB) has defined the frames of reference for each bony segment from specific anatomic points and rotations according to Euler angles formalism [5].

These kinematic methods have some limitations. The first practical difficulty is detecting the anatomical landmarks with accuracy. The scapula is particularly difficult to assess because it is flat and surrounded by muscles, not readily visible during a clinical examination. Another difficulty is determining the GH rotation center because it cannot be palpated and must be calculated. There are also limitations that depend on the Euler angles convention due to mathematical singularities, particularly for large arm movements. However, the main limitation is soft tissue artefact (movement occurring between the skin and underlying bone) related to the use of sensors fixed on the skin. For some methods based on multiple calibration, a scapula tracker device or computed optimization methods have been developed to reduce the cutaneous artefact [6,7]. The "gold standard" kinematic method uses cortical pins inserted in the bones [3,8], which is invasive and not usable in clinical routine. The most-used 3D kinematic method is the "acromial method": the positions of the anatomical points are calibrated by reference to a 6-DoF frame cluster of 3D optic sensors fixed on the acromion. These studies are mostly based on arm elevation tasks in the sagittal and frontal planes (classically, "flexion" and "abduction"). Arm elevation relative to the trunk (humero-thoracic elevation) refers to the angle between the humerus and the thorax, regardless of the plane of elevation imposed by the task. The error seems acceptable for arm elevation $< 120^\circ$ [8,9].

From a biomechanical perspective, the GH joint has 6 DoF; 3 rotation degrees and 3 translations. The translation mobility of the humeral head results from the inequality of the curvature of the humeral head and glenoid; however, the translations measured by radiography, MRI or EOS remain small. Hence, in clinical anatomy, the GH joint is considered an enarthrosis "ball-and-socket joint". The GH complete elevation involves an automatic humeral lateral rotation [10].

The scapula movements relative to the trunk are currently described by 3 rotations: internal/external rotation (commonly named protraction/retraction) about the vertical trunk axis, the internal rotation taking the scapula medial border away from the thorax; medial/lateral rotation, about an antero-posterior axis perpendicular to the scapula plane, the lateral rotation taking the scapula inferior angle away from the spinous processes line; and anterior/posterior tilt, about an axis along the scapula spine, the anterior tilt taking the scapula inferior angle away from the thorax [5] (Fig. 2). Several scapulo-thoracic kinematics studies

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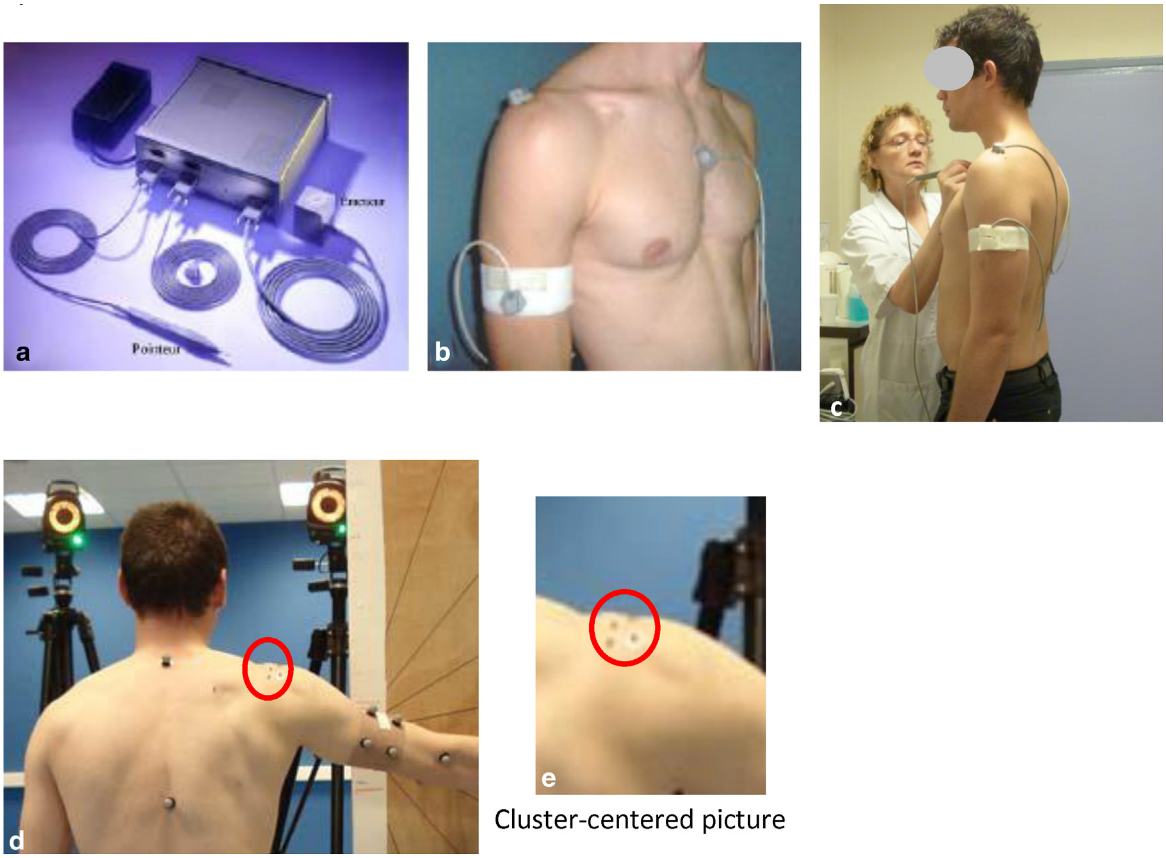

Fig. 1. Method for assessing 3D shoulder kinematics: a–c: example of electromagnetic device: Polhemus Fastrak electromagnetic device consisting of a transmitter and 4 receivers (3 fixed sensors and 1 movable) hardwired to the system's electronic unit; d: example of optoelectronic device: Vicon optoelectronic system emitting infrared waves picked up by passive optical markers and using a cluster of 3D optic sensors (circled in red) (Brochard et al., 2011).

using the "acromial method" found consensual results for the scapula resting position, (arm alongside the body): 30° to 40° internal rotation, rotation close to 0° and 10° anterior tilt. During arm elevation, the studies showed an increase in the scapula lateral rotation (up to 50°) and posterior tilt (up to 30°) regardless of the plane of elevation. Internal-external rotation was more variable. Nevertheless, most studies showed, from the rest position to 120° arm elevation, an increase in internal rotation in the sagittal plane and a decrease in internal rotation in the frontal plane [9,11].

The arm is connected to the trunk by the clavicle through the AC and SC joints. At rest, relative to the clavicle (AC joint), the scapula is in internal rotation of about 60°, in medial rotation of about 5° and in anterior tilt of about 10°; during arm elevation, up to 90°, scapula internal rotation increases about 10°, then decreases over 100° (i.e., relative external rotation); the ranges of lateral rotation and posterior tilt are about 20° and 15°, respectively. The clavicle movements relative to the thorax (SC joint) are described using 3 rotations: elevation/lowering about an axis pointing forward, protraction-retraction about an axis aligned on the thorax vertical axis and anterior/posterior axial rotation about the clavicle axis (Fig. 3) [5]. The in-vivo studies showed at rest, retraction of approximately 20°, a few degrees of elevation, and rotation close to 0°. The humerus elevation is accompanied by large 3D movements of the clavicle: retraction of about 10°, elevation of about 5°, and posterior axial rotation of about 25° [10,11].

Hence, the complete description of the movements of the scapula requires taking into account the movements of the clavicle in the AC and SC joints. Recently, quantifying the position and orientation of the scapula was proposed with the combined measure of 3D rotation and translation of its geometrical center (this description is geometrically correct and does not involve any hypothesis regarding the position of the instantaneous axis of rotation) [12]. Indeed, the presence of the clavicle, the ovoid shape of the thorax and the muscular structures that maintain the scapula against the thorax (notion of scapula closed chain) suggest a rotation–translation kinematic coupling, which reduces the number of independent DoF.

Later, we suggested using 3 "functional" DoF to describe the full mobility of the scapula (therefore taking into account the mobility of the clavicle through AC and SC joints). ST internal rotation is associated with anterior and lateral displacement of the center of the scapula, posterior tilt is associated with inferior displacement probably constrained by the curved surface of the thorax, with the scapula lateral rotation probably performed tangentially to the thorax surface [4].

These motions explain arm elevation up to about 150°. Further elevation implies a synergetic participation of the thoracic-lumbar spine, as confirmed by several studies [12].

To conclude, the complete upper limb elevation is principally the combination of the GH and ST joint movements (rotations and translations). ST motion involves a coordinated mobility of the AC and SC joints. For both clinical settings and research, assessment of the shoulder complex should not only be limited to GH movements but also must include the associated scapula-clavicle and trunk movements.

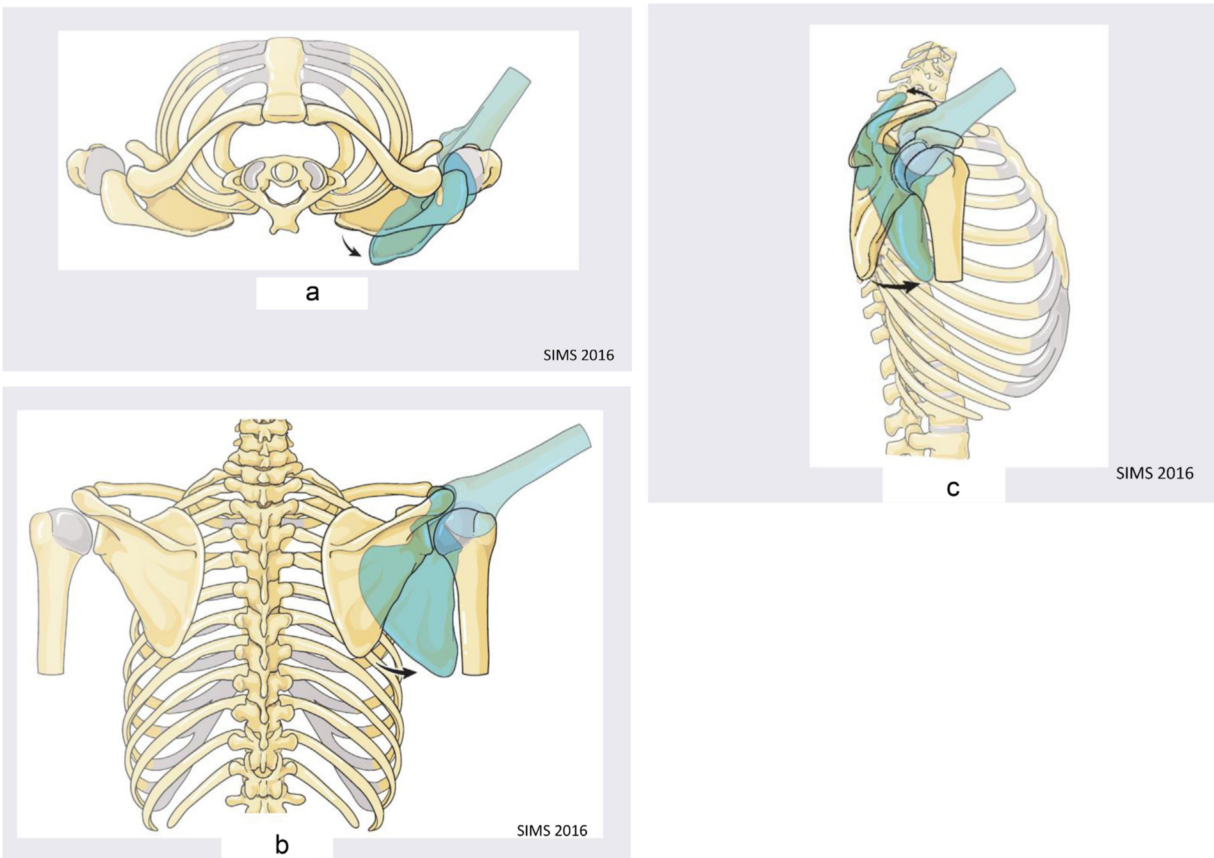

Fig. 2. Scapular movements relative to the trunk described by 3 rotations: internal/external (a), lateral/medial (b), anterior/posterior tilt (c).

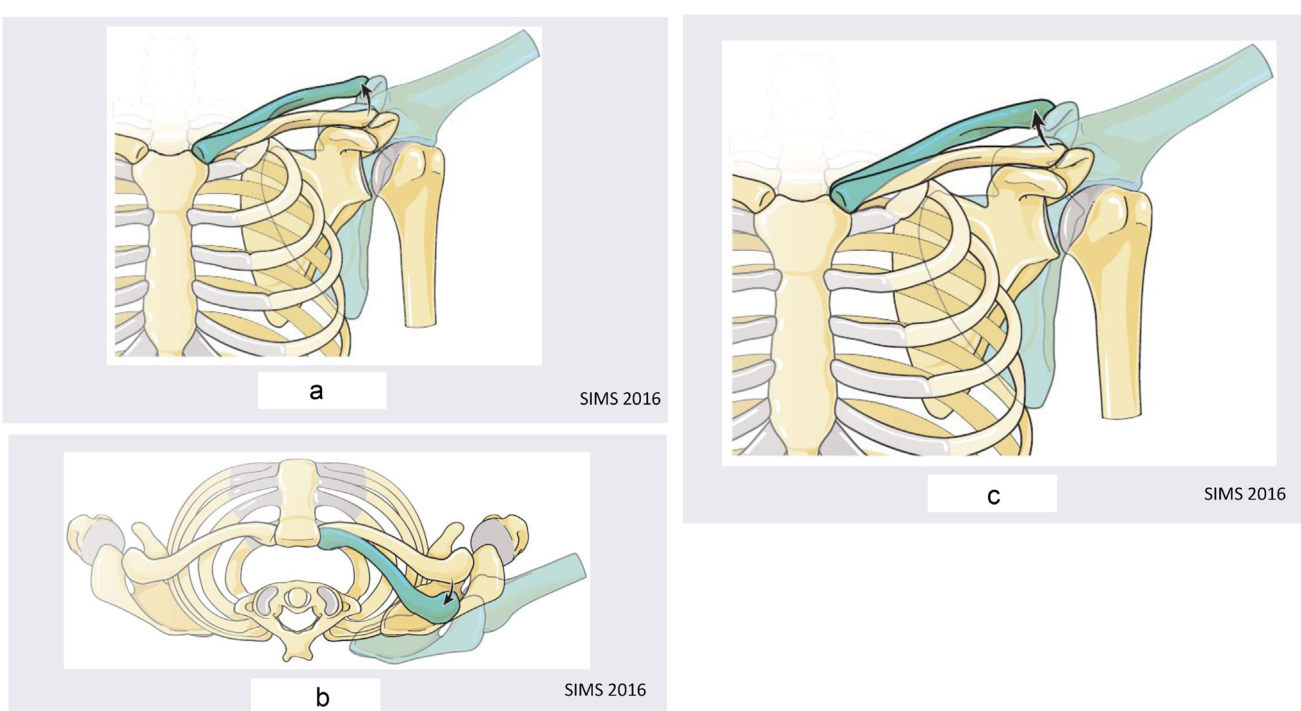

Fig. 3. Clavicle movements relative to the trunk described by 3 rotations: elevation/lowering (a), protraction-retraction (b) and anterior/posterior axial rotation (c).

Disclosure of interest

The authors declare that they have no competing interest.

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