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ORIGINAL ARTICLE

Digital data acquisition of shoulder range of motion and arm motion smoothness using Kinect v2

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Background: Range of motion (ROM) is a clinically important parameter in evaluating joint function. However, dynamic evaluation to determine the quality of the arm motion using digitized measurement is often overlooked during clinical assessment. We evaluated the accuracy of Kinect v2 (Microsoft, Redmond, WA, USA) as a digital tool for measuring shoulder ROM objectively and proposed a concept of motion smoothness reflecting the quality of arm motion.

Methods: Ten male participants were included in a 2-stage experiment. First, shoulder ROM was measured in 4 static poses (flexion, abduction, external rotation, and internal rotation) with Kinect v2, a 3-dimensional (3D) motion analysis system, and goniometry. Second, participants performed a point-to-point arm motion as naturally as possible. Kinematic data were collected with Kinect v2 and the 3D motion analysis system and then postprocessed to acquire parameters related to motion smoothness, including peak to mean velocity ratio, acceleration to movement time ratio, and number of peaks.

Results: Kinect v2 resulted in very good agreement of ROM measurement ($r > 0.9$) with the 3D motion analysis (95% limits of agreement < ±8°) compared with goniometry (95% limits of agreement < ±10°). Kinect v2 also showed a good correlation and agreement of measurement of motion quality parameters compared with the 3D motion analysis (peak to mean velocity ratio, acceleration to movement time ratio, and number of peaks: $r = 0.769$, discrepancy = ±0.1; $r = 0.922$, discrepancy = ±5%; and mean = 1 ± 0, respectively).

Conclusions: We show that Kinect v2 can be used as a reliable tool to measure shoulder ROM and arm motion smoothness.

Level of evidence: Basic Science Study; Kinesiology

Keywords: Shoulder; range of motion; Kinect; goniometry; motion analysis; motion smoothness

Range of motion (ROM) of the shoulder joint is an important clinical parameter related to glenohumeral disorders or functional evaluation of the shoulder before and after treatment.[9,13] A common method for measuring this parameter is the standard goniometer, which has been found to be reliable in a number of studies, making it a well-established

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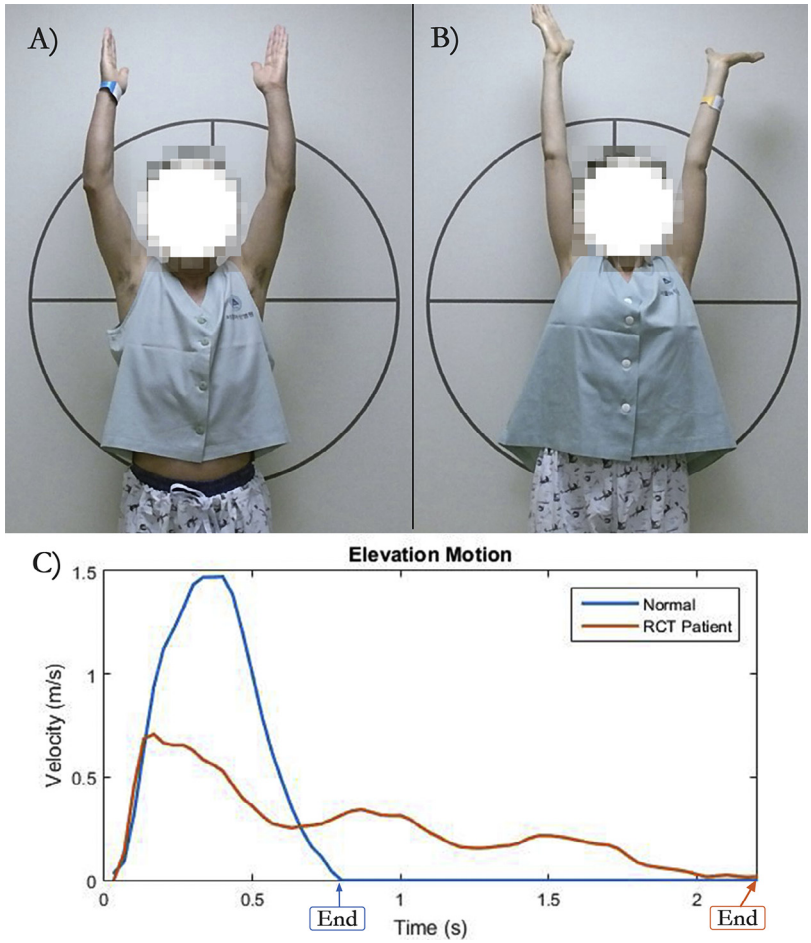

Figure 1 (**A**) Normal subject. (**B**) Patient with rotator cuff tear (*RCT*). (**C**) Arm velocity during elevation. Both subjects showed a high static shoulder range of motion, but the velocities of the subjects were different, which indicates the difference of the smoothness and the effort to reach this maximum elevation.

and widely accepted method for assessing ROM of the shoulder joint.[4,14,18] However, goniometry can be affected by several factors, such as the observer's experience or the method for estimating the center of rotation.[2,6,7,18,21] Thus, the measurement may vary among testers in clinical situations. In addition to low interobserver reliability and reproducibility,[19] standard goniometers are limited in that they measure only static joint angles. Therefore, a more accurate and digitized measurement of shoulder ROM may be valuable.

In clinical practice, postoperative evaluation focuses primarily on static outcomes (ie, ROM values) while often not documenting dynamic evaluation of the joint. On the basis of our observation, it is not unusual for patients to have a high degree of arm elevation after surgery (eg, flexion > 160°), but they require extra effort and a longer duration to reach this maximum elevation (Fig. 1). Thus, static ROM measurement alone does not comprehensively assess the function or disability of the shoulder joint. Dynamic evaluation including a digitized means to quantify the quality of the arm movement when the joint is in motion may be useful.[1,20] In the mechanical engineering field, a tangential velocity profile of arm motion has been used to illustrate the measurement of motion quality. A symmetric bell-shaped, unimodal velocity profile is expected from healthy individuals who are able to perform a smooth arm motion.[1,20] However, this digital evaluation generally requires a 3-dimensional (3D) motion analysis system, which is expensive and impractical in clinical settings (with markers required to be attached to the patient and postprocessing equipment required).

Kinect (Microsoft, Redmond, WA, USA) is a technology that has been adapted to measure shoulder ROM.[8,10,12] Kinect obtains depth images using a built-in infrared projector and complementary metal oxide semiconductor sensor to track the motion of individual joints in 3 dimensions. Several studies have tested the validity and reliability of Kinect for shoulder joint ROM measurement[8,10,12] with current measurement systems. However, these investigations were limited to the comparison of static shoulder ROM, and only a few studies used a 3D motion analysis system as the "gold standard" despite its high accuracy for shoulder measurement.[11]

To our knowledge, no researchers have assessed the validity and reliability of Kinect to measure motion smoothness–based parameters, and no study has yet assessed the validity and accuracy of the second-generation Kinect (Kinect for Xbox