J Shoulder Elbow Surg (2016) 25, 216-223

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JOURNAL OF
SHOULDER AND
ELBOW
SURGERY

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Measurement of active shoulder motion using the Kinect, a commercially available infrared position detection system

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Background: The shoulder's ability to participate in sports and activities of daily living depends on its active range of motion. Clinical goniometry is of limited utility in rigorously assessing limitation of motion and the effectiveness of treatment. We sought to determine (1) whether a validated position-sensing tool, the Kinect, can enable the objective clinical measurement of shoulder motion and (2) the degree to which active range of motion correlates with patient self-assessed shoulder function.
Methods: In 10 control subjects, we compared Kinect motion measurements to measurements made on standardized anteroposterior and lateral photographs taken concurrently. In 51 patients, we correlated active motion with the ability to perform the functions of the Simple Shoulder Test (SST).
Results: In controls, Kinect measurements strongly agreed with photographic measurements. In patients, the total SST score was strongly correlated with the range of active abduction. The ability to perform each of the individual SST functions was strongly correlated with active motion. The active motion in well-functioning patient shoulders averaged 155° ± 22° abduction, 159° ± 14° flexion, 76° ± 18° external rotation in abduction, −59° ± 25° internal rotation in abduction, and −3.3 ± 3.7 inches of cross-body adduction, values similar to the control shoulders. Use of the Kinect system was practical in clinical examination rooms, requiring <5 minutes to document the 5 motions in both shoulders.
Discussion: The Kinect provides a clinically practical method for objectively measuring active shoulder motion. Active motion was an important determinant of patient-assessed shoulder function.
Level of evidence: Level III, Diagnostic Study.

Keywords: Shoulder; motion; active; measurement

Active range of shoulder motion enables patients to perform activities of daily living and to participate in sports.[31,38,43] Restoration of active range of motion is one of the major goals for patients having treatment for shoulder conditions.[19,34,42,44,49]

Ranges of motion are important elements of commonly used shoulder outcome measures; for example, they account for 40% of the total Constant score.[26] However, there is wide variability in the way in which the range of shoulder motion is measured in clinical practice. This includes differences in the experience and training of the person making the measurements; whether and how a hand-held goniometer is used; how the center of rotation is estimated; the plane in which

This prospective study was approved by our Human Subjects Review Committee (Approval #47398).

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1058-2746/$ - see front matter © 2016 Journal of Shoulder and Elbow Surgery Board of Trustees.
http://dx.doi.org/10.1016/j.jse.2015.07.011

shoulder motion is measured; whether the patient is lying, sitting, or standing; whether the motion is active or passive; and the control for errors related to trunk lean and rotation.[6,8,9,15,22,25,28,32,36,39,45,46,48,50] This difficulty is exemplified by the observation that the interobserver variability in the range of motion measurement in the Constant score can exceed 20%, even when a standardized goniometric method is used.[7] The variability in the clinical measurement of shoulder motion makes it difficult to rigorously evaluate the extent of the limitations and the effectiveness of different approaches to the management of common pathologic processes of the shoulder, such as rotator cuff disease, internal rotation deficit,[10,13,14,20,27,30,35] and arthritis, as well as to determine the effects of interventions, such as remplissage, on the range of shoulder motion in living patients.[11,37]

This investigation explored the clinical measurement of the active range of shoulder motion using the Kinect (Microsoft, Redmond, WA, USA), an inexpensive, commercially available infrared system for the detection of body position. The use of the markerless Kinect in the measurement of shoulder positions has been extensively validated by comparison to marker-based optical motion capture systems.[1-5,12,18,21,23,24,41,47]

We sought to answer 4 questions. First, in normal control subjects, how do the Kinect measurements of abduction, flexion, external rotation in abduction, internal rotation in abduction, and cross-body adduction correlate with measurements of these arm positions made on standardized anteroposterior and lateral photographs taken concurrently? Second, can the Kinect system efficiently and practically measure the range of active shoulder motion of patients in the clinic setting? Third, how does the measured range of active motion correlate with patients' self-reported shoulder function as documented by the 12 functions of the Simple Shoulder Test (SST)? Fourth, what are the objectively measured ranges of active motion in normally functioning shoulders?

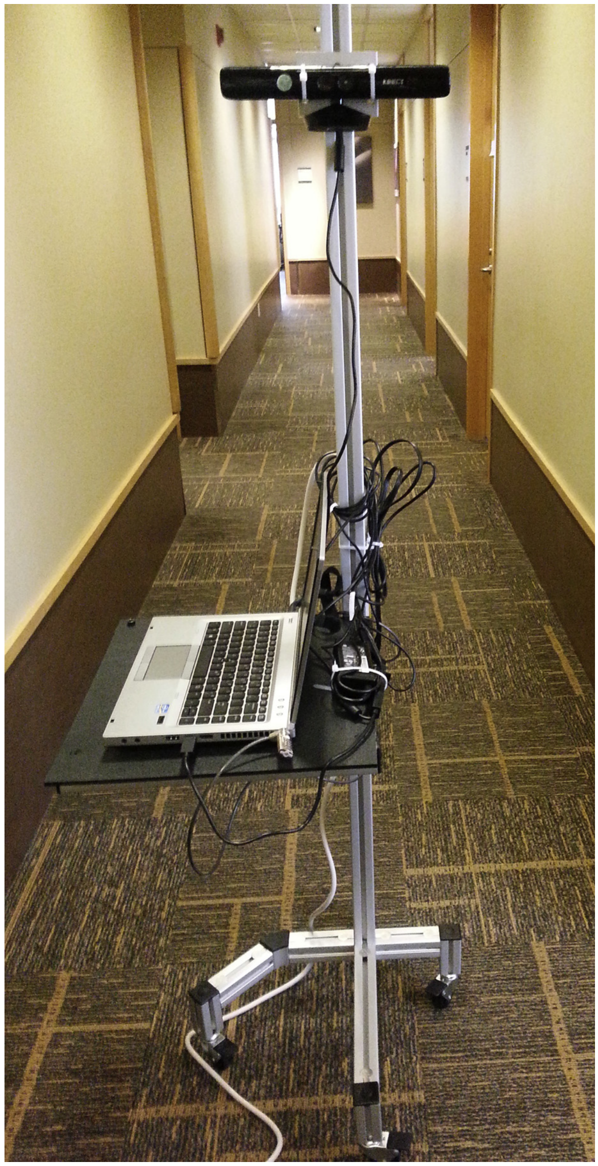

Figure 1 The Kinect sensor (Microsoft, Redmond, WA, USA) is an inexpensive (<$150), commercially available device with an infrared emitter and depth-sensing cameras enabling it to determine in 3 dimensions the location of the trunk and limbs of a person facing it. The sensor is mounted on a stand so that its height can be adjusted to the level of the subject's shoulder. The system is controlled by software on an ordinary laptop computer.

Materials and methods

The Kinect is an inexpensive (<$150), commercially available device used in computer games for the observer-independent detection of body position without the attachment of markers or sensors or any physical contact with the subject (Fig. 1). Instead, it projects infrared laser light on the person standing facing it and uses depth-sensing cameras to create a 3-dimensional body map by analyzing the pattern of the light reflected from the subject. The Kinect superimposes known relationships of the human trunk and limbs on this pattern, allowing the determination of the 3-dimensional positions of the forearm, elbow, arm, shoulder, and trunk (Fig. 2). The Kinect output enables the quantification of (1) humerothoracic abduction (the angle between the arm and the axis of the trunk in the coronal plane), (2) humerothoracic flexion (the angle between the arm and the axis of the trunk in the sagittal plane), (3) external rotation in abduction (the angle of the forearm above the horizontal when the arm is abducted 90° and the elbow is flexed to 90°—given a positive sign), (4) internal rotation in abduction (the angle of the forearm below the horizontal when the arm is abducted 90° and the elbow is flexed to 90°—given a negative sign), and (5) cross-body adduction (the distance in inches that the point of the elbow can reach across the midline of the trunk—given a positive sign if the elbow reaches across the midline). Each of the 5 measurements is made with the subject's body in the same position facing the sensor.