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ORIGINAL ARTICLE

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A biomechanical study of activities of daily living using neck and upper limbs with an optical three-dimensional motion analysis system

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Abstract In activities of daily living such as eating meals, the neck and upper limbs move in coordination. However, no methods have been established to analytically and quantitatively capture motion of the neck and limbs during these activities. We used a Vicon 512 system to simultaneously measure ranges of motion (ROMs) for the cervical spine, shoulders, elbows, and forearms. Correlations between the motion analyzer and the universal goniometer were >0.76. Repeatability of measurements using this analyzer were ≤3° for all values. This system is thus highly accurate and can be useful for motion analysis of the neck and upper limbs. The sum of flexion angles for the cervical spine, shoulders and elbows were almost constant for each activity, at 261° for shampooing, 207° for washing the face, and 185° for eating a meal.

Key words Daily activity · Neck movement · Three-dimensional (3D) motion analysis · Upper limb movement · Vicon

Introduction

In activities of daily living that use the upper extremities, such as eating meals, washing the face, and shampooing, the neck and upper limbs move in coordination. Conversely, if part of this coordinated system is impaired, compensatory movement of the other components will be indispensable for accomplishing activities. However, disability of the upper limb and neck is evaluated by functional assessment, mainly by measuring range of motion (ROMs) for each joint and assessing typical activities of daily living using a questionnaire. Data obtained using these methods are therefore subjective, static and nonanalytical.

With recent rapid advances in computer technology, motion analysis using optical three-dimensional (3D) motion analyzers has become more sophisticated and has seen application in various fields including gait analysis, computer graphics, and computer game animation.[1–4] To the best of our knowledge, no previous reports have examined systems evaluating combined motion of the neck and upper limbs.[5–7] This kind of technology would seem applicable to quantitative analysis of motions of the neck and upper limbs. The purpose of the present study was thus to assess the reliability of using a motion analyzer and to analyze the neck and upper limb motion during activities of daily living in a healthy volunteer. Analysis of neck and upper limb motion during activity would help in the formation of reconstruction plans appropriate for the individual condition of patients with joint deterioration.

Material and methods

System overview

The Vicon 512 system (Vicon Peaks, CA, USA) was used as an optical 3D motion analyzer. This system was placed in the rehabilitation room of our institution. Markers comprising inflated light-reflective plastic balls (diameter, 25 mm) were attached to the skin of the subject. Marker motions were tracked and captured on charge-coupled device (CCD) cameras, and visualized on a computer display. Based on these data, each joint motion was calculated automatically on a Vicon 4.5 workstation.[8]

Individual markers were placed at 23 points as designated by the manufacturer (Fig. 1 and Table 1): head, 4

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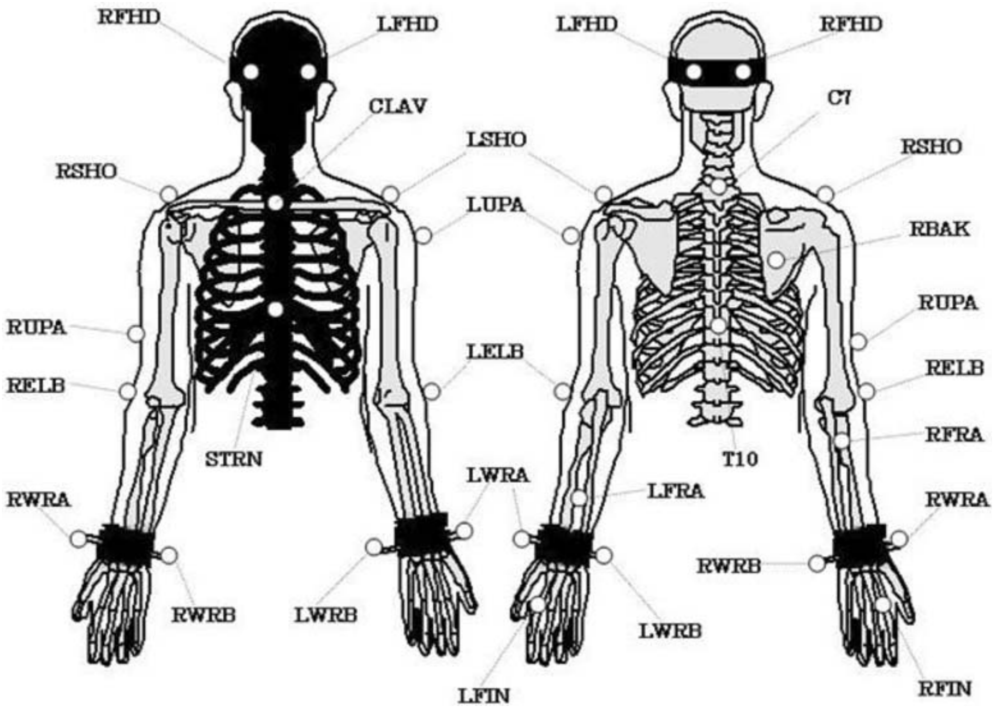

Fig. 1. Marker arrangement designated by Vicon. *Abbreviations*: see Table 1

Table 1. Marker configuration defined by Vicon

Marker name	Definition
LFHD	Left front head
RFHD	Right front head
LBHD	Left back head
RBHD	Right back head
C7	7th cervical vertebrae
T10	10th thoracic vertebrae
CLAV	Clavicle
STRN	Sternum
RBAK	Right back
LSHO	Left shoulder marker
LUPA	Left upper arm marker
LELB	Left elbow
LFRA	Left forearm marker
LWRA	Left wrist marker A
LWRB	Left wrist marker B
LFIN	Left fingers
RSHO	Right shoulder marker
RUPA	Right upper arm marker
RELB	Right elbow
RFRA	Right forearm marker
RWRA	Right wrist marker A
RWRB	Right wrist marker A
RFIN	Right fingers

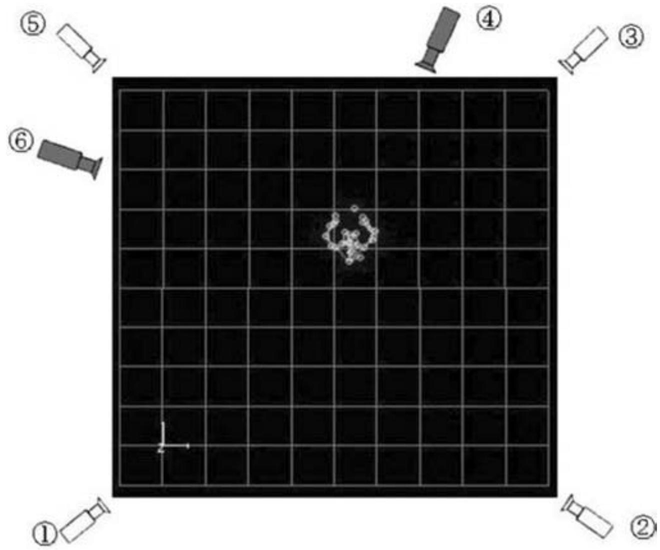

Fig. 2. Top view of set-up for this study

markers; trunk, 5 markers; and each upper limb, 7 markers. As markers were light and did not require a power or light source such as a light-emitting diode, subjects were able to move naturally. Six CCD cameras were placed around each subject, with four cameras placed at a height of 3 m, and the remaining two cameras placed at a height of 1 m to capture the front of the thoracic region (Fig. 2). Sampling frequency of the cameras was 60 Hz.

Evaluation of accuracy

Performance and accuracy of the Vicon 512 system has been confirmed previously.[9,10] However, in clinical trial, while moving skin markers during various motions a deterioration in the accuracy can occur. Therefore, the first part of the study assessed the accuracy of the motion analyzer on neck and upper limb motions in a clinical setting.

Subjects comprised five healthy volunteers (3 women, 2 men). Mean subject age was 23 years (range, 20–28 years). Ranges of motion examined were cervical spine flexion and extension, shoulder flexion, elbow flexion and extension, and forearm pronation and supination. The following two examinations were performed. First, maximum ROMs were examined by comparing angles calculated using the analyzer with those measured using a conventional universal goniometer (Minato Medical Science, Osaka, Japan). In the analysis of differences between two methods the correlation coefficient was used and *P* values were adjusted with Pearson's correlation coefficient test. The level of significance was set at a *P* value of 0.05 or less. Next, the error of this system consisted of standard deviations of calculated maximum ROMs by repeating all measurements three times. Makers were reapplied between each measurement. Repeatability in measurements of ROMs were examined by comparing the error of the analyzer with those of the conventional universal goniometer.

Analysis of motions in activities of daily living

Three motions were studied using the same five volunteers participated in the evaluation of accuracy: eating a meal, washing the face, and shampooing. The motions were not actually performed, but were acted out. Points of maximum angle in cervical spine flexion, shoulder flexion, and elbow flexion were measured during these activities, and relationships between each maximum angle were then analyzed.

Results

Maximum angle of each joint measured by the motion analyzer and universal goniometer are summarized in Table 2. The correlation coefficient was >0.76 for all values (range, 0.76–0.94). Correlation between the motion analyzer and universal goniometer was very high for cervical flexion (0.90), shoulder flexion (0.94), and elbow flexion (0.91). *P* values with Pearson's correlation coefficient test were less than 0.05 at all angles.

Error of measurements using the analyzer was examined by looking at differences in three repeated measurements (Table 3). Standard deviations of values were ≤3° for all values (range, 0.78–2.56°). Repeatability was very high for shoulder flexion (0.78°) and elbow extension (0.89°).

The system was next used to analyze motions for shampooing, washing the face, and eating a meal. Figure 3 shows the motion analysis for shampooing in a healthy volunteer (Case 1). When shampooing, the neck and upper limbs move in coordination, not separately. In Case 1, shampooing required 39° of flexion for the cervical spine, 61° of flexion for the shoulder, and 135° of flexion for the elbow. Maximum angles of flexion measured during these activities for the cervical spine, shoulder, and elbow are shown in Table 4. Maximum angle of flexion for each joint was almost constant for the three activities. The elbow required maximum elbow flexion for all activities, at 151° for shampooing, 140° for washing the face, and 146° for eating a meal. Conversely, the angle of flexion for the cervical spine varied for different activities, at 46° for shampooing, 16° for washing the face, and –8° for eating a meal. As maximum flexion angle for each joint was almost constant for these three activities, the sum of cervical spine, shoulder, and elbow flexions was defined as the total flexion angle (Table 5). Total flexion angle was almost constant for the three activi-

Table 2. Correlation between maximum angle of each joint measured using the Vicon 512 system and the universal goniometer

	Motion analyzer	Goniometer	γ
Cervical			
Flexion	47	50	0.90
Extension	64	56	0.89
Shoulder			
Flexion	161	160	0.94
Elbow			
Flexion	175	161	0.91
Extension	6	6	0.83
Forearm			
Pronation	75	76	0.76
Supination	100	93	0.78

γ, correlation coefficient

Table 3. Mean and standard deviations of maximum ranges of motion using the motion analyzer for three repeated measurements

		Mean	SD
Cervical	Flexion	47	2.03
	Extension	64	2.56
Shoulder	Flexion	161	0.78
Elbow	Flexion	175	1.81
	Extension	6	0.89
Forearm	Pronation	75	2.35
	Supination	100	2.12

Table 4. Maximum flexion angle measured during shampooing, washing the face and eating a meal for the cervical spine, shoulder and elbow flexion

	Shampooing	Washing the face	Taking a meal
Cervical			
Flexion	46 ± 10	16 ± 7	–8 ± 13
Shoulder			
Flexion	64 ± 9	50 ± 7	43 ± 6
Elbow			
Flexion	151 ± 9	140 ± 5	146 ± 5

Numbers are shown in degrees

Table 5. Sum of cervical spine, shoulder and elbow flexion (defined as total flexion angle) for shampooing, washing the face and eating a meal

Case	Shampooing	Washing the face	Taking a meal
1	244	215	195
2	288	209	186
3	242	202	181
4	264	199	172
5	264	209	194
Total flexion angle	261 ± 18	207 ± 8	185 ± 10

Numbers are shown in degrees

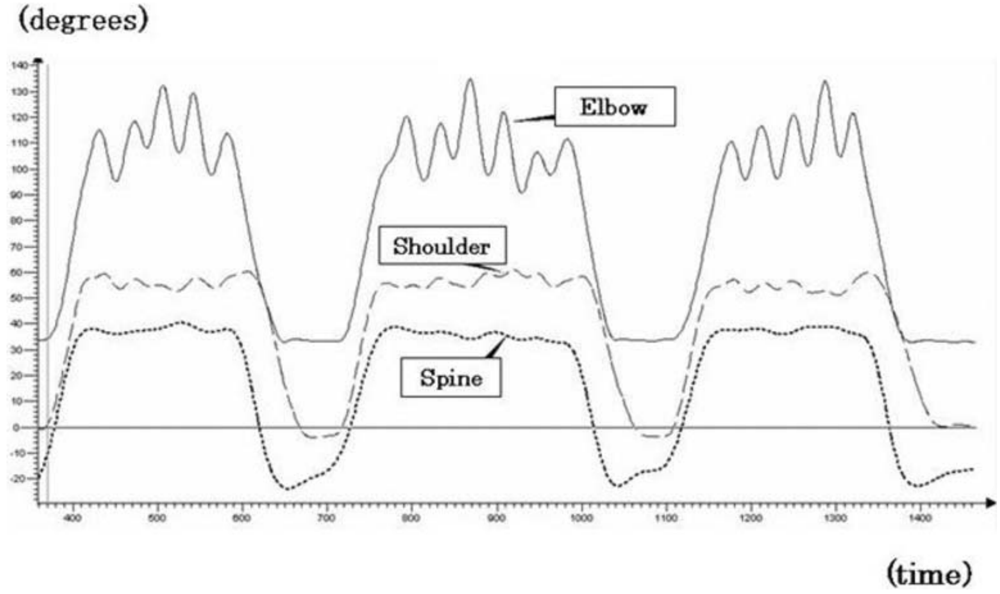

Fig. 3. Joint angles at cervical spine and upper limbs for shampooing in a healthy volunteer (Case 1)

ties, at 261° for shampooing, 207° for washing the face, and 185° for eating.

Discussion

Range of motion is typically evaluated using the universal goniometer. This method is simple, but large interexaminer differences can occur and simultaneous evaluation of multiple joints is not possible. While electrogoniometers are able to measure ROMs for multiple joints simultaneously, accuracy is considered low because of the bulkiness of the equipment.[11–13]

Electromagnetic motion analysis and optical 3D motion analysis systems are used for measurement of ROMs for multiple joints simultaneously. Both systems use markers for taking measurements and are highly accurate.[9,10] However, when markers are placed on the skin, accuracy may suffer because of skin motion.[2,5,14–20] In addition, the electromagnetic motion analysis system has a limited measuring area and metal can distort the magnetic field, while optical 3D motion analysis allows measurement of a wide area, but markers are sometimes measured incorrectly.

Accuracy of the Vicon 512 system has been evaluated using a gait analysis, revealing a high degree of accuracy.[9,10] As this system has not previously been used to evaluate movement of the neck and upper limbs, we assessed the accuracy of the system for movements of the neck and upper limbs. Error in measurements of ROMs for the neck and upper limbs using a universal goniometer have been reported in several studies.[21–26] A goniometric error at the elbow of 2.4°–3.4° was reported by Fish and Windgate.[21] In the present study, repeatability of the analyzer was examined by looking at differences over three repeated measurements. Standard deviation of the values was between 0.78° and 2.56°, almost equal to the standard deviation of measurements using a conventional goniometer. Next, maximum ROMs were examined by comparing angles calculated using this analyzer with those measured using a conventional goniometer. Correlation coefficient between the analyzer and goniometer was examined. Generally, a correlation coefficient >0.9 is very high, while <0.69 is considered low.[27] In this study, correlation coefficient between the analyzer and goniometer was >0.69 for all values. Maximum ROMs examined using this analyzer and the goniometer were closely correlated. The Vicon 3D motion analysis system thus appears useful for evaluating motion of the neck and upper limbs.

In activities of daily living that use the upper extremities, such as shampooing, washing the face, and eating, the neck and upper limbs move in a coordinated manner. Flexion angle for the shoulder and elbow in the three activities is almost constant, with the elbow requiring a maximum flexion angle for all activities. On the other hand, flexion angle for the cervical spine varies with different activities. The necessary angle of flexion for each activity varies for each joint. As the maximum angle of flexion for each joint was almost constant for each activity, the sum of the cervical spine, shoulder, and elbow flexion, defined as total flexion angle, was almost constant for the three activities, at 261° for shampooing, 207° for washing the face, and 185° for eating. The total flexion angle is suspected of having a minimum cumulative flexion angle to achieve the three activities. In this study shoulder abduction, rotation of forearm, and wrist flexion were not assessed, as the maximum angle varies over time. As these motions have a close relation to each activity, we intend to evaluate them in future.

For patients with multiple joint deterioration as in rheumatoid arthritis, surgical reconstruction is performed according to evaluation of each lesion, and this sometimes results in unsatisfactory improvements of disability. One reason for this is that the neck, shoulder, elbow, forearm, and wrist are not recognized as interrelated functional units. Analysis of impairments of neck and upper limb lesions in multiple arthropathies as changes in functional units would enable us to determine appropriate multiple joint reconstruction plans to achieve maximum improvement in activities.

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