Elbow Kinematics During Sit-to-Stand-to-Sit of Subjects With Rheumatoid Arthritis

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- Independence in mobility is dependent on the ability to rise from a chair. Elbow kinematics of subjects with rheumatoid arthritis were compared to those of subjects with no known elbow pathology. Through a case study approach, four subjects with varying elbow pathology and symptoms, were compared with a control group of 10 subjects on four kinematic variables. Results indicated that whereas the overall movement pattern was similar between the two groups, a trend toward increased deviation occurred with increased elbow involvement (as measured using the Morrey Elbow Evaluation). The total time taken to complete the task increased and the maximum velocity decreased as scores on the Morrey Evaluation decreased. When the minimum flexion angle (maximum extension) used during the activity was compared with the minimum flexion angle available, the angle used was consistently 15° to 20° less than that available. This possible need for a residual range raises questions about the generally accepted belief that activities require between 30° to 130° of flexion and 100° of rotation.

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Pain, weakness, adjacent joint involvement, flexion deformity and lack of supination at the elbow cause disability to individuals with rheumatoid arthritis (RA) significant enough to interfere with activities of daily living (ADLs). Standing, one of the most common ADLs plays a role so critical in independence and mobility that the most important factor reported by clients with arthritis when choosing a chair was whether it was easy to get out of. This was more important than comfort. In addition, by raising the seat and arm height of chairs, 77% more residents in a nursing home were able to complete the sit-to-stand movement independently.

Even though biomechanical analysis has focused on the lower extremity during the sit-to-stand movement, the importance of the arms in standing has been highlighted by findings that their use decreased joint forces at the knee. Lower extremity joint angles were altered by raising the height of the chair, but were not altered by the speed of ascent or the use of the arms to aid movement.

Wheeler et al were the first to report on elbow angles during standing. They found that young adults flexed to 81.6° (SD = 5.27) and older adults flexed to 76.7° (SD = 7.50). One further report of required movement found the elbow flexion arc during standing to be from 20.3° to 94.5°. The rotation arc required was from 33° of pronation to 9.5° supination.

One study has examined kinematic variables in addition to range of motion of the upper extremity of subjects with no known pathology. The movements of sit-to-stand and stand-to-sit were subjected to a descriptive analysis that yielded a definition of phases, examination of the peak angles, peak angular velocity during each movement and the sequencing of key events. Based on changes in angular direction four flexion-extension phases (flexion phase 1, extension phase 1, flexion phase 2, and extension phase 2) and four clinically useful rotation phases (supination phase 1, pronation phase 1, supination phase 2, and pronation phase 2) were defined (fig 1). Individual subjects repeated the movements with little variability. However, among the subjects greater variability existed. Subjects differed in the joint angles and angular velocity recorded but used the same sequence of flexion/extension and rotation events. Key events during flexion/extension and rotation tended to occur close in time, if not at the same time.

The effect of age on kinematics of standing are briefly described in the literature. In the lower extremity angular displacement does not significantly change with age. Using a sample of 10 healthy elderly Millington et al found similar angular patterns at the trunk, hip, and knee as those reported for younger subjects. Tracking the upper extremity, they reported two movement patterns when subjects were allowed to move their arms freely during the movement. Subjects were requested not to use their arms to assist with the movement.

Reports of the effect of pathology have primarily been restricted to survey and questionnaire data. Kinematic analysis is limited. Lower extremity analysis during recovery after a stroke showed that improvements made were more related to velocity than angular displacement. Five subjects with RA awaiting elbow arthroplasty used significantly less (p = .05) elbow motion than a control group during three functional activities, one of which was standing. During standing the maximum extension angle was 35.60° for the rheuma-
Fig 1—Sample curve of a control subject showing changes in direction with selected points, phases, and movement of subject. (A) Flexion/extension. (B) Rotation indicates location of maximum angular velocity. Stick figures indicate position of subject. Inset shows an overlay of three trials for the same subject.

toid group and 11.33° for the control group. When the available range of motion was examined, it was clear that the subjects with RA were not extending their elbows through the same range as the control group even when this range was available to them. These studies are the only ones found to characterize the kinematic events of the upper extremity during standing. This paper compares the kinematic variables used by subjects with RA to those used by subjects with no known elbow pathology.
ELBOW KINEMATICS: SIT-TO-STAND-TO-SIT, Packer

Fig 2—Chair used by all subjects during testing. Subject sitting in starting position with arms resting on chair arms.

METHODS

Subjects

For individuals, the progression of RA is varied and unpredictable. At any single joint the disease may lead to pain, instability, decreased motion, and/or bony destruction. In addition, decreased strength and function are reported. This number of possible symptoms makes definition and selection of homogeneous groups difficult. In addition, the large variability between subjects would necessitate a large sample size to detect even a large effect size with any power. For these reasons as well as the exploratory nature of the investigation, a case study approach was selected. Subjects attending a rheumatology clinic who had reported elbow symptoms were invited to participate. Four female subjects with varying elbow symptoms were selected from those who volunteered. Previous research yielding data on a group of 10 subjects with no known pathology\(^1\) was used as the control group. This group consisted of a sample of convenience of 10 women with a mean age of 52.4 years (SD = 6.7 years) recruited from colleagues and acquaintances. This research was approved by the Ethics Review Committee of the School of Rehabilitation Therapy and all subjects signed an informed consent form to indicate willingness to participate.

Measurement Tools

To describe each subject and their degree of impairment and disability, a clinical history and evaluation was completed. The clinical Morrey Elbow Evaluation\(^2\) which includes measurements of pain, range of motion, strength, instability, and reported function was conducted. The measurement and point allocation described by Morrey et al\(^3\) was selected because of its comprehensive nature and its ability to reflect limitations in range of motion should a severe limitation in range exist in one direction or the other. The optoelectric measurement system and experimental protocol used have been described in a previous article\(^4\) when reporting on the findings of kinematic variables of the subjects (control group) with no known pathology. The same optoelectric system and protocol were used to collect data reported in the present article, therefore, they will be described only briefly. The reader is referred to Packer et al\(^5\) for details.

A Waterloo Spatial Motion Analysis Recording Technique (WATSMART) system was used to collect 3-dimensional (3D) coordinate locations of light-emitting diodes (LEDs) attached to two outriggers, one for the arm and one for the forearm. The LEDs defined each segment as a rigid body in 3D space\(^6\) from which joint angles were then calculated.

Two cameras were placed in a uniform location with respect to all three planes. All data was collected at 50Hz with the duration adjusted to accommodate the normal speed of the subject. Custom-written software using a direct linear transformation algorithm and the floating axis method\(^7\) was used to calculate joint angles. When compared with a calibration dummy the mean difference between the WATSMART and the potentiometers was less than 1.6° in all three planes.

Table 1: Description of Subjects and Results of Morrey Elbow Evaluation

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Year Since Onset of Elbow Symptoms</th>
<th>Score (SD) on Morrey Elbow Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pain</td>
</tr>
<tr>
<td>1</td>
<td>55</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Control Group (n = 10)</td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>(SD)</td>
<td>(6.7)</td>
<td></td>
<td>(0.0)</td>
</tr>
</tbody>
</table>

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Fig 3—Overall movement patterns of the control subjects and the four subjects with RA. (A) Flexion/extension. (B) Rotation. The shaded area represents ± 1 SD for the control group. The single lines represent the mean curve for each subject for available trials (minimum = 3; maximum = 5 trials). ▲ control; ---, subject 1; ----, subject 2; . . . ., subject 3; -- - , subject 4.

Table 2: Angles Recorded at Each Selected Point for Each Subject and the Control Group

<table>
<thead>
<tr>
<th>Point</th>
<th>1 Mean Angle (SD)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Mean of all Subjects with RA</th>
<th>Mean of Control Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F.</td>
<td>-14.88</td>
<td>-42.07</td>
<td>-28.33</td>
<td>4.38</td>
<td>-20.23</td>
<td>-15.95</td>
</tr>
<tr>
<td></td>
<td>(.957)</td>
<td>(5.62)</td>
<td>(4.75)</td>
<td>(4.52)</td>
<td>(19.91)</td>
<td>(16.46)</td>
</tr>
<tr>
<td>F.</td>
<td>-3.31</td>
<td>-11.69</td>
<td>8.90</td>
<td>33.27</td>
<td>8.45</td>
<td>8.45</td>
</tr>
<tr>
<td></td>
<td>(.560)</td>
<td>(5.62)</td>
<td>(7.86)</td>
<td>(7.97)</td>
<td>(18.69)</td>
<td>(17.13)</td>
</tr>
<tr>
<td>F.</td>
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<td>-18.29</td>
<td>-15.77</td>
<td>8.86</td>
<td>7.94</td>
<td>-14.16</td>
</tr>
<tr>
<td></td>
<td>(.146)</td>
<td>(4.68)</td>
<td>(4.40)</td>
<td>(2.85)</td>
<td>(12.27)</td>
<td>(11.89)</td>
</tr>
<tr>
<td></td>
<td>(.447)</td>
<td>(4.22)</td>
<td>(3.30)</td>
<td>(3.93)</td>
<td>(-9.82)</td>
<td>(16.22)</td>
</tr>
<tr>
<td>F.</td>
<td>-6.22</td>
<td>-21.90</td>
<td>-18.20</td>
<td>2.33</td>
<td>-11.09</td>
<td>-7.90</td>
</tr>
<tr>
<td></td>
<td>(.04)</td>
<td>(3.71)</td>
<td>(7.81)</td>
<td>(2.97)</td>
<td>(11.12)</td>
<td>(11.95)</td>
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<tr>
<td>F.</td>
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<td>-31.69</td>
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<td>-15.57</td>
</tr>
<tr>
<td></td>
<td>(.29)</td>
<td>(7.08)</td>
<td>(10.84)</td>
<td>(15.53)</td>
<td>(-21.85)</td>
<td>(10.59)</td>
</tr>
</tbody>
</table>
seated with their buttock fully at the back of the seat; arms resting on the chair arms; hips, knees, and elbows all flexed to approximately 90° (fig 2). After the command, “Ready, go,” each subject was asked to stand up completely, pause and then sit down again using her arms to aid in lowering herself to sitting “in the normal way.” Five trials were collected for each subject to ensure camera visibility of the markers in a minimum of three trials.

Data Analysis

The following four descriptive analyses were performed: (1) overall movement patterns; (2) examination of peak angles and arcs; (3) calculation of maximum angular velocity; and (4) sequencing of key events. Phases were compared with those previously reported for the control group (fig 1). Peak angles were defined as the maximum and minimum angles reached during the entire movement. The minimum and maximum angles and the arc were calculated first for each trial, and then averaged for each subject. In the case of control subjects, an overall mean was then calculated. Angular velocity was defined as the maximum slope calculated from two consecutive points during each phase. Key events were defined as the changes in angular direction defined by the phases as well as the transition point between sitting and standing (see Packer et al. for details).

Of the five trials performed by each subject a minimum of three trials resulted in acceptable marker visualization. All data reported is the mean of a minimum of three trials. In the case of control subjects, the group means were calculated after calculation of each subject mean to account for the varying number of trials per subject.

RESULTS

The control subjects had a mean height of 5’3” and a mean weight of 144.5 lbs. The four subjects with RA averaged 5’4” in height and 145 lbs. in weight. All subjects with RA were community-living adults. All were ambulatory without mobility aids, although one subject preferred to use a wheelchair for long distances outdoors. The variability in symptomatology is best understood by presentation of brief case histories of each of the four subjects. Table 1 also provides a simultaneous comparison of all subjects.

Subject 1 was a 55-year-old housewife with RA diagnosed 39 years ago. She had been experiencing elbow symptoms for approximately 5 years. On clinical evaluation she had elbow range of 15° to 135° of flexion and 85° supination to 80° of pronation. Of the four subjects, she had the least amount of function and the greatest amount of daily pain as measured on the Morrey Elbow Evaluation.
Subject 2 was a 65-year-old woman with an 11-year history of RA with 8 years of elbow involvement. She showed limited elbow motion, particularly rotation (flexion: 26° to 140°; rotation 185° supination to 46° pronation) and strength, pain, and instability at the elbow. Her reported function, however, was not as low as subject 1 or subject 3. This subject had the lowest score of all four on the Morrey Elbow Evaluation.

Subject 3, age 64, has had a short history (7 years) of RA with only 1 year of elbow symptoms. Her elbow showed no instability, but some evidence of loss of strength and motion, particularly rotation (flexion: 30° to 145°; rotation: 65° supination to 45° pronation).

Subject 4, age 36, was diagnosed with RA as a child at age 8. She has experienced elbow symptoms for approximately 12 years. Despite this she achieved the highest score on the Morrey Elbow Evaluation. She had minor limitations in movement (flexion: 21° to 155°; rotation: 100° supination to 90° pronation).

Overall Movement Patterns

The overall movement patterns of the four subjects were first visually compared with that of the control subjects. The activity pattern of each subject was superimposed on the activity pattern of the control group, represented by a band of values equal to ±1 SD for each data point (fig 3). Data points of the subjects that fall outside this range can be interpreted as different in some way from the control pattern. In fig 3 both the angle and the timing of elbow movement are represented. Although the angles and timing appear different, the overall pattern, particularly during flexion-extension, is similar between subjects with RA and the control group. All subjects with RA seem to have taken longer to complete the task than the control group. This is particularly notable for subject 2. The order in which subjects completed the activity, from longest to shortest, was subject 2, subject 1, subject 3, and subject 4. This is the same order, from lowest to highest, that subjects ranked on the Morrey Elbow Evaluation.

Subjects 1, 3, and 4 used flexion-extension joint angles outside the range used by the control subjects: subject 1 using less range and subjects 3 and 4 reaching larger flexion angles. The rotation patterns of the four subjects were also similar. Less data points fell outside the rotation range than the flexion range.

The similarity of the visual inspection indicated the feasibility of continuing the analysis by selecting the points needed to define each phase (fig 1). All points were easily selected in the flexion-extension curves. In the rotation curves points R1 to R7 were easily selected for all subjects. Points R1 to R7 were not consistently identifiable. In two of 4 trials for subject 1 none of these points could be located. Point 6 was missing for one trial in subject 4 and point 7 was missing for subject 3. A minimum of two trials for each subject yielded data for all points. Where the points were not identifiable all data analysis was done with the points available. The angles at each selected point were consistent for each subject with small standard deviations (table 2). They did not consistently match the mean angles shown by the control group.

Examination of Peak Angles and Arcs

The minimum and maximum angles reached during the entire activity were calculated (table 3, fig 4). These angles did not consistently occur at the same selected point (eg. F1, F2, etc) for all subjects and so differed slightly from the angles recorded at each point. Subjects 1 and 2, who received the lowest scores on the Morrey Elbow Evaluation used much smaller flexion ranges than both the control group and the other two subjects. In particular they did not use the inner range of flexion. The minimum flexion angle used by all subjects, including the control subjects, was consistently 15° to 25° greater than that available to them as measured by manual goniometry during the Morrey Elbow Evaluation. That is they did not use the final 15° to 25° degrees of extension available to them (fig 4). Plotting the available range and the maximum used range in each of the other three directions (maximum flexion, pronation, and supination) shows a similar trend—a decrease in available range corresponds to a decrease in used range.

Maximum Angular Velocity

The angular velocity of each phase is illustrated in fig 5. The maximum angular velocity, as measured by the slope, showed great variation between the four subjects. Slope is dependent on the time taken to complete the activity as well as the excursion spanned. Subject 1 and 2 took longer to
complete the task, which they both did with a small flexion arc. Subject 1 also used a small rotation arc. Subject 3 took longer to complete the activity. Only subject 1 showed a correspondingly slower slope. Subjects 2 and 3 generated slopes similar to the control group during flexion and in the upper range or greater than the control group during rotation. Subject 4, whose timing and range were most similar to the control group, achieved comparable angular velocities.

Sequencing of Flexion-Extension and Rotation Events

In the control group the timing of the key events occurred in a set sequence. In addition, overlaps in the 95% confidence intervals showed a temporal relationship between the flexion-extension and rotation points that seemed to occur in pairs. The following points occurred very close in time, if not at the same time in the control group: F1 and R1; F2 and R2; and F3 and R3. The data from the four subjects was difficult to compare with that of the control group because of the increased overall time taken for the subjects with RA to complete the task. For this reason the points did not occur within the confidence intervals recorded for the control group. Closeness in time of the flexion points and rotation points could not be analyzed, only viewed descriptively. They are reported in Table 4 which suggests that there is a relation between the time of occurrence of the same pairs of points. For example, points R2 and F2 consistently occur within less than 0.12 seconds of each other.

DISCUSSION

The use of case studies in this research has allowed four different analyses to be done with clients with varying degrees of elbow involvement secondary to RA. The paucity of literature regarding the effects of elbow pathology recommends this exploratory approach. The disadvantage is the descriptive nature of the data, which suggests trends and understanding but does not yield conclusive evidence. The advantages are the ability to use small numbers of subjects, when a large homogeneous group would be difficult to find, and the vast amount of descriptive data that is gained.

The overall trend seems to be that the more severely involved the elbow, as measured by the Morrey Elbow Evaluation, the more deviant is the movement pattern when compared with the control group. Subject 2, who scored lowest on the evaluation took longest to complete the combined task of sit-to-stand and stand-to-sit; used the smallest arc of movement and the slowest angular velocity. Subject 4 who scored highest on the evaluation was most similar to the control group in all aspects. It is impossible to determine whether one symptom (pain, instability, weakness, etc) contributed more to this relationship or whether it was the combined symptomatology. From a clinical perspective this may be an academic question, because rarely in RA is one symptom extremely severe with absence of all others. The common pattern is for increased severity of symptoms to be coincidental.

The small arc and slow overall movement shown by subject 1 clearly contributed to the slower angular velocity. It seems that in the subjects with less severe symptoms, angular velocity approaches that recorded by the control subjects. During recovery from stroke, improvement in standing has been reported to primarily related to increases in angular velocity of the lower extremity segments. Although the number of subjects was small in both studies, this trend may be important for therapeutic programs for many different client groups.

The arc used by all four subjects and the control group...
showed an interesting trend. When the minimum flexion angle (maximum extension) used during the activity was compared with the minimum flexion angle available, the angle used was consistently 15° to 25° less than that available. This discrepancy suggests that 15° to 70° of movement beyond that required by the task must be available. This need for a residual range may help to explain this finding. In the past, it has been reported that most ADLs can be performed with a range of 30° to 110° of flexion and 100° of rotation. If a residual range is needed, using these estimates as goals for normal ADLs would result in too small a range of motion.

CONCLUSION

Comparison of the kinematic variables of four subjects with RA to a control group with no known pathology suggested a trend of increased deviation with increasing severity of symptoms. As the severity of pain, range of motion, instability, and the impact on functional activities increased so did the differences in overall movement pattern including the length of time to complete the task, the amount of joint excursion used and the angular velocity recorded. All subjects, including the control group used 15° to 20° less extension than that which they had available to them. Under use of range was also evident in maximum flexion and rotation angles.

Four case studies only suggest a trend that should be further investigated for not just this activity, but other common ADLs.

References