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# Assessment of spinal mobility in ankylosing spondylitis using a video-based motion capture system

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ABSTRACT

This paper describes the use of a video-based motion capture system to assess spinal mobility in patients with ankylosing spondylitis (AS). The aim of the study is to assess reliability of the system comparing it with conventional metrology in order to define and analyze new measurements that reflect better spinal mobility. A motion capture system (UCOTrack) was used to measure spinal mobility in forty AS patients and twenty healthy subjects with a marker set defining 33 3D measurements, some already being used in conventional metrology. Radiographic studies were scored using the modified Stoke Ankylosing Spondylitis Spine Score index (mSASSS). Test–retest reliability studies were performed on the same day and over a two-week period. Motion capture shows very high reliability with Intraclass Correlation Coefficient values ranging from 0.89 to 0.99, low Standard Error of the Measurement (0.37–1.33 cm and 1.58°–6.54°), correlating very well with the Bath Ankylosing Spondylitis Metrology Index (BASMI) ($p < 0.001$) and, in some individual measures (cervical flexion, cervical lateral flexion, back inclination, shoulder–hip angle and spinal rotation), with mSASSS ($p < 0.01$). mSASSS also added significantly to the variance in multivariate linear regression analysis to certain measures (back inclination, cervical flexion and cervical lateral flexion). Quantitative results obtained with motion capture system using the protocol defined show to be highly reliable in patients with AS. This technique could be a useful tool for assessing the outcome of the disease and for monitoring the evolution of spinal mobility in AS patients.



## 1. Introduction

Ankylosing Spondylitis (AS) is a chronic rheumatic disease that mainly affects the spine and in which the inflammatory process induces structural damage characterized by the fusion of joints as well as intervertebral space (Wanders et al., 2005). Loss of spinal mobility is a major feature of the disease and it is one of the criteria that the patient must fulfill to be diagnosed with AS, according to the New York modified diagnostic criteria (van der Linden et al., 1984). Metrologic assessment of spinal mobility has been widely used in the diagnosis, follow-up, as well as responsiveness to treatment in patients with AS (Viitanen et al., 2000).

ASAS (Assessment in AS working group) recommends the use of the Bath Ankylosing Spondylitis Metrology Index (BASMI) (Jenkinson et al., 1994), which includes five measurements: the modified Schober test, spinal lateral flexion, intermalleolar distance, tragus to wall distance and cervical rotation. BASMI is calculated based on certain measurements obtained using elementary instrumentation such as tape measures or goniometer. Structural damage in AS may be measured with different scoring methods on radiographs of the spine such as: the Bath Ankylosing Spondylitis Radiology Index (BASRI) (MacKay et al., 1998), the Stoke Ankylosing Spondylitis Spine Score (SASSS) (Averns et al., 1996), and a modification of the SASSS (mSASSS) (Creemers et al., 2005). The latter index scores cervical and lumbar spine according to erosions, syndesmophytes and bone bridges. mSASSS was demonstrated in clinical trials to be the most appropriate method to score radiographic progression in AS patients (Wanders et al., 2004).

Usually BASMI is used for the assessment of mobility and mSASSS for structural damage. In assessing disease-modifying potential of newly introduced highly cost biological therapies in the treatment of AS, it is essential to demonstrate the improvement

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of spinal mobility. So, more precise and reliable measurement tools are needed to correctly assess therapeutic results (Fleurence and Spackman, 2006).

Automated motion capture is a recently-developed technology that allows human movement to be measured in an objective and quantitative manner with high levels of precision. This technology has been used successfully in sports, clinical medicine, industry, ergonomics, animation and virtual reality, among others (Castro et al., 2006).

There are two main objectives in this study: (1) to evaluate the use of a video-based motion capture system to assess spinal mobility in patients with AS by using conventional metrological measurements obtained with our motion system and (2) to propose new 3D measurements that could better reflect spinal mobility. Finally construct validity studies were performed for both objectives; mobility results were correlated with conventional metrology (BASMI) and radiographic score (mSASSS) and multivariate linear regression analyzing structural damage were also undertaken.

## 2. Patients and methods

### 2.1. Patients

Forty AS patients according to New York modified criteria (van der Linden et al., 1984) (36 males and 4 females) and twenty healthy subjects (10 males and 10 females) as control group who were willing to participate in the study, were consecutively included. AS patients had at least five years of disease duration with varying degrees of limited spinal mobility as measured with BASMI. To analyze the data of BASMI we divided the patients into 3 groups of affectation: low, medium and high degree of affectation according to BASMI score: 1) low BASMI $< 3$, 2) medium BASMI between 3 and 5 and 3) severe BASMI $> 5$.

There were no differences between the control group regarding age ($35.8 \pm 10.8$ years), weight ($72.1 \pm 12.4$ kg), height ($174.4 \pm 14.4$ cm), body mass index (BMI) ($23.6 \pm 3.5$), joint or spinal pathologies and the patients from AS group (age $38.3 \pm 12.5$), weight ($75.8 \pm 11.2$), height ($172.6 \pm 7.9$) and BMI ($24.38 \pm 3.6$).

Patients gave their informed consent to participate and the study was approved by the ethical committee.

### 2.2. Motion capture protocol

A motion capture system, the UCOTrack (formerly SOMCAM3D), was used to obtain mobility measurements. The system was previously evaluated for precision and accuracy by comparing it with other commercial systems (Castro et al., 2006). Preliminary results showed that it is suitable for working in human motion analysis (Collantes et al., 2008). Four digital cameras were connected through firewire ports to a computer. The markers were white Styrofoam hemispheres measuring 2.5 cm in diameter and were covered with reflective material. Although the capture speed is 50 frames per second, only 10 fps were finally obtained since the movements are continuous and extensive in time. All the datasets for the kinematic measurements were filtered using a second-order Butterworth filter with a cut-off frequency of 5 Hz. The maximum values of each movement (peak) were considered for each range of movement (ROM). The same operator of the system obtained the results for all the trials. She is experienced and competent in its use. Markers were placed by a trained physiotherapist.

### 2.3. Kinematic data collection protocol

The location of the markers on the subject is shown in Fig. 1. These markers define the segments which are used to calculate positions, angles and speeds. Measurements were taken on the cervical spine and on the dorsal and lumbar spine while the subject made frontal flexion/extension, lateral flexion and rotational movements.

Cervical frontal flexion (CF) is calculated as the angle formed by the segments 3–16 and 18–19 projected onto the sagittal plane. Cervical rotation (CR) and lateral cervical flexion (CL) is obtained as the angle formed by the segments 1–2 and 4–5 on the transverse and coronal planes respectively. Floor to finger distance (FFD) is

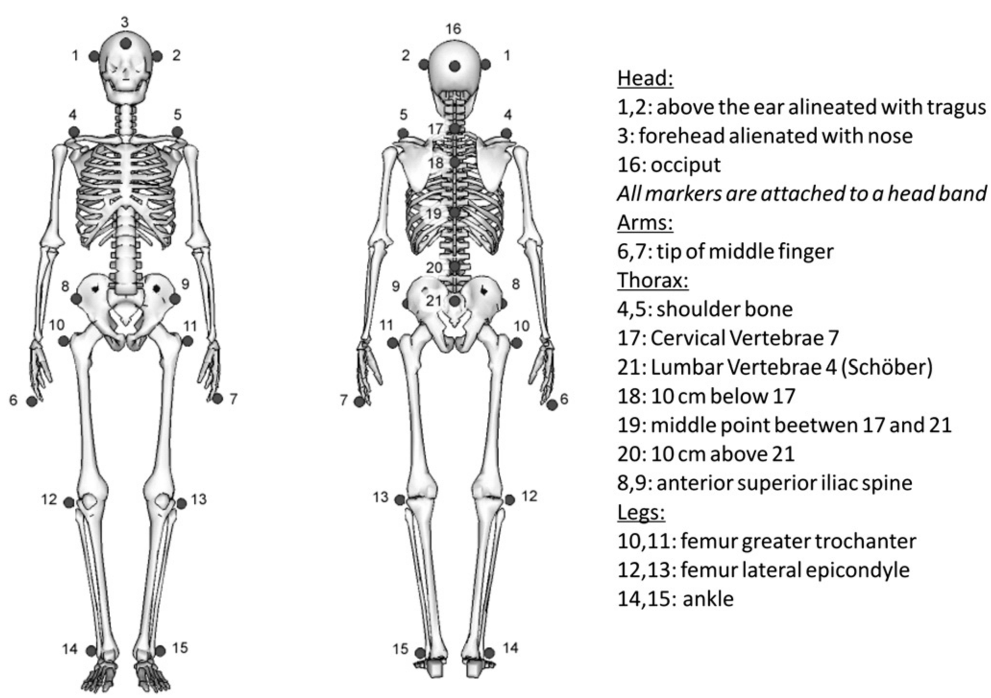


**Fig. 1.** Marker set.

calculated as the minimum distance to the floor of Mark 6 in a frontal flexion movement. Using the angle formed by the segments 17–18 and 20–21 in their projections on the sagittal and coronal planes, spinal angle in frontal flexion (SF) and lateral flexion (SL) are calculated. Distance from the markers 6 and 7 to the floor in lateral flexion are used to calculate right and left lateral flexion distances (LFR LFL). Flexion/extension of the segment 20–21, initially of 10 cm, are used in modified Schober (flex + ext) (MS) and modified Schober (flex) (MSF) measurements. The first one contains the sum of both quantities and the second only extension (as defined in modified test Schober). By the angle formed by the segments located on the shoulders (4–5) and hips (8–9) in their projections on the transverse and coronal planes, trunk rotation (TR) and shoulder–hip (SH) angle in lateral flexion are calculated. Tilting of the segment defined between marks 17 and 21 relative to the floor in the sagittal plane is used to calculate slope of back in frontal flexion (BIF), if we add the extension we have back inclination (flex + ext) (BI). If we evaluate the slope of this segment in the coronal plane during lateral bending we have back inclination lateral flexion (BIL). CR, FFD, MS, LFR and LFL obtained with tape measure or goniometers are often used in conventional metrology but the rest of measures are new.

Each of the movements must be repeated three times before beginning the next one. The subjects were tested on three occasions, two on the same day (a few minutes apart) and another one two weeks later. Markers were not reapplied between each measurement in test–retest. The tests were performed between 5:00 pm and 7:00 pm to avoid the morning stiffness that characterizes AS.

### 2.4. Data analysis

In order to analyze the reliability we assessed relative reliability (Intraclass Correlation Coefficient – ICC) and absolute reliability (Standard Error Measurement – SEM) (Atkinson and Nevill, 1998) obtained in the same day and two weeks tests. Statistical analysis was performed using SPSS™ 14.0 for Windows. Construct validity was assessed by analyzing relations between motion capture results, conventional metrology results (Schober test, chest expansion, occiput to wall distance, ...), and structural damage radiological scores.

## 3. Results

### 3.1. Descriptive data

The group of patients with AS had the following characteristics: age at diagnosis 25.8 ± 7.9, evolution of disease 14.5 ± 10.84 years, BASMI 3.37 ± 2.46 and mSASSS 31.4 ± 24.1. Thirty three (82%) of these patients were human leukocyte antigen (HLA) B27 positive. The descriptive statistics of the ROM measurements are shown in Table 1. For each measurement mean and standard deviation (SD) values are shown in four columns: one for control group and the other three for the different groups of patients according affectation level. Also reductions of ROM according to control group are expressed for each group.

### 3.2. Reliability

Table 2 shows results of reliability and validation. The ICC shows very high reliability in the measurements with ICC values ranging from 0.89 to 0.99. SEM varied from 1.76° to 6.54° in angular measurements and from 0.96 cm to 1.33 cm in distances. All measurements obtained by the system correlated very well with BASMI ($p < 0.001$). Also high correlation values were obtained for the mSASSS index ($p < 0.05$). This index was divided in three columns in Table 2: total index, cervical part and lumbar part of the index.

**Table 1**
Values obtained for healthy subjects and subjects with different degrees of AS.

| Measurement | Healthy ($n = 20$) | Low BASMI < 3 ($n = 20$) | | Medium BASMI 3–5 ($n = 8$) | | High BASMI > 5 ($n = 12$) | |
|---|---|---|---|---|---|---|---|
| | Mean (S.D.) | Mean (S.D.) | Red | Mean (S.D.) | Red | Mean (S.D.) | Red |
| BASMI | 0.60 (0.46) | 1.28 (0.64) | – | 4.01 (0.53) | – | 6.41 (1.35) | – |
| mSASSS | – | 7.75 (5.12) | – | 35.33 (10.01) | – | 59.00 (13.52) | – |
| *Cervical movements* | | | | | | | |
| CF (°)[a] | 125.74 (13.29) | 107.93 (13.89) | 14% | 70.03 (18.20) | 44% | 45.64 (35.59) | 64% |
| CR (°) | 151.08 (10.49) | 143.75 (9.27) | 5% | 90.64 (24.41) | 40% | 64.74 (36.54) | 57% |
| CL (°)[a] | 93.24 (9.22) | 85.99 (11.28) | 8% | 44.30 (27.86) | 52% | 20.36 (19.87) | 78% |
| *Lumbar frontal flexion* | | | | | | | |
| FFD (cm) | 5.78 (5.71) | 7.40 (7.18) | – | 21.42 (3.80) | – | 21.86 (8.75) | – |
| SF (°)[a] | 81.31 (23.88) | 58.44 (16.76) | 28% | 45.13 (19.19) | 44% | 23.23 (12.63) | 71% |
| MS (cm) | 9.58 (1.03) | 8.44 (2.79) | 12% | 5.51 (2.12) | 42% | 3.30 (2.09) | 65% |
| MSF (cm)[a] | 6.98 (0.99) | 6.79 (2.92) | 3% | 4.24 (1.51) | 39% | 2.66 (1.88) | 62% |
| BI (°)[a] | 147.22 (15.17) | 132.27 (14.53) | 10% | 106.87 (23.45) | 27% | 99.07 (17.47) | 33% |
| BIF (°)[a] | 104.05 (13.79) | 101.36 (9.80) | 3% | 79.31 (13.95) | 24% | 78.04 (15.50) | 25% |
| *Lumbar lateral flexion* | | | | | | | |
| LFR (cm) | 27.73 (5.15) | 21.91 (5.11) | 21% | 15.71 (8.75) | 43% | 11.05 (4.69) | 60% |
| LFL (cm) | 25.68 (3.67) | 22.21 (6.38) | 14% | 16.23 (7.40) | 37% | 11.10 (4.39) | 57% |
| SL (°)[a] | 93.54 (18.81) | 70.04 (28.51) | 25% | 40.63 (14.26) | 57% | 28.38 (22.17) | 70% |
| SH (°)[a] | 101.70 (11.46) | 86.69 (22.07) | 15% | 52.20 (17.12) | 49% | 43.84 (20.01) | 57% |
| BIL (°)[a] | 85.83 (12.22) | 72.99 (18.28) | 15% | 51.72 (21.63) | 40% | 37.63 (15.45) | 56% |
| *Trunk rotation* | | | | | | | |
| TR (°)[a] | 127.45 (14.88) | 102.31 (25.18) | 20% | 70.75 (16.01) | 44% | 56.33 (8.05) | 56% |

Red, % reduction of ROM, as compared to healthy subjects.
BASMI, Bath Ankylosing Metrology Index; mSASSS, modified Stoke Ankylosing Spondylitis Spine Score; CF, cervical frontal flexion; CR, cervical rotation; CL, cervical lateral flexion; FFD, floor to finger distance; SF, spinal angle frontal flexion; MS, modified Schober (flex + ext); MSF, modified Schober (flex); BI, back inclination (flex + ext); BIF, back inclination (flex); LFR, right FFD; LFL, left FFD; SL = spinal angle lateral flexion; SH, shoulder–hip angle lateral flexion; BIL, back inclination lateral flexion; TR, trunk rotation.
[a] New measurement not used in conventional metrology.

**Table 2**
Results of reliability and validation.

| Measurement | Correlation with BASMI (Pearson) | Correlation with mSASSS (Pearson) | | | Same day test–retest | | 2 Weeks test–retest | |
|---|---|---|---|---|---|---|---|---|
| | | Total | Cerv | Lumbar | ICC (95% CI) | SEM | ICC (95% CI) | SEM |
| *Cervical movements* | | | | | | | | |
| CF[a] | −0.89** | −0.86* | −0.86* | −0.83* | 0.995 (>0.989) | 1.76° | 0.987 (>0.964) | 2.85° |
| CR | −0.92** | −0.92** | −0.91** | −0.91** | 0.992 (>0.983) | 2.50° | 0.996 (>0.988) | 1.58° |
| CL[a] | −0.89** | −0.92** | −0.92** | −0.88* | 0.992 (>0.981) | 2.24° | 0.995 (>0.987) | 1.77° |
| *Lumbar frontal flexion* | | | | | | | | |
| FFD | 0.74 ** | 0.84* | 0.80* | 0.85* | 0.985 (>0.962) | 1.12 cm | 0.989 (>0.966) | 0.96 cm |
| SF[a] | −0.75** | −0.74† | −0.68† | −0.78* | 0.929 (>0.804) | 5.32° | 0.892 (>0.530) | 6.54° |
| MS | −0.81** | −0.82* | −0.76† | −0.87* | 0.909 (>0.775) | 0.63 cm | 0.904 (>0.714) | 0.62 cm |
| MSF[a] | −0.73** | −0.80* | −0.73† | −0.85* | 0.945 (>0.865) | 0.37 cm | 0.887 (>0.454) | 0.54 cm |
| BI[a] | −0.80** | −0.80* | −0.72† | −0.86* | 0.988 (>0.969) | 2.19° | 0.986 (>0.957) | 2.37° |
| BIF[a] | −0.72** | −0.78* | −0.69† | −0.84* | 0.963 (>0.908) | 2.12° | 0.976 (>0.929) | 2.03° |
| *Lumbar lateral flexion* | | | | | | | | |
| LFR | −0.83** | −0.83* | −0.78* | −0.87* | 0.929 (>0.824) | 1.33 cm | 0.951 (>0.855) | 1.11 cm |
| LFL | −0.84** | −0.83* | −0.76* | −0.88* | 0.965 (>0.913) | 1.03 cm | 0.951 (>0.855) | 1.22 cm |
| SL[a] | −0.79** | −0.83* | −0.80* | −0.84* | 0.934 (>0.837) | 6.42° | 0.953 (>0.861) | 5.42° |
| SH[a] | −0.88** | −0.81* | −0.73* | −0.88* | 0.987 (>0.969) | 2.51° | 0.989 (>0.967) | 2.31° |
| BIL[a] | −0.86** | −0.87* | −0.80* | −0.91* | 0.966 (>0.915) | 2.95° | 0.962 (>0.887) | 3.12° |
| *Trunk rotation* | | | | | | | | |
| TR[a] | −0.86** | −0.88* | −0.85* | −0.89** | 0.996 (>0.989) | 1.77° | 0.977 (>0.930) | 4.24° |

**$p < 0.001$, *$p < 0.01$, †$p < 0.05$.
BASMI, Bath Ankylosing Metrology Index; mSASSS, modified Stoke Ankylosing Spondylitis Spine Score; ICC, intraclass correlation index; SEM, standard error of the measurement; CF, cervical frontal flexion; CR, cervical rotation; CL, cervical lateral flexion; FFD, floor to finger distance; SF, spinal angle frontal flexion; MS, modified Schober (flex + ext); MSF, modified Schober (flex); BI, back inclination (flex + ext); BIF, back inclination (flex); LFR, right FFD; LFL, left FFD; SL = spinal angle lateral flexion; SH, shoulder–hip angle lateral flexion; BIL, back inclination lateral flexion; TR, trunk rotation.
[a] New measurement not used in conventional metrology.

### 3.3. *Construct validity*

Conventional measurements: Schober, occiput to wall distance, tragus to wall distance, lumbar lateral flexion distance, finger to floor distance, and cervical rotation showed significant Pearson correlations with the measurements obtained by the system ($p$ value varied from <0.05 to <0.001). Chest expansion did not correlated well with cervical measurements, but it did have a good correlation with lumbar measurements ($p < 0.05$). Intermalleolar distance showed poor correlation with both motion system and with BASMI and mSASSS. The low correlations with this measure may be due to the large variability in the intermalleolar distance measurements. To explore the independent contribution of structural damage (mSASSS) in explaining the reduction in the different mobility measurements obtained by the system, multivariate linear regression analysis was undertaken. After adjusting for age and body mass index, using the different measures as the dependent variable, mSASSS added significantly to the variance ($R^2$ varying from 0.93 to 0.96, $p < 0.001$) to BI, BIF, CF and CL.

## 4. Discussion

The assessment of spinal mobility in AS patients is very important as it indicates the structural damage. For this reason, mobility evaluation is included in all the recommendations of disease assessment and follow-up. In this paper we propose a video-based motion capture system to solve the accuracy and reliability problems of conventional metrology involved in assessing mobility in AS patients. The precision and accuracy of the system have already been demonstrated in previous studies (Castro et al., 2006; Collantes et al., 2008).

It is common practice to test the reliability of measurement systems either on healthy subjects or only on individuals with different levels of AS (Haywood et al., 2004). However, since patients with AS can make abnormal movements that could influence this reliability, both healthy subjects (control group) and patients with AS were included in this study.

In a review of studies on cervical mobility, Chen et al. (1999) report ICC values for the inclinometer of 0.4–0.9. For Video-based and electromagnetic systems, they reported values of over 0.9, with the average ICC value for all the technologies of 0.7. All the movements showed a substantial degree of reliability (>0.82). Reliability was high even when they studied AS patients with deteriorated mobility. SEM results were also very low especially in cervical movements and in trunk rotation. Schober test shown very low absolute reliability when is obtained with the system (0.37 cm).

Previous reports showed correlation between radiologic damage and metrology in patients with AS, (Wanders et al., 2004; Machado et al., 2010) as well as association of functional status and disease activity with spinal mobility (Kaya et al., 2006; Almodóvar et al., 2009; Vesović-Potić et al., 2009). Correlation between the measurements obtained in our study is high. When we used BASMI as an indicator of the affectation level, high correlation values appeared, especially in those related to neck mobility. Similarly, high correlation values were obtained using the radiological index, mSASSS. Cervical movements had higher correlation values with the cervical part of the radiological index and lumbar movements with lumbar part of the index. According to multivariate linear regression analysis, are significantly associated with mSASSS (BI, BIF, CF and CL) and reflect the reduction of mobility due to structural damage.

Some components of BASMI are measured with the system: cervical rotation, modified Schober and lateral flexion calculated as CR, MSF and LFR/LFL. With these measures obviously high correlation values appeared, but also appeared at the rest of the measurements (for example trunk rotation or shoulder–hip angle). The mSASSS is really independent of the measures obtained by the system, because different concepts are evaluated (number of erosions, bony bridges, … versus spinal mobility) and high correlation values appeared, so mSASSS could be used as standard reference for validation purposes of the method.

There are certain measurements that should not be considered for future studies due to their variability and poor correlation, but there are some new measurements that appear to reflect better the affectation level and achieve better reliability than traditional measurements.

According to high correlation levels with BASMI and mSASSS for validation, and high values of ICC and low values of SEM for reliability, Back inclination (flex + ext) (BI) seems to be the best measure to assess lumbar frontal flexion, and shoulder–hip (SH) angle for lateral lumbar flexion. Trunk rotation (TR) is also a measure to take in mind because of its good results. Finally all the measures of cervical movements showed good results but especially cervical flexion (CF).

Although conventional metrology measures obtained with the system showed higher values of accuracy and reliability than the same ones obtained by standard tools, the previously highlighted measures are impossible to obtain without this kind of systems and reflect better affectation level in the patient.

It would be interesting to include this type of measurements in studies on biological therapies in which mobility has been shown to improve in the short term; however, a precise and quantitative study of this improvement has not been made. More studies are needed to investigate the responsiveness of the measurements in short to middle term. Correlation with clinical parameters and questionnaires of disease activity should also be analyzed. More studies comparing radiological and mobility results must be done to analyze whether motion capture information could replace X-rays.

## 5. Conclusion

In this study, results obtained show that the use of the motion capture technologies produce precise and reliable quantitative results for the measurements that are traditionally included in the assessment of AS. In addition, we have defined new measurements that appear to show better the level of affectation in AS patients. Thus, the use of the motion capture systems to obtain these measurements can be of great aid in assessing and monitoring AS.

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