Cervical Spine Assessment Using Passive and Active Mobilization Recorded Through an Optical Motion Capture

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ABSTRACT

Objective: The purpose of this study was to develop and measure a protocol for evaluation of cervical range of motion (ROM), based on passive mobilization (PM) combined with active mobilization (AM) and recorded through an optical motion capture system.

Methods: Passive and active mobilization were applied to 24 asymptomatic participants. Cervical ROM was recorded in 3 anatomic planes (transversal, frontal, and sagittal) using a precision optical system and a set of rigid bodies placed on the sacrum, spinous processes of the C7-T1 vertebrae, and the head. Three captures were made for each participant, distributed over 2 days. The characteristics of the PM, the interaction with the AM, and the coherence patterns between tests were analyzed. Reliability was studied for these procedures.

Results: The reliability results of the PM were high in all analyzed indices; only flexion showed low values. Reliability of AM was greater than PM for flexion, extension, and lateralization because of the similarity to rotation. No statistically significant differences were found comparing PM and AM techniques.

Conclusion: The authors present a cervical ROM assessment based on combined PM and AM protocols at different sessions. This model demonstrated high reliability, individually and combined, and no differences were detected between PM and AM ROMs. Because the evaluator, instrumentation, and the patient are factors that could influence outcomes, the authors suggest that they be combined in protocols. These protocols could be used to evaluate the functional and structural capacity of patients and inform clinical outcomes. (J Chiropr Med 2018;17:167-181)

Key Indexing Terms: Cervical Vertebrae; Range of Motion, Articular; Reproducibility of Results

INTRODUCTION

Musculoskeletal disorders of the cervical spine have a high incidence and prevalence and are considered a public health problem, especially in developed countries.^{1,2} Although there have been significant contributions in different fields to access cervical spine injury, such as whiplash associated disorder (WAD), several diagnostic tests that assess cervical-area alterations, “whiplash severity grading systems,” diagnostic imaging tools, and scales such as the Quebec Task Force, seem to be insufficient for predicting possible complications of symptomatology.^{3,4}

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The diagnostic difficulty is because traumatic cervical spine injuries and their associated symptoms are diverse. Variables that have been measured to quantify the degree of dysfunction are isometric muscle strength,⁵ motion velocity, smoothness,⁶ and cervical range of motion (ROM).⁷⁻¹⁴ Because of the relationship between joint dynamics and the dysfunction location,⁹⁻¹¹ the ROM is often used to quantify severity and treatment.⁷ This index is also used by the American Medical Association^{4,15} to assess physical damage; it also is used in specific legislation in countries, such as Spain (Law 35/2015)¹⁶ for the assessment of damage caused by traffic accidents.

One method to evaluate cervical ROM uses voluntary patient movements under the instructions of an evaluator, called active mobilization (AM). This type of mobilization does not require physical interaction between the patient and the evaluator¹⁷ and provides relevant functional information.¹⁸ However, application of AM as an isolated technique is questioned.¹⁷⁻¹⁹ Because of the influence of the patient's subjectivity motivated by psychosocial factors,^{2,20-22} different types of errors may be observed, and the AM technique has high variability of results and a low capacity to predict chronic symptoms.^{7,8,18} Likewise, it

does not provide clinical information to determine structural function.^{20,22}

Another method is passive mobilization (PM).^{11,23} In this case, an external force is induced by the examiner to move specific body parts up to the joint limits while the participant relaxes the joint that is being explored.^{18,24} Passive mobilization allows the examiner to assess the “physiological barrier,” the structural information of the joint under assessment, which is useful in clinical decision making for treatments.²⁵⁻²⁷ It is assumed that this range is not influenced by psychosocial factors, as in AM, because the captured ROM mainly depends on action and perception of the examiner during the test.^{22,28} Therefore, authors have reported a lower variability in the results in applying PM techniques.^{10,18}

Most PM techniques use subjective analyses based on the examiner’s perception,¹⁷ so is not considered the gold standard.^{7,17,18} Consequently, the challenge associated with PM is to provide studies that analyze its properties and characteristics through objective kinematic measurements, enabling its validation as a diagnostic technique.

To validate methodologies based on PM, it is necessary to apply criteria related to accuracy and reliability.^{29,30} The criteria involve some standards satisfying reliability, which require that the measurement must be repeatable and invariant to external factors (ie, the subjectivity of the evaluator, technical-system commitment, and others).

In a systematic review⁷ of 46 reliability studies and 21 validation studies where PM and AM techniques were applied, 8 PM studies were found, which described the passive technique used.³¹ There is a problem when explaining the characteristics and properties using PM combined with objective measures. In general, PM reliability has not been analyzed in depth,^{7,8,32} and only a few have used objective measurements for the analysis of PM techniques.^{12,17}

If AM and PM were combined for assessment, they could possibly provide greater sensitivity and specific diagnostic information in the clinical-care setting. In addition, the problem concerning the subjectivity of both, which is derived from the evaluator in the PM and is derived from the psychosocial factors of the participant in the AM, might be mitigated by their combination.

Motion capture (MoCap) systems provide precision; however, they are not exempt from sources of errors, such as those derived from the marker placement on particular anatomic areas that move with respect to the underlying bones and those due to the conditions of application in a specific area or use conditions in a specific field.³³ The evaluator’s ability to perform a correct grip on the patient is a critical aspect in the measurement of the ROM movements during PM, where the reflective markers can be hidden or even moved by the evaluator if he or she is not sufficiently trained. Consequently, the variability of the system depends on the design of the set and its degree of integration, that is, the placement of markers, the checks, the understanding of the movements by the participant, the

instructions to the patient, or the training of the evaluator in the use of the system. Therefore, the added value provided by MoCap technologies can be diminished in the clinical setting if the possible sources of error are studied in their practical application, which is the general purpose of this study.

Therefore, the objectives of this study were the following: (1) to develop a cervical ROM assessment protocol based on PM; (2) to check the system reliability using the PM and AM, individually and combined; (3) to perform a comparison of both techniques, PM and AM; and (4) to understand the influence and interactions between tests when applied together.

METHODS

Instrumentation

Cervical mobility was recorded through a MoCap system composed of the following components: (1) set of 8 OptiTrack cameras (Flex 13, 1.3 PM, 56° field of view, and 120 frames per second) and the OptiTrack Motive 1.9 application (NaturalPoint Inc, 2016), and (2) software motion characterization Move-Human Sensors (University of Zaragoza, Aragon, Spain),³⁴ implemented in Vizard VR Toolkit³⁵ (WorldViz, Santa Barbara, California) virtual reality platform and the intellectual property of the University of Zaragoza.

OptiTrack Motive controls the cameras and processes the movement data of certain rigid bodies (RBs), providing 6 degrees of freedom for each of them. The RBs information is read in real time by Move-Human Sensors through a peripheral network communication protocol, and is transferred to a 3D digital human model. At the beginning of each capture, an anatomic calibration process to adjust the digital model to the anthropometry of the participant and associate the position and orientation of each RB with the corresponding body segment is completed by matrix transformation. The software allows visualizing and recording cervical movements in real time while applying the PM or AM techniques.

The RBs correspond to groups of 3 markers (reflective spheres) placed on a rigid support. Each RB was individually designed for an appropriate fit adjustment to its corresponding body part. Three RBs were used to record the cervical kinematics: 1 on the sacrum, another on the spinous processes of vertebrae C7-D1, and another on the head (Fig 1).

Participants

Twenty-four asymptomatic participants (16 men and 8 women) aged 32 ± 11.35 years participated in the study. Anthropometric characteristics from the population are shown in Table 1. The inclusion criteria were the absence of the following: a history of neck or head pain; cervical trauma; vestibular, visual, or nervous problems; or surgeries in the cervical region. These data were collected by interview, which was guided by the same evaluator.

Fig 1. Location of rigid bodies in the sacrum, the spinous processes of C7-D1 vertebrae, and the head.

All participants signed an informed consent to participate in this study and for the filming of the test for research purposes. This study received a favorable dictum on the biomedical research project from the Clinical Research Ethics Committee of Aragón (Spain). This study received authorization from the Aragón Engineering Research Institute of the University of Zaragoza, where the test of this study was conducted.

Process

Figure 2 shows the design of the study. Each participant was evaluated in 3 sessions (S) on 2 different days. A 10-minute interval was established between S1 and S2 and

more than 24 hours between S2 and S3. The citation times to conduct the assessment were assigned to avoid morning stiffness.³¹

In each session, an AM and PM of the cervical ROM were performed in sequential order. The AM test was performed by 2 operators (biomedical engineers), and the PM was performed by an examiner (therapist specializing in orthopedic manual therapy). There was no contact between the operators and the examiner physiotherapist during the entire study. The operators and examiner were specialists in the operation and instrumentation of the system used.

At the beginning of each session, the participant was instructed to adopt a natural and upright posture, ensuring a 90° angle between hips and knees, with forearms relaxed and resting on the thighs. A blackless, on-swivel and adjustable height chair was used. Next, an anatomic calibration process was performed to adjust the anthropometry of the human model participant (Fig 3).

Prior to each evaluation, a series of warmup exercises was conducted to prepare the cervical muscles and facilitate the participant's familiarity with the movements.

In both ROM evaluations (PM and AM), the following sequence of movements was followed: cervical flexion-extension (F-E); cervical rotation (R), right (RR) and left (LR); cervical lateralization (L), right (RL) and left (LL); measuring the full ranges (F-E, R-R, L-R) and mean ranges (F, E, LR, RR, LL, and RL) with the system. Figure 4 describes the

Table 1. Anthropometric Characteristics of the Participants

	Age (y)	Height (cm)	Weight (kg)
Total			
(N = 24)	32 (11.35)	179.04 (11.47)	73.03 (7.31)
Male			
(N = 16)	32 (11.74)	186.20 (8.67)	84.35 (5.45)
Female			
(N = 8)	35 (10.7)	164.75 (9.99)	57.59 (7.48)

Fig 2. Method design and process scheme. AM, active mobilization; MoCap, motion capture; PM, passive mobilization.

captured movements and the reference systems considered for the analysis.

The AM was executed by continuous and sequential movements performed by the participant without physical assistance from the operator. Each participant was instructed to reach the maximum range without symptoms or pain. The speed of execution was determined by the participant without the influence of any operator.¹¹

The PM consisted of anatomic structure mobilization of the participant through the hands and the body by the examiner, avoiding the compensatory movements of the thoracic region. Palpating the spinous processes of the C6, C7, and D1 vertebrae and globally mobilizing the cervical

spine to feel movement from C7 to D1 at the base of occipital bone provided movement information. Figure 5 shows the PM technique of F-E.

The PM protocol was followed to perform the movements until the “end feel,”^{24,36} with the final resistance in the palpation hand.^{17,18} During the PM, an attempt was made to avoid the appearance of sources of error, both verbal and gestural, toward study participants that could come from the examiner’s prejudices on age, aesthetics, and expressions. In addition, a warm up was held to prevent the muscular protection effect of the participant in performing the movements. The mobilization was conducted by a therapist trained in orthopedic manual therapy.

Fig 3. Anatomical calibration.

Fig 4. Sequence of movements followed in the range of motion evaluations.

Statistical Analysis

The variables considered in the statistical study were the average of the 3 ROM movements; full ranges of F-E, R-R, and L-L; and mean ranges of F, E, RR, LR, RL, and LL.

The following studies were conducted using Minitab 17 statistical software. First, an exploratory analysis of the data was conducted, including the control of possible outliers and a normality test. The means and standard deviations are

Fig 5. Passive mobilization for the movement of flexion-extension.

Table 2. Normal Data Study From AM and PM

Movement	Technique	μ (SD) S1	μ (SD) S2	μ (SD) S3	Average (SD)	P value
F	PM	50.82 (11.1)	48.81 (8.02)	49.80 (9.44)	49.81 (9.45)	.382
	AM	50.37 (10.17)	49.33 (9.70)	50.18 (8.89)	49.94 (9.47)	.392
E	PM	68.38 (16.24)	69.53 (14.98)	71.30 (15.16)	69.73 (15.25)	.282
	AM	66.97 (12.92)	69.07 (13.04)	68.38 (12.47)	68.14 (12.66)	.220
F-E	PM	122.33 (19.79)	122.87 (19.61)	126.74 (17.09)	123.98 (18.68)	.074
	AM	119.87 (18.58)	120.74 (18.47)	121.06 (16.86)	120.55 (17.75)	.262
LR	PM	80.08 (9.42)	79.42 (10.22)	81.41 (6.92)	80.33 (9.03)	.604
	AM	75.45 (8.17)	78.75 (10.06)	77.95 (8.98)	77.4 (9.07)	.008
RR	PM	73.05 (9.35)	72.51 (9.78)	74.19 (9.97)	73.25 (9.51)	.534
	AM	73.76 (7.83)	75.47 (7.71)	76.51 (9.19)	75.25 (8.24)	.065
R-R	PM	156.98 (13.80)	155.21 (15.40)	162.79 (14.80)	158.33 (14.52)	.200
	AM	152.28 (14.63)	157.13 (15.08)	158.09 (17.18)	155.83 (15.63)	.009
LL	PM	39.59 (6.36)	40.35 (5.80)	38.67 (8.45)	39.54 (6.69)	.680
	AM	39.97 (7.40)	41.54 (6.85)	39.75 (6.47)	40.42 (6.90)	.590
RL	PM	40.96 (7.36)	42.26 (8.49)	44.61 (5.80)	42.61 (7.36)	.886
	AM	42.42 (5.66)	43.41 (5.86)	43.29 (5.47)	43.04 (5.69)	.855
L-L	PM	84.79 (13.50)	88.02 (12.87)	88.31 (11.73)	87.04 (12.69)	.871
	AM	85.4 (12.01)	87.94 (11.09)	85.92 (11.24)	86.42 (11.45)	.583

AM, active mobilization; E, extension; F, flexion; F-E, flexion-extension; L-L, complete range of motion from lateralititation; LL, cervical lateralization left; LR, cervical rotation left; PM, passive mobilization; R-R, complete range of motion from rotation; RL, cervical lateralization right; RR, cervical rotation right; S1, session 1; S2, session 2; S3, session 3; SD, standard deviation.

shown in Table 2. The averages of the 3 sessions were compared using a repeated-measure analysis of variance (ANOVA), with 2 fixed factors (participants and sessions). The influence of the 6 measures (3 AM and 3 PM) on the ROM was evaluated through ANOVA. When the ANOVA indicated significant differences, the Tukey test was used to determine the pairwise differences. All factors were defined as fixed. The differences between the 2 types of evaluations (AM and PM) were analyzed using the Bland-Altman method³⁷ for interest movements. To evaluate the reliability of the system, using both types of mobilizations (PM and AM), 3 different statistical methods were applied: the interclass correlation coefficients (ICCs),³⁸ the Bland-Altman method,³⁷ and the standard error of measurement (SEM).³⁹ To evaluate important changes in the clinic, the minimal detectable change (MDC) and the coefficient R (95%) were calculated. A comparative analysis of the reliability results achieved in the PM and AM evaluations has been conducted (Tables 3 and 4).

RESULTS

The results are displayed in graphs in Figure 6 (AM) and Figure 7 (PM), which are generated from the MoCap application. Statistical analysis (Table 2) shows the results of the exploratory analysis and the average for the movements studied in each session. All movements in both types of assessments, PM and AM, fulfilled the normality hypotheses.

Regarding the comparison results between sessions (S1, S2, and S3) by ANOVA, there were no statistically significant differences for the movements studied ($P > .050$), with an exception found for LR and R-R in AM movement.

Regarding the influence between assessments (3 PM and 3 AM), the ANOVA test results (type of evaluation, time [sessions], direction of movement, and participants) reported no significant ROM difference between (1) the type of evaluation ($P > .05$) or (2) the time of sessions ($P > .05$) for all movements (F-E, L-L, RR, and LR).

Table 3. *Passive Mobilization Reliability Results*

Intraexaminer (S1-S3)					Intraexaminer (S1-S2)				Global Mean Intraexaminer			
Movement	R (95%)/ Average	SEM/ Average	MDC/ Average	ICC	R (95%)/ Average	SEM/ Average	MDC/ Average	ICC	R (95%)/ Average	SEM/ Average	MDC/ Average	ICC
F	0.431	0.152	0.422	0.428 (0.00-0.87)	0.228	0.163	0.223	0.814 (0.73-0.96)	0.329	0.158	0.323	0.621
E	0.184	0.065	0.180	0.909 (0.86-0.98)	0.196	0.069	0.200	0.911 (0.88-0.98)	0.190	0.067	0.190	0.910
F-E	0.138	0.049	0.135	0.878 (0.81-0.98)	0.102	0.036	0.100	0.954 (0.93-0.99)	0.120	0.042	0.117	0.916
LR	0.106	0.038	0.104	0.855 (0.24-0.92)	0.133	0.047	0.130	0.849 (0.78-0.97)	0.120	0.042	0.117	0.852
RR	0.210	0.074	0.206	0.607 (0.79-0.97)	0.134	0.047	0.131	0.844 (0.81-0.97)	0.172	0.061	0.168	0.726
R-R	0.083	0.029	0.081	0.828 (0.75-0.99)	0.107	0.038	0.105	0.78 (0.67-0.95)	0.095	0.034	0.093	0.804
LL	0.135	0.048	0.132	0.91 (0.85-0.99)	0.197	0.070	0.193	0.699 (0.54-0.94)	0.166	0.059	0.163	0.805
RL	0.246	0.087	0.241	0.666 (0.38-0.94)	0.273	0.096	0.267	0.78 (0.65-0.95)	0.259	0.092	0.254	0.723
L-L	0.158	0.056	0.155	0.799 (0.21-0.98)	0.136	0.048	0.134	0.89 (0.83-0.98)	0.147	0.052	0.144	0.845

E, extension; *F*, flexion; *F-E*, flexion-extension; *ICC*, interclass correlation coefficient; *L-L*, complete range of motion from lateralittation, cervical lateralization left; *LR*, cervical rotation left; *MDC*, minimal detectable change; *R-R*, complete range of motion from rotation; *RL*, cervical lateralization right; *RR*, cervical rotation right; *SEM*, standard error of measurement.

Table 4. Active Mobilization Reliability Results

Intraoperator A (S1-S3)					Intraoperator B (S1-S3)				Global Mean Intraoperator (A & B)			
Movement	R (95%)/ Average	SEM/ Average	MDC/ Average	ICC	R (95%)/ Average	SEM/ Average	MDC/ Average	ICC	R (95%)/ Average	SEM/ Average	MDC/ Average	ICC
F	0.161	0.057	0.158	0.864 (0.71-0.98)	0.214	0.076	0.210	0.803 (0.60-0.97)	0.188	0.066	0.184	0.834
E	0.108	0.038	0.106	0.919 (0.90-0.99)	0.113	0.040	0.110	0.955 (0.92-0.99)	0.110	0.039	0.108	0.937
F-E	0.096	0.034	0.094	0.875 (0.83-0.99)	0.071	0.025	0.069	0.967 (0.94-0.99)	0.083	0.030	0.082	0.921
LR	0.142	0.050	0.139	0.709 (0.38-0.96)	0.109	0.039	0.107	0.913 (0.82-0.99)	0.125	0.044	0.123	0.811
RR	0.137	0.048	0.134	0.631 (0.33-0.96)	0.138	0.049	0.135	0.827 (0.64-0.98)	0.137	0.049	0.135	0.729
R-R	0.089	0.032	0.087	0.738 (0.64-0.97)	0.069	0.024	0.067	0.953 (0.90-0.99)	0.079	0.028	0.077	0.846
LL	0.141	0.050	0.139	0.834 (0.75-0.99)	0.156	0.055	0.153	0.746 (0.35-0.98)	0.149	0.053	0.146	0.790
RL	0.123	0.044	0.120	0.889 (0.80-0.99)	0.083	0.029	0.082	0.858 (0.62-0.99)	0.103	0.036	0.101	0.874
L-L	0.062	0.022	0.061	0.943 (0.80-0.99)	0.116	0.041	0.114	0.822 (0.44-0.98)	0.089	0.032	0.087	0.883

E, extension; *F*, flexion; *F-E*, flexion-extension; *ICC*, interclass correlation coefficient; *L-L*, complete range of motion from lateralittation; *LL*, cervical lateralization left; *LR*, cervical rotation left; *MDC*, minimal detectable change; *R-R*, complete range of motion from rotation; *RL*, cervical lateralization right; *RR*, cervical rotation right; *SEM*, standard error of measurement.

Fig 6. Graph of flexion-cervical extension movement during active assessment technique active mobilization (cervical Rx).

The comparison between types of mobilization was studied using the Bland-Altman method. The ROM data corresponding to the average of the 3 sessions for each participant was used for this comparison (Table 5). In this study, no statistically significant differences ($P > .050$) were found, except for R-R, which is of .05 order, and LR, which included the value zero in the interval.

Tables 3 and 4 show the reliability results. Enderlein and Fleiss⁴⁰ considered “excellent reliability” for ICC values to be greater than 0.75 and “fair to good reliability” values to be

between 0.4 and 0.75. According to this classification, the values obtained from the ICC demonstrate good to excellent reliability for all movements and mobilizations for PM (ICC = 0.621-0.916) and AM (ICC = 0.729-0.937). Only the F movement showed lower reliability values for the PM (ICC = 0.428; case intraexaminer S1-S3).

The level of agreement between the 3 sessions, also called the change in mean, was evaluated using the Bland-Altman method.³⁷ The t test for paired samples (between sessions) revealed that there are no systematic

Fig 7. Graph movement of flexion-extension technique used for passive assessment, passive mobilization (cervical Rx).

Table 5. Bland-Altman Method Results for the Differences Between the PM and AM Methods

Differences Between Methods (PM-AM)					
Movement	Size Sample	$\mu d(SD_d)$	R (95%)	P^a	$\mu(95\% \text{ CI})$
F	Total (n = 23)	0.43 (7.13)	14.26	.290	(-3.51; 2.66)
E	Total (n = 23)	1.77 (5.41)	10.82	.130	(-0.57; 4.11)
F-E	Total (n = 22)	3.36 (7.88)	15.76	.059	(-0.13; 6.85)
LR	Total (n = 24)	2.70 (4.36)	8.72	.006	(-0.86; 4.54)
RR	Total (n = 20)	1.15 (5.64)	11.28	.372	(-3.79; 1.49)
R-R	Total (n = 20)	3.95 (7.12)	14.24	.022	(0.62; 7.28)
LL	Total (n = 18)	0.67 (5.59)	11.18	.616	(-2.10; 3.45)
RL	Total (n = 19)	1.04 (5.58)	11.16	.426	(-1.65; 3.73)
L-L	Total (n = 17)	3.87 (9.29)	18.58	.105	(-0.91; 8.65)

AM, active mobilization; CI, confidence interval; E, extension; F, flexion; F-E, flexion-extension; L-L, complete range of motion from lateralization left; LL, cervical lateralization left; LR, cervical rotation left; PM, passive mobilization; R-R, complete range of motion from rotation; RL, cervical lateralization right; RR, cervical rotation right; SD_d , standard deviation of differences.

^a P value student's t test for paired samples.

differences for all movements analyzed in both techniques ($P > .020$).

Moreover, reliability was assessed by variability measures, such as SEM, r (95%), or MDC. These values assess the errors regarding reliability, following the approach of Strimpakos et al.³¹ The following ranges of values were found: PM (r [95%]/average = 0.095-0.329; SEM/average = 0.034-0.158; MDC/average = 0.093-0.323) and AM (r [95%]/average = 0.079-0.188; SEM/average = 0.028-0.066; MDC/average = 0.077-0.184).

DISCUSSION

Evaluated Asymptomatic Population

This study is focused on the design of the system and the protocols for cervical spine assessment through ROM measurement. A sample of asymptomatic participants was selected. This was motivated by the specific objectives of this work, where there are factors that influence AM and PM, either alone or in combination. These factors are the technological and operational system, the placement or possible movement of the markers during capture, the clinical protocol of tests, the environment where they are conducted, the personal factors of the participant, or the factors related to the operator who conducts the evaluation.

Therefore, before assessing patients with cervical spine pathology, it is necessary to study the influence of all the factors not related to the patient's own cervical pathology to analyze the factors related to the system operation and related to the cervical physiological movement of asymptomatic people. This allows laying the groundwork for its real application in clinical settings with pathologic

participants, which will allow the authors to detect the differences with the asymptomatic population of this study. Furthermore, it is useful for the early detection of pathologies, which constitutes the goal of this study.

Considerations of the Applied Experimental Protocol

To address the objectives of this study, a specific experimentation protocol has been designed. A total of 3 sessions were conducted. In each session, PM and AM were performed in sequential order. The first 2 sessions (S1 and S2) were made consecutively after a short break without touching the markers or RBs. The third session (S3) was conducted the following day and logically required the relocation of the RBs. The applied experimental protocol covers the different possibilities of evaluating the influence of factors that are relevant to the purposes of this study:

1. Placement of the RBs and their possible movement during the capture or after a rest where the participant can be relocated in the seat (between S1 and S2).
2. During the PM, the examiner may inadvertently touch the RBs on the D2 vertebrae or head, which could cause small movements and errors in the capture.
3. Complete relocation of the RBs (between S2 and S3), which can be a source of variability to analyze.
4. The learning effect of the participant between S1 and S2, which would not be expected between S2 and S3.
5. The resting effect between tests, which is short between S1 and S2 and complete between S2 and S3.
6. The effect of performing an AM technique first and then a PM, given the possible influence of one over the other. It is of interest to obtain a protocol for

clinical application that combines the use of both techniques, especially for the forensic field, to study the degree of consistency and collaboration of the patient.

7. The effects of the AM applied by the operator (biomedical engineer) that do not require physical interaction with the patient during the capture and the PM performed by the examiner (chiropractic physician) that requires interaction. The protocol established that there was no interaction between the evaluators.

Given the singularity of PM, where it is necessary to reach the limits of the physiological barrier of the participant's cervical spine, it was considered necessary to block this variability inherent to the knowledge of the technique, training, skill, or experience of the examiner because in this paper, the authors aim to study the effect of the rest of the described factors. However, it is necessary to consider that, in clinical practice, for the follow-up of a patient during a treatment (simulated with the sequence of sessions S1 or S2 with S3), it is convenient that the same examiner performs the test, applying the same criteria of PM in the same way. Regarding both considerations, the authors tried to analyze all the exposed factors, excluding the variability of the examiner that conducts the PM, while the follow-up of a patient in a clinic justifies that only a single examiner participated in the 3 sessions.

Both considerations seek to analyze all the intervening factors (not including the variability of the examiner that carries out the MP) and the follow-up of a patient in clinic, justifies that in the 3 sessions (S1, S2, and S3), a single examiner would intervene. We only need to know the reproducibility performed by 1 physiotherapist, since we compare this with the AM. In contrast, 2 operators participated in the AM. For study purposes, the mean values of both have been considered and collected in Table 4. The statistical analysis corresponding to the interoperator evaluation is included in a technical note.⁴¹

This study proposes a method of evaluation for those with cervical trauma (eg, WAD), based on a methodology that combines the PM and AM techniques, providing information on the structural and functional actions, respectively. The validation was conducted through an analysis of the results provided by the MoCap system. Then, the aspects regarding comparison between AM and PM and the reliability of both tests are discussed.

Data Comparison Between Tests

No statistically significant differences ($P > .050$) in the ROM during PM and AM (F-E, RR, and L-L) were found (Table 5), except for the LR motion and R-R range. This last result was more pronounced in S1 and may be motivated by a lack of learning and cervical spine tone before a little training and familiarization with these movements.

Given the predetermined order of testing (AM and PM), it is necessary to analyze the interactions between them to study the possible influence between tests performed in combination. For this purpose, an ANOVA was conducted, which showed an identical ROM in all assessments made (3 AM and 3 PM), which shows that there is no influence between each test. These results are consistent with the fact that both mobilizations (PM and AM) seek to achieve a nonanatomic physiological barrier based on the concepts of manual therapy.²⁴

These findings differ from those reported in the literature^{8,17,23,32,42,43} by other authors comparing the ROM between types of mobilizations (AM and PM). Rutledge et al¹⁷ used standardized and predefined PM criteria to reach the cervical movement physiological barrier. Their results show a higher ROM in the AM relative to the PM. In contrast, under the same objective, Castro et al⁴³ reported contrasting results.

One explanation for this discrepancy may be associated with the variety of systems and protocols used and the population sample characteristics. In addition, the methodologies are not usually explained in detail, hence the need for studies that analyze these aspects in depth. The fact that psychological, social, and compensatory factors are involved in the WAD etiologic study required the study of the consistency of the measures to assess the degree of patient cooperation in testing.⁴ Therefore, ensuring an adequate differential diagnosis that reports intentionally or unintentionally exaggerated pain is required. While AM techniques are influenced by these factors, PM techniques are conditioned by the subjectivity of the examiner, which depends heavily on training and experience.¹⁷

The compromise between evaluator, instrumentation, and patient becomes a set of factors to consider that should not be influenced by the function studied. Consequently, the use of isolated techniques is insufficient to ensure a proper diagnosis.

Reliability: Passive Mobilization

To determine the reliability of both techniques, different reliability coefficients have been calculated, representing various aspects of reliability.^{29,37} The ICC is the preferred retest correlation coefficient.²⁹ Following the classification proposed by Enderlein and Fleiss⁴⁰ for this index, the results show a reliable, good to excellent range from 0.621 (RR) to 0.916 (F-E), with the exception for the value of the F movement, which was 0.428 (intraexaminer S1-S3) in Table 3.

Results reported in the literature^{18,31,32,42,44,45} show good to excellent levels of reliability using different systems and protocols for movements in complete cycles (F-E, R-R, and L-L). Strimpakos et al³¹ discussed PM reliability with an ultrasound system, Zebris CMS 20, in different body positions. Their results report ICC values from 0.83 to 0.94 in a sitting position and 0.84 to 0.97 while standing. Morphett et al¹⁸

Fig 8. Ultrasound scanning of treated structures. MGM, maximus gluteus muscle; NT, tip of the needle; PM, piriformis muscle; SN, sciatic nerve.

obtained similar results, using the Cybex 320 electromagnetic system. Assink et al³² obtained results of this lower index, ranging from 0.73 to 0.77, with the Flock of Birds system device. Williams et al⁴³ and Love et al⁴⁴ analyzed the reliability for half-cycle movements. However, these studies work with symptomatic population samples and are not comparable to the results of this study.

The results in the literature for this ICC index are generally high and classified as “excellent reliability.” This index considers many factors (sample population, the physiotherapy or tester effects, instrumentation, etc), which are considered in the reliability.^{29,38} However, its isolated application is not sufficient and can lead to misleading results due to the factors on which it depends.²⁹ Therefore, a complete analysis of reliability requires studying more concepts using statistical methods, which would deepen the characteristics and properties of the PM and AM techniques.^{7,10,29,37}

Changes in the Mean

The next step in analysis is to calculate the reliability of the possible changes in ROM mean obtained between sessions (intraexaminer S1-S3 and intraexaminer S1-S2). The change in mean is mainly due to a systematic component, which studies differences that are consistently induced between sessions (learning effect, onset of fatigue, or fear of movement) and can be detected through methods such as those developed by Bland-Altman.³⁷

Analyzing the results of Table 3, no significant changes were observed in the ROM mean for movements ($P > .020$) except the full range of L-L. The authors conclude that there are no systematic differences, which suggests the suitability of the designed PM protocol. No pattern has been found among the differences in the obtained measurements between the 2 sessions, and the average of these for the movements studied, thus ensuring that differences do not vary systematically in the measurement interval. A graphic illustration of the results of this is shown in Figure 8.

Measurement Variability

To demonstrate the absence of systematic changes, it is necessary to quantify the variability size of the measurements between sessions. Aspects that show real variability given by methodology (technical, protocol, and instrumentation) system factors are called “standard error or typical variation.” Accordingly, at this point, less variability is the most sensitive method when discriminating between healthy and pathologic participants to report more reliable measurements.

An index for measuring variability is the SEM. This helps to estimate the measurement dispersion errors when estimating the true measure between the observed measurements in different sessions.^{29,39,46}

Reliability of movement with this index has not been studied. Only Strimpakos et al³¹ were found to have a well-defined protocol, working in an asymptomatic population. The results of the cited study presented an analysis of full ROM (F-E, R-R, and L-L), which ranged from 0.031 to 0.048 and are similar to the results achieved in the present work with the range of 0.034 to 0.052 (Table 3).

The use of MoCap systems provided objective measurements of the real capacity of cervical mobility, as stated by Rutledge et al¹⁷ and Alqhtani et al¹² for PM and Inokuchi¹³ and Song et al¹⁴ for AM. This provided an advantage over evaluations based exclusively on the subjectivity of the evaluator and his or her experience in the field. However, the added value provided by these technologies may be impaired or even not useful in the clinical setting if the possible sources of error considered in this study are not studied and controlled in their practical application.

Interpretation of Results

To facilitate the interpretation of results, the MDC index was obtained. This index is calculated on the variability of the measurements represented by the SEM multiplied by

1.96 and the square root of 2 to include 95% of the observations of differences between measurements.²⁹ Consequently, the MDC is similar to the “limits of agreement” proposed by Bland-Altman (R [95%]), converging on the same conclusions about the variability of the measurements.

Indices (R [95%] and MDC) are values used by the evaluators to judge significant changes in clinical results as a limit point. Consequently, the lower the value, the more sensitive the technique is required to be to detect these changes. No direct references were found in the literature for the ratio R (95%) relative to PM. Analyzing results of MDC from the mean, the authors obtained values ranging from 0.093 to 0.144 in full ranges and between 0.117 (LR) and 0.323 (F) for half cycles (Table 3).

These values are in range with those obtained by Strimpakos et al,³¹ who analyzed the full ROM and were the only authors who used this index with a well-described protocol and asymptomatic participants. The reliability results confirm the validity of the PM technique used for assessment of cervical ROM in the movements studied. Only the F movement showed low reliability values for all indices analyzed.

The F movement presents biomechanical and anatomic difficulties. The natural curvature (kyphosis) hinders the general PM for C0 to C7, and the tendency for the movement focuses on the media segments. If one wants to involve all anatomic structures, making a maximum amplitude mobilization, the upper and lower cervical spine should be technically and structurally distinguished because their biomechanics are different.⁴⁷

Comparison of Reliability of Passive and Active Mobilization

Considering the overall global reliability values from the ROM means, the F-E movements and L-L in AM show better results regarding PM, which is similar to the case of R-R (Tables 3 and 4). The R-R movement comes to 70% of the C2 to C3 cervical segments; therefore, reaching the physiological barrier is easier for the examiner by focusing mainly on this segment to achieve most of the range of amplitude movement.⁴⁷

In the case of F-E and L-L movements, although they involve the same number of cervical segments, they require controlling greater distances of the cervical spine by the examiner because the ROM, to achieve the desired barrier, is more homogeneously distributed between the vertebrae, which means greater difficulty of execution. In this regard, as claimed by some authors,^{47,48} there must be a compromise between the technical and biomechanical motion characteristics when applying the PM technique. Moreover, a correct design of instrumentation is also important to provide a good compromise between technology and instrumentation.⁴⁹

Clinical Appreciations and Future Research

It is suggested that the use of a combined AM and PM test system in a single session could provide benefits for clinical practice. This methodology should further evaluate the combination of functional and structural action, that could provide greater information to diagnose WAD.

Given the need for a compromise between the PM evaluation technique and cervical spine biomechanical characteristics, mainly for F movement, greater control is available and achievable if the examiner structurally distinguishes between the upper and lower cervical spine, respecting the structural and biomechanical differences of both sections. This would facilitate the evaluation by obtaining more relevant information and greater reliability.

Limitations

Although the population sample was sufficient, the accuracy of the study would have been improved with a larger sample. Likewise, the influence of the participation of several examiners to perform PM has not been studied because the purpose was to analyze the rest of the factors that intervene in the conducted tests. However, the characterized and controlled factors of this experimentation and the results of this study that show that the reliability is adequate for the AM and PM, applied in isolation or combination, opens the possibility of studying the influence of combining 2 operators in future studies.

Future studies should investigate the properties of PM group techniques in symptomatic participants with diverse levels of disability because the sensitivity and specificity of the techniques studied here could be potentiated in clinical application.

Recently, the use of techniques based on virtual reality show more functional assessments over conventional methods like AM and are able to obtain increased ROM for both asymptomatic¹⁹ and symptomatic²¹ participants. Unlike conventional functional techniques, virtual reality replicates the natural cervical sensory stimuli causing spontaneous movements.^{6,21,50} Consequently, for a correct evaluation of the functional action, it would be desirable to integrate distraction techniques and emotional modulation, which could positively complement traditional techniques.

Applying MoCap advanced systems, as used in this study, allows the evaluator to obtain cervical movement data dynamically in the 3 anatomic planes. This allows the evaluator to obtain measures of coupled or secondary movements, knowing the angular velocities or repositioning errors of the patient when they try to return to the starting point.⁵⁰ This information may be relevant and meaningful to detect possible cervical spine disorders. Therefore, it would be of interest to delve into the possibilities of this information for diagnostic purposes.

CONCLUSIONS

The authors present a cervical ROM assessment based on combined PM and AM protocols at different sessions. This model demonstrated high reliability, individually and combined, and no differences were detected between PM and AM ROMs. Because the evaluator, instrumentation, and the patient are factors that could influence outcomes, the authors suggest that they be combined in protocols. These protocols could be used to evaluate the functional and structural capacity of patients and inform clinical outcomes.

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CONTRIBUTORSHIP INFORMATION

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Practical Applications

- When the practitioner is instructed in PM to try to reach the “end-feel,” there were no significant differences between applying AM or PM to the cervical spine assessment.
- The application of PM combined with AM techniques may be an alternative for assessment and diagnosis of the cervical spine.

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