Validity and reliability of two Smartphone applications to measure the lower and upper cervical spine range of motion in subjects with chronic cervical pain

Jacobo Rodríguez-Sanz[a,b,*], Andoni Carrasco-Uribarren[a,b], Sara Cabanillas-Barea[a,b], César Hidalgo-García[a,b], Pablo Fanlo-Mazas[a,b], María Orosia Lucha-López[a,b] and José Miguel Tricás-Moreno[a,b]

[a]*Faculty of Health Sciences of Zaragoza, Zaragoza, Spain*
[b]*Physiotherapy Research Unit, University of Zaragoza, Zaragoza, Spain*

Abstract.

BACKGROUND: Cervical pain is the biggest musculoskeletal health problem in industrialised countries. There is an important association between this and decrease in range of motion.

OBJECTIVE: Estimate the validity and reliability intra and inter examiner of two Smartphone apps regarding the measurement of lower and upper cervical spine range of motion in subjects with chronic cervical pain.

METHODS: A cross-sectional study was conducted. The sample consisted of 25 subjects with chronic cervical pain. An examiner made a measurement of the range of motion using the CROM device as a gold standard, afterwards, another examiner did the same using a Smartphone, in order to establish validity. After this, the Smartphone examiner and a new examiner simultaneously conducted the intra and inter examiner reliability.

RESULTS: Measurement of the lower and upper cervical spine range show an excellent validity (> 0.75), with an excellent intra and inter reliability (> 0.75) in all movements except flexion of upper cervical spine (0.75–0.65).

CONCLUSION: The two Smartphone applications used in this study showed an excellent validity compared to the CROM. The intra and inter reliability is excellent for all movements, except for the upper cervical spine flexion.

Keywords: Range of motion, cervical spine, validity, reliability, CROM, inclinometer

1. Introduction

Cervical pain is the biggest musculoskeletal health problem in industrialised countries, representing 14.6% of all current musculoskeletal health problems [1,2]. 50% of the adult population will experience cervical pain at some moment during the year [3].

Symptoms are not always associated with structural lesions of the tissues. For this reason, we sometimes have to focus on the restoration of normal function, rather than the injury itself [4].

Reduced cervical range of motion (ROM) is a common discovery in people with cervical pain [5,6] and according to Prushansky and Dvir [7] there are different cervical pathologies, such as cephalea and cervical pain, where variations of the cervical movement have clinical relevance. Therefore, in many cases the treatment aims to restore it [8,9].

In addition, cervical disability has been linked to

*Corresponding author: Jacobo Rodríguez-Sanz, Physiotherapy Research Unit, University of Zaragoza, C/Domingo Miral s/n, 50009, Zaragoza, Spain. Tel.: +34 636 136 789; E-mail: jacobors@unizar.es.

a reduced range of motion in various studies. Lee et al. [10,11] observed the early appearance of changes in the ROM in a number of subjects who further developed cervical pain. Measurement showed a significant decrease of the active left rotation ROM, and a larger cervical retraction ROM in the first measurement. It also showed a decrease of the active extension ROM in the second measurement as a result of the subjects' sensitivity to cervical pain in comparison to asymptomatic subjects. Hanten et al. and Jordan et al. had previously proved that besides a smaller extension range, the total range between cervical protraction and retraction in the horizontal level was lower in subjects with cervical pain, in comparison to healthy individuals [12,13].

Cervical ROM has been used as part of the clinical criteria in illness classification [14], and for assessing the effectiveness of the re-education programs [15]. The Guides of American Medical Association (AMA) functional model for the evaluation of permanent disability are based primarily on the measurement of the cervical ROM [7].

Hence, the interest in the assessment and treatment of different functional parameters, such as the ROM, has increased exponentially during the last two decades [15,16]. The ROM exploration is a routine in the assessment of subjects who present either pain or cervical dysfunction [17,18], it is essential for the objective assessment of cervical dysfunction [19], cervical symptomatology and the effects of any intervention [20,21].

For this reason, it is necessary for cervical ROM assessments to be objective, acceptable, and reproducible. Currently the most objective way to clinically measure the ROM is the CROM device (Cervical Range of Movement) [1,2,8,10,22]. However, it is an expensive instrument that can be an impediment for usage in clinical environments, and invites to validate more economical instruments [8].

There are studies which have validated the use of mobile phone apps to measure the shoulder's ROM, and the lower cervical spine (LCS) ROM in a reliable way in healthy subjects [23]. However, studies about the use of different apps in symptomatic subjects have not been carried out, and there are not studies about the use of these apps in the measurement of the upper cervical spine (UCS) ROM while UCS is an area where hypo-mobility is frequent [24], and the C0-C1 segment has a highly frequent symptomatic implication regarding subjects with cervical pain and cephalea [25].

Therefore, the objective of this study is to estimate validity, using CROM as the gold standard, and the in-

tra and inter examiner reliability of smartphone applications in the measurement of the lower and upper cervical spine ROM in subjects with chronic cervical pain.

2. Methods

2.1. Study design

A cross-sectional study was conducted between November 2016 and May 2017 in Zaragoza, Spain. The CROM was used as gold standard to establish the validity of the "Clinometer" and "Compass" Smartphone applications. For the study of both inter and intra reliability, a correlational descriptive research was designed.

2.2. Participants

Twenty-five participants with chronic cervical pain (11 men and 14 women), with ages from 18 to 53 years old (average ± DT: 25 ± 6.72), 1.71 (7.78) meters of height, and 67.10 (± 14.45) kilograms in weight with a body-mass index of 22.74 (± 3.44) were included in the study. Eighty-four percent of the sample did physical activity for an average of 6.84 (± 5.99) hours per week. 88% of the sample worked for an average of 6.52 (± 3.53) hours per day. Thirty-two percent of the workers did their job standing in biped position, 37% in seating, and 31% worked in both positions.

The average duration of neck pain in the participants was for 70.48 (± 67.25) months, being a bilateral pain in 76% of cases, and presenting associated cephalea in 60% of participants.

One hundred percent of subjects indicated the cervical area as painful, 68% indicated the trapezius muscle area, 84% the dorsal area, and 76% the occipital area. The inclination, the LCS extension and the LCS and UCS flexion were the most symptomatic movements.

All participants lived in Zaragoza and were measured at the Faculty of Health Sciences of the University of Zaragoza. All subjects volunteered and provided written informed consent [26]. Participants were included in the study if they were over 18 years old, with more than 3 months of cervical pain evolution. The exclusion criteria were selected depending on cervical clinical guides [26], being: recent spine, head or mouth surgery, diabetes mellitus, recent infection and/or inflammatory arthritis, and cervical and/or brain traumatism records.

All subjects carefully read the protocol that would be applied and they signed the informed consent form,
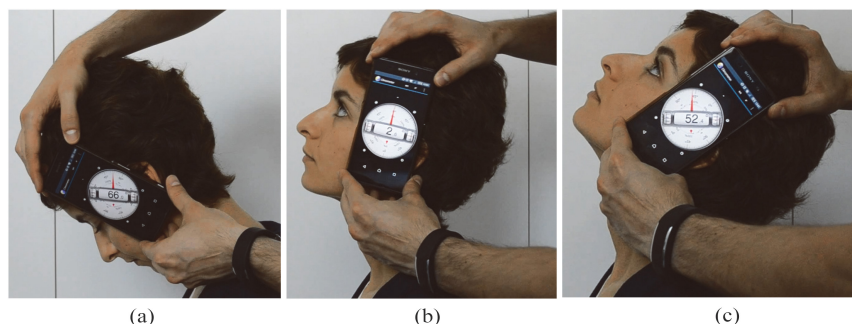
Fig. 1. Position of the Smartphone for the measurement of flexion and extension in the inferior cervical spine. (a) Position at end range of flexion. (b) Starting position. (c) Position at end range of extension.
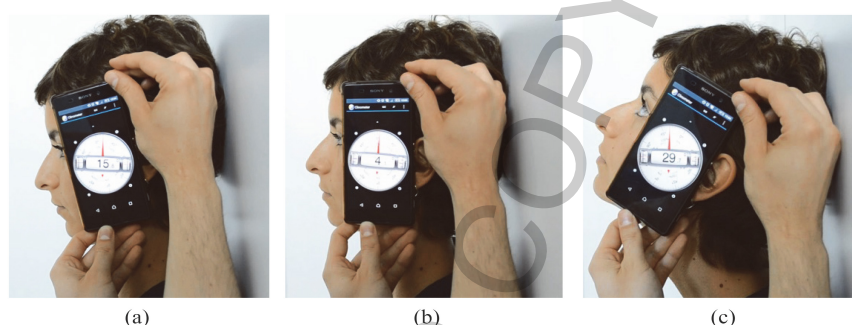

Fig. 2. Position of the Smartphone for the measurement of flexion and extension in the upper cervical spine. (a) Position at end range of flexion. (b) Starting position. (c) Position at end range of extension.

which was in accordance with the ethical principles of the Helsinki Declaration [20]. No subject received financial compensation, and all subjects were informed that they would not be operated. All subjects met all the researchers, and the instruments that would be used in the study were shown to them prior to the study.

2.3. Measurement instruments

2.3.1. Cervical range of motion (CROM)

CROM was used both to measure the LCS ROM (flexion/extension, inclinations and rotations) and the UCS ROM (flexion/extension). The CROM is similar to some glasses in which there are three inclinometers, located in three different areas: one for flexion/extension (sagittal plane) near the left ear; and another one for inclinations located in the patient's forehead (frontal plane), both dependent on gravity. The final inclinometer is on the top part of the head (horizontal plane), and it is used to register rotations. This last inclinometer is magnetic dependent, and hence the patient wears a magnetic neckless around his neck. This instrument is considered the gold standard, as its validity and reliability have been extensively studied [1,2,8,10,22,23,27,28].

2.3.2. Smartphone applications

The Smartphones used in this study were Xiaomi A1®. Two apps were used in this study. Clinometer [29] is an app which uses three accelerometers (LIS302DL accelerometer). This application uses three internal linear axes to measure the direction of the pull of gravity. For this, the gyroscope stays in one position, no matter the orientation. When placed against a solid surface, the inclinometer compares the angle of the object to the gyroscope, and displays the results using the software interface [23]. This application was used to assess the movements in the sagittal and frontal planes.

LCS flexion/extension was taken with the Smartphone placed on one side of the head, aligned with the ear (see Fig. 1). The UCS flexion/extension was taken in a similar way to the LCS. However, it was decided to place the patient's head against the wall in order to focus and ease the UCS movement (Fig. 2) [9].

Left/right LCS inclination movements were measured by placing the Smartphone on the contralateral side of the head, aligned with the eyes (Fig. 3) [23].

To measure the LCS rotation ROM in horizontal plane, the application *Compass* was used [30]. The chip used (AKM AK8975), senses the field in three
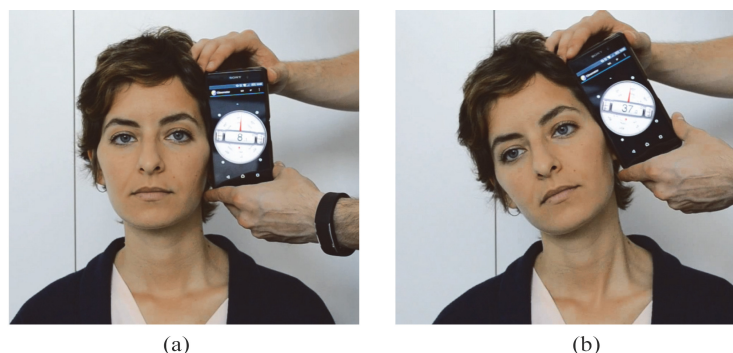
Fig. 3. Position of the Smartphone for the measurement of right lateral flexion. (a) Starting position. (b) Position at end range of right lateral flexion.

Fig. 4. Position of the Smartphone for the measurement of right rotation. (a) Starting position. (b) Position at end range of right rotation.

directions, and from this information can deduce the location of the magnetic field pointing north. It also uses the accelerometer, which tracks the movement of the device to measure changes in orientation. Rotation measurements were taken with the Smartphone placed on the patient's head, with the phone aligned with the nose (Fig. 4) [23].

2.4. Procedures

All examiners reached an agreement about how to indicate the movements to each participant, in order to standardise measurements, and how to place the Smartphone for each movement. In addition, the examiners practiced with 15 subjects to standardise the measurements (they were not included in the final sample). Participants were asked to actively make the maximum movement without pain to flexion/extension, to left/right inclination and to left/right rotation LCS ROM, as well as to flexion/extension UCS ROM. This was because the subjects were symptomatic, and the objective was to cause them the least possible irritation.

Participants made the movements in seated, relaxed position, with a closed mouth, especially during extension movements. To measure UCS movement, they were in standing position with the head against a wall, as described by Ernst et al. [9].

2.4.1. Procedures for the validity study

Two trained physiotherapists with cervical ROM measurement experience took the measurements (one was in charge of measuring with the Smartphone, and the other was working independently with the CROM).

Subjects were told how every movement was to be made. In addition, during the movement, a person from outside the study stabilised the trunk and shoulder girdle in order to avoid exceeding the cervical spine ROM required and avoid compensations.

All measurements were taken following the same order: flexion, extension, right and left inclination and right and left LCS rotation. Afterwards the UCS flexion and extension was measured [9,23].

For the sagittal and frontal planes, examiners had a consensus meeting in which they agreed that measure-

ments would always correspond to the total range in degrees: the difference between final and initial measurements. For example, a starting position of 10° towards the extension and an end-range of 50° in flexion gives us a total flexion of 60° (50° − (−10°) = 60°). The measurement just explained was decided upon because it was the most adequate to compare to the Smartphone application, as the phone alignment with the ear was not necessarily the same as that of the CROM. However, in the studies that use the CROM, usually the final measurement is the one chosen. The total range (in degrees) was also used for the rotation and flexion/extension UCS movements [23].

2.4.2. Assessment with the CROM

Examiner 1 (in charge of CROM) placed himself on the patient's left side in order to start the assessment of the lower cervical flexion. Immediately after this, the participant made three repetitions of LCS flexion until reaching the first feeling of tension and/or pain, we use the average of three measurements as final value. Examiner 1 assessed his results in silence. Afterwards the process was repeated toward the LCS extension, inclinations and rotations [23].

Finally, UCS flexion was measured. For this, the subject was placed in standing position with their head against the wall. The subject made a UCS flexion until reaching the first feeling of tension/pain, and repeated the movement three times, we use the average of three measurements as final value. Examiner 1 wrote the results in silence. The process was then repeated for the extension [9].

2.4.3. Assessment with the Smartphone applications

Subsequently, Examiner 2 (in charge of the Smartphone) placed himself on the left side of the patient, with the phone positioned as explained previously, in order to start the assessment of the lower cervical flexion. He followed the same process as Examiner 1, then wrote down the results in silence, on a page blinded from Examiner 1. The same process was repeated for the extension, inclinations, rotations and the UCS. We use the average of three measurements as final value.

To measure the sagittal and frontal plane, it was agreed, including the Smartphone, that all measurements would always correspond to the total range in degrees. The difference between the initial and final measurement would be for example: on starting position of 10° towards the extension and a final position of 50° of flexion give us a total flexion of 60° (50° − (−10°) = 60°). The total range in degrees was

also used for the UCS rotation and flexion/extension. We use the average of three measurements as final value [13].

2.4.4. Procedures for the reliability study

Once the validity process for the 25 participants was complete, 10 participants were arbitrarily chosen to make the intra and inter examiner reliability. The reliability measurements were taken, allowing a ten minutes break from the first measurement. This was done in the same room and under the same conditions as the previous measurements. A consensus session was held by the examiners to establish the measurement method, which was agreed to be similar to that established for the validity process.

Examiner 2 (in charge of the Smartphone) took all the measurements again, in order to obtain the intra examiner reliability, and simultaneously, a new examiner, Examiner 3, made the measurements to obtain inter examiner reliability. As the subjects were symptomatic, it was decided to carry out this process simultaneously, in order to cause as little irritation as possible.

Measurements were made following the same order as in the validity process, and each examiner had his own sheet on which to write down the results in silence and in an independent way.

For both LCS and UCS flexion/extension movements, Examiner 2 placed himself in the right side of the patient, and Examiner 3 in the left side. In this way, neither examiner could see the results recorded by the other. We use the average of three measurements as final value.

For the rotation movement, it was impossible to take simultaneous measurements, as examiners would have not been blinded. Therefore Examiner 2 took the measurements first, and then Examiner 3. We use the average of three measurements as final value for Examiner 2 and the average of three measurements as final value for Examiner 3 too.

In addition, a person from outside of the study stabilised the trunk and shoulder girdle during the movement, in order to avoid it exceeding the required cervical ROM, and avoid compensation.

2.4.5. Statistical analysis

Descriptive statistics were made for each movement of the ROM (degrees), both for the Smartphone applications and CROM measurements, using the mean and standard deviation. Finally, the analysis of the descriptive variables was done [23].

Table 1
Validity criteria with the Smartphone compared to CROM

	Examiner 2, Smartphone (mean ± SD)	Examiner 1, CROM (mean ± SD)	ICC ± [95% CI]
Upper cervical spine flexion	12.96° ± 3.73°	12.61° ± 3.86°	0.98 [0.95–0.99]
Upper cervical spine extension	25.01° ± 5.90°	25.37° ± 5.87°	0.97 [0.94–0.99]
Lower cervical spine flexion	54.41° ± 11.18°	53.76° ± 11.70°	0.98 [0.95–0.99]
Lower cervical spine extension	61.83° ± 13.81°	60.40° ± 13.50°	0.98 [0.97–1]
Lower cervical spine right inclination	34.62° ± 7.89°	36.25° ± 7.32°	0.92 [0.81–0.97]
Lower cervical spine left inclination	36.86° ± 6.73°	37.84° ± 6.06°	0.96 [0.90–0.98]
Lower cervical spine right rotation	63.98° ± 10.61°	62.26° ± 9.98°	0.93 [0.84–0.97]
Lower cervical spine left rotation	66.72° ± 9.77°	64.91° ± 10.21°	0.96 [0.90–0.99]

Table 2
Intra examiner reliability criteria with the Smartphone

	Examiner 2, 1st measurement (mean ± SD)	Examiner 2, 2nd measurement (mean ± SD)	ICC	95% CI
Upper cervical spine flexion	11.55° ± 2.33°	12.13° ± 2.36°	0.73	–0.07–0.93
Upper cervical spine extension	24.97° ± 4.20°	24.64° ± 4.73°	0.98	0.93–1
Lower cervical spine flexion	51.15° ± 12.52°	46.92° ± 15.19°	0.90	0.60–0.98
Lower cervical spine extension	57.14° ± 16.17°	52.74° ± 14.38°	0.94	0.70–0.99
Lower cervical spine right inclination	38.64° ± 6.30°	36.97° ± 6.91°	0.83	0.34–0.96
Lower cervical spine left inclination	41.05° ± 5.76°	37.94° ± 6.81°	0.88	0.23–0.97
Lower cervical spine right rotation	64.50° ± 9.56°	62.02° ± 7.79°	0.89	0.57–0.97
Lower cervical spine left rotation	64.47° ± 8.11°	63.14° ± 6.00°	0.96	0.84–0.99

To estimate the validity of the study criteria, the ICC was used to assess the consistency and agreement respectively. The ICC verifies whether the values are the same and it does not only make associations. ICC was also used for the intra and inter examiner reliability.

ICC values vary from 0 to 1 [26]. For the interpretation of the ICC validity this study used > 0.75 excellent, 0.75–0.65 good 0.65–0.50 moderate and < 0.50 poor [23,31]. 95% IC was constructed around the estimated point to account for sample variation.

3. Results

The validity of the Smartphone applications results when compared to gold standard (CROM) have demonstrated excellent values in all movements (ICC > 0.75, $r > 0.75$, $p < 0.000$). Table 1 shows the completed ROM results and means, with typical deviation from CROM measurements of both CROM and Smartphone applications.

Intra examiner results related to Smartphone applications showed an excellent reliability in all movements (ICC > 0.75) with the exception of upper cervical flexion, which showed a good reliability (ICC $= 0.73$). Table 2 shows complete ROM results and means, along with the typical deviation from the first and second measurements of Examiner 2, with the Smartphone applications.

Inter examiner reliability results for the Smartphone applications showed an excellent reliability in all movements (ICC > 0.75), with the exception of upper cervical flexion which showed a good reliability (ICC $= 0.68$). Table 3 shows complete ROM results and means, with their typical deviation from the second measurement of Examiners 2 and Examiner 3, with the Smartphone applications.

4. Discussion

This study is the first to assess the validity and reliability of the Smartphone applications "Clinometer" and "Compass" for the measurement of LCS and UCS ROM in subjects with chronic cervical pain, using the CROM as gold standard, showing an excellent validity, and an excellent reliability for all movements, except for the UCS flexion which is good. Currently there is a study which assessed the lower cervical spine ROM in healthy participants by using the same mobile applications as this study. However, in that study no symptomatic subjects took part, UCS ROM was not assessed and the iPhone was the evaluation instrument [23].

4.1. Validity

Cervical ROM with the Smartphone applications compared to the CROM has showed good results in all movements, with excellent validity (ICC > 0.75).

Table 3
Inter examiner reliability criteria with the Smartphone

	Examiner 2, 1st measurement (mean ± SD)	Examiner 3, 1st measurement (mean ± SD)	ICC	95% CI
Upper cervical spine flexion	11.55° ± 2.33°	12.09° ± 2.65°	0.68	–0.32–0.92
Upper cervical spine extension	24.97° ± 4.20°	25.60° ± 5.07°	0.97	0.90–0.99
Lower cervical spine flexion	51.15° ± 12.52°	46.28° ± 15.30°	0.90	0.56–0.98
Lower cervical spine extension	57.14° ± 16.17°	55.77° ± 13.16°	0.98	0.92–1
Lower cervical spine right inclination	38.64° ± 6.30°	37.60° ± 6.72°	0.88	0.52–0.97
Lower cervical spine left inclination	41.05° ± 5.76°	37.85° ± 7.52°	0.87	0.30–0.97
Lower cervical spine right rotation	64.50° ± 9.56°	63.95° ± 6.65°	0.86	0.41–0.97
Lower cervical spine left rotation	64.47° ± 8.11°	63.04° ± 6.80°	0.94	0.77–0.99

There are other studies which have used CROM as the gold standard to validate different cervical ROM instruments for assessment, such as radiographic tests, universal direction finding or visual stimuli [32]. Other studies have compared the CROM validity to the "Zebris" system, obtaining an excellent validity for flexion (ICC > 0.75), extension (ICC > 0.75), and good validity in the right inclination (ICC 0.75–0.65). Left inclination obtained a moderate validity (ICC 0.65–0.50). Instrumental validity for rotation movements was poor (ICC < 0.50) [32].

A very similar study obtained an excellent validity in the LCS flexion and right inclination movements (ICC > 0.75), good for left inclination movement (ICC 0.75–0.65), moderate in extension and right rotation (ICC 0.65–0.50) and poor for the left rotation movement (ICC < 0.50) [23].

Studies regarding the validity of these applications for UCS movements have not been found.

It is possible that the good results obtained are due to a symptomatic sample (chronic cervical pain participants) having been studied, and their being directed to make as much asymptomatic movement as possible. Therefore, they were able to identify the first painful cervical point, and the measurements have less variation between themselves.

4.2. Intra examiner reliability

The findings in this study show an excellent intra examiner reliability for all cervical spine movements (ICC > 0.75) with the exception of the UCS flexion which was good (ICC = 0.73).

There is a study which made the intra examiner reliability in a similar way to this research, and obtained excellent reliability in movements in LCS flexion, extension, right and left inclination (ICC > 0.75), and good (ICC 0.75–0.65) for right and left rotation [23].

Studies about the intra examiner reliability in the UCS movements for these applications have not been found.

In the UCS cervical flexion the biggest interval confidence (CI: −0.07–0.93) was obtained. This variability might be caused by the subjects' irritation. Although efforts to avoid discomfort were made, it is probable the large amount of requested movements might have contributed to producing these results. Besides, this movement was the one where participants reproduced the least ROM (11.55° ± 2.33; 12.13 ± 2.36), which could mean that a mistake of, for example, 3° in the measurement, could be more important than in an ampler movement, such as the LCS flexion (51.15° ± 12.52; 46.92 ± 15.19); (ICC = 0.90, CI: 0.60–0.98).

4.3. Inter examiner reliability

The findings in this study show an excellent inter examiner reliability for all cervical movements (ICC > 0.75) with the exception of the UCS flexion which was good (ICC = 0.68).

There is a study which made the inter examiner reliability in a similar way to this research, obtaining a poor reliability in all LCS movements (ICC < 0.50) except for the right inclination, which was moderate (ICC 0.65–0.50) [23].

Studies about the inter examiner reliability in the UCS movements for these applications have not been found.

A high interval confidence (CI: −0.32–0.92) was obtained in the UCS cervical flexion, which would be explained in a similar way to the intra examiner reliability results.

There is a important difference between the results obtained in that study and those obtained in our research. These variations might be caused by the fact that in this study, inter examiner reliability was made simultaneously, so every movement was measured, removing the possible bias due to the existing differences between two consecutive movements. In the transverse plane movements, simultaneous measurements were

not possible to allow blinding of the examiners, so measurements were taken first by one examiner, then afterwards by the other.

Simultaneous measurements were decided upon, in order to cause the least possible irritation to participants with chronic cervical pain.

In conclusion the Smartphone applications "Clinometer" and "Compass" have been proved of an excellent validity, by using CROM as gold standard in the LCS and UCS ROM measurements in subjects with chronic cervical pain.

The Smartphone applications "Clinometer" and "Compass" have been proved of an excellent intra and inter examiner reliability in the LCS ROM and in the UCS extension, and a good intra and inter examiner reliability has been proved in the measurement of the UCS flexion ROM in participants with chronic cervical pain.

As Tousignant-Laflamme et al. indicates, a group of participants with chronic cervical pain has been introduced and UCS measurements have been added, as they are relevant to these kinds of subjects.

It would be of interest to measure participants with different kind of cervical pathologies related to the cervical ROM such as cervicogenic cephalea.

Acknowledgments

Conflict of interest

None to report

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