Validation of the device for evaluation of muscular strength in the cervical spine region

Posłuszny A, Myśliwiec A, Saulicz E, Mikołajowski G, Linek P, Saulicz M

Department of Kinesitherapy and Special Methods in Physiotherapy, The Jerzy Kukuczka Academy of Physical Education, 40-065, Mikolowska 72B, Katowice, Poland.

Abstract

Background: In the physiotherapeutic practice, the need for measurements of e.g. range of motion or strength of the cervical spine muscles results from a variety of degenerative processes in the area of the head, cervical spine and shoulder girdle. In Poland, we designed a measurement stand based on the equipment described in foreign literature. Validation of the measurement stand was performed in order to determine the usefulness of this stand for measurements of maximal strength and muscle torques for the isometric contraction of the cervical spine muscles

Material/Methods: A group of 13 women was examined to validate the device. The criteria for inclusion into the study group were adult age, no back pain and head pain syndromes. Validation of the equipment consisted in the calculation of the intraclass correlation coefficient (ICC). Three measurements were performed for each movement in three planes: initial measurement (I), second measurement after 15 minutes (II) and the third measurement after a week (III). The ICC coefficient was calculated based on the methodology discussed in the study by Shrout and Fleiss (1979).

Results: The results of the measurements reached the "excellent" level of the ICC coefficient between the first and the second test. In the case of the first and the third tests, the ICC coefficient reached the "good" level for the movements in the sagittal and transverse planes and the "excellent" level for the movements in the frontal plane.

Conclusions: The measurement system used in the measurement stand designed by the authors of the present study can be successfully used for comparative studies of several groups or repeated examinations of the same study group after application of a specific therapeutic procedure. The stand cannot be used for evaluation whether the results obtained are consistent with the standards for specific populations or for comparison with the results obtained from other devices.

Keywords: validation; force meter; maximal isometric contraction; cervical spine muscles

Coresponding author

Myśliwiec Andrzej
Department of Kinesitherapy and Special Methods in Physiotherapy,
The Jerzy Kukuczka Academy of Physical Education,
40-065, Mikolowska 72A, Katowice, Poland.
a.mysliwiec@awf.katowice.pl

INTRODUCTION

Measurements of basic biomechanical parameters (such as mobility or muscular strength in the area of the cervical spine are very difficult in the physiotherapeutic practice. This mainly results from the complicated structure of this body segment. On the one hand, this region is formed by tiny, seemingly delicate and varied bone structures. On the other hand, myofascial connections with lower spinal regions and the shoulder girdle require good stabilization.

The proximity of important structures of the nervous system and the circulatory system is also important for the measurement of biomechanical parameters. The role of the cervical spine is not only to perform movements of the head but also to maintain the head in proper position during all everyday activities and routines. Any disturbances in the structure and function of the cervical spine may influence the function of adjacent structures, i.e. shoulder girdle and upper limbs, function of the peripheral and central nervous systems and sensory organs located in the head (Lewitt 2001, Wysocki et al. 2003, Myers 2009, Petty 2010, Lee et al. 2011).

In the physiotherapeutic practice, the need for measurements of e.g. range of motion or strength of the cervical spine muscles results from a variety of degenerative processes in the area of the head, cervical spine and shoulder girdle. The inflammatory processes, degenerative changes or congenital changes in the anatomical structure modify the range of motion, muscular strength and motor control (Latash et al. 1993, Madeleine 2010, Bahiraei 2014, Nijs et al. 2014). Therefore, it is necessary for the process of physical rehabilitation to ensure reliable measurements of biokinematic parameters of cervical spine.

Although the measurement of the range of motion of the cervical spine is possible by means of such tools as Cervical Range of Motion (CROM) (Audette et al. 2010, Fletcher and Badny 2008, Williams et al. 2010), gravitational or digital (e.g. Saunders Cybex) inclinometers (Gadotti and Magee 2008, Prushansky et al. 2010), ultrasound-based motion analysis system (Zebris Meditechnik GmbH) (Strimpakos et al. 2005), Cervicoscope (Antonaci et al. 2000), 3D motion analysis system BTS SMART (Gregorii et al. 2008) or Spinal Mouse (Ripani et al. 2008), the measurement of muscular strength is the most complex due to the small number of instruments available in the Polish market. An isolated measurement of the muscular strength involves the measurement of maximal force, moment of force (for movements performed in the transverse plane) and isometric muscle contraction during the movement in the specific plane and direction. A specific device is needed for the purpose to prevent other body segments from moving.

Part of the researchers cited in the study have used commercial devices such as the Multi Cervical Rehabilitation Unit (MCRU) (Chiu et al. 2002), Biodex (Seng et al. 2002, Cagnie et al. 2007) or KinCom (Garcés et al. 2002). However, the most of them used their own measurement systems designed for the purposes of their own studies. However, not all the systems allowed for measurements in all planes. The test stand used by Jornada et al. (1999) allowed for measurements of movements only in the sagittal plane. The equipment used by Levoska et al. (1992), Chiu et al. (2002) or Deslandes et al. (2008) ensured measurements in the sagittal and frontal planes. Other studies have evaluated the movements in the sagittal and transverse planes (Ylinen et al. 1999, Seng et al. 2002, Chiu i Sing 2002, Garcés et al. 2002, Ylinen et al. 2004, Salo et al. 2006, Rezasoltani et al. 2008). The findings of the studies concerning measurements in all the planes of motion have also been published (Kumar et al. 2001, Strimpakos et al. 2004).

Analysis of the literature reveals a substantial variability in terms of methodology of performing measurements of maximal strength and moment of force for the isometric contraction of the cervical spine muscles. This concerns both the measurement equipment, method of stabilization of the subject's body segments and the subject's body position.

Aim of the Study

Due to poor availability of the equipment for measurement of the maximal force and moment of force during isometric contraction of the cervical spine muscles in the Polish market, which is likely to contribute to the lack of publications concerning such measurements in Poland, we designed a measurement stand based on the equipment described in foreign literature. Validation of the measurement stand was performed in order to determine the usefulness of this stand for measurements of maximal strength and muscle torques for the isometric contraction of the cervical spine muscles.

We also asked the following research question:

1. Is the measurement stand for evaluation of maximal isometric contraction of the cervical spine muscles during attempts to perform movements in the sagittal, frontal and transverse planes a reliable diagnostic tool?

MATERIAL AND METHODS

Description of the equipment

The authors of the present publication designed their own system for measurement of force and moment of force for isometric contraction of the cervical spine muscles based mainly on the descriptions of the measurement systems contained in publications by Ylinen et al. (1999, 2004), Strimpakosa et al. (2004) and Salo et al. (2006) (Figure 1, Figigure 2).

The main part of the measurement stand, which had to be made by the authors, was a steel frame. One of its components (guide) was fixed to the wall of the room where the measurement was performed. The guide was fixed vertically by means of screw anchors, which
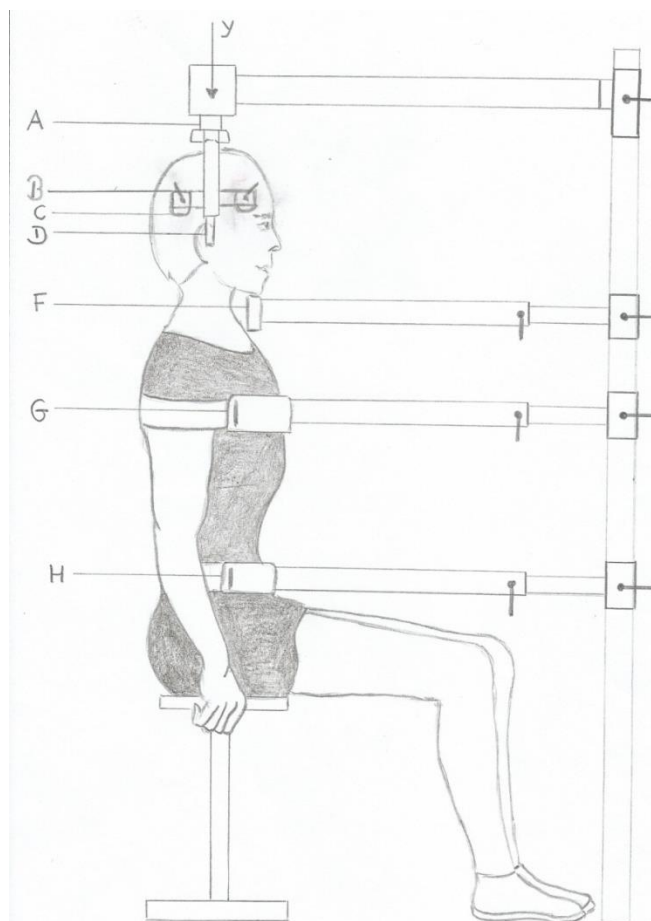
Figure 1. Person tested in a sitting position.

A – moment of force (torque) sensor, B - head holder adjustment, C – head holder, D - extension to monitor motion of the axis (y) going through the outlets of ear canals (on both sides of the head), F - chin support reducing associated movements, G - stabilization of the shoulder girdle, H - stabilization of the pelvic girdle; (based on *Reproducibility of isometric strength: measurement of neck muscles*, Ylinen et al. 1999).

Figure 2. Vertical and horizontal head alignment.

The vertical axis **y** passes through the center of the dynamometer sensor and follows the rotation axis of the axis vertebra **y'**. On the side an ear canal *a,* situated right above the top of axis vertebra tooth *d*. The horizontal axis **x** should go through the nasion and opisthion points on the skull (based on *Reproducibility of isometric strength: measurement of neck muscles*, Ylinen et al. 1999).

ensured the stability necessary for accurate measurements. Four horizontal arms were attached to the guide at a right angle. The screws allowed adjustment of the arm height and distance from the subject. The highest arm was used for mounting of the force meter for the measurements of the moment of force during the attempt to perform movement in the transverse plane. Another arm, mounted below the highest one, was used for fixation of the force meter for the measurement of the force generated during the attempt to perform movements in the sagittal and frontal planes. At the same time, during the measurements concerning movements in the frontal plane, this component was used as a chin support for the subject. The chin support minimized the chance of performing additional movements. Other two lower 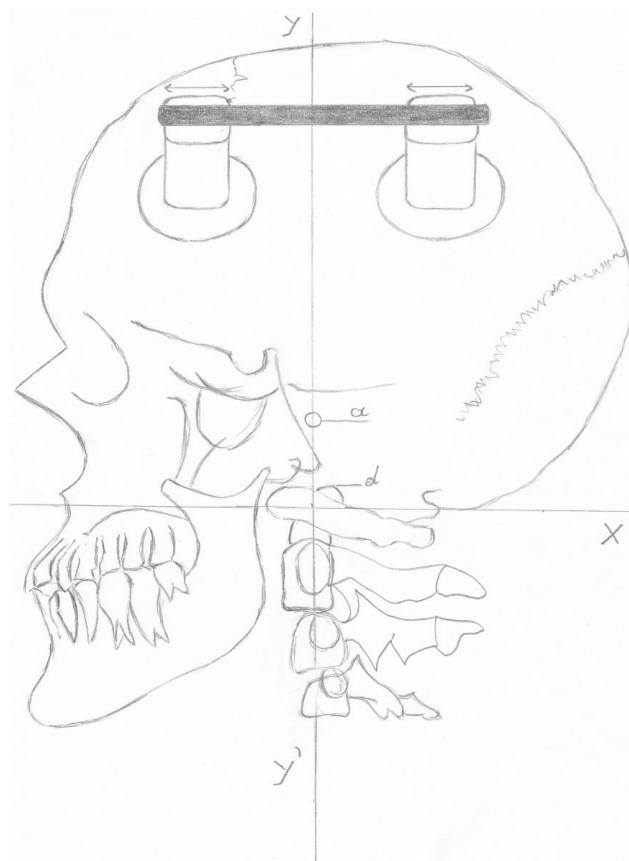arms fixed to the vertical guide were equipped in wide belts and used for subject's stabilization in the area of the shoulder girdle and pelvic girdle.

The design of the equipment used force meters available in the market. However, the authors ensured that all the force meters had valid calibration certificates in order to minimize measurement errors. The measurements of the force of isometric muscle contraction during movements in the sagittal and frontal movements were performed by means of the SAUTER FK250 force meter, with the measurement range of from 0 to 250 N and accuracy of ± 0,1 N. The device had the valid calibration certificate No. F.33.2014. Measurement of the moment of force of isometric muscle contraction during the attempted movements in the transverse plane was performed using the YATO YT-0762 torque wrench with the measurement range of from 0 to 200 Nm, and accuracy of ± 0.01 Nm. This equipment also had the valid calibration certificate No. 130116000023.

Research procedure

The subject was sitting on a chair with their back facing the wall, with arms kept relaxed along the body and feet placed conveniently on the ground. The shoulder girdle and pelvis girdle were immobilized by means of belts to the vertical arms of the equipment's frame (the first and the second arm from the bottom). During the measurement in the transverse plane, the subject's head was stabilized by means of the special band with holders. The holders could be slightly moved on the band, which allowed for finding the "convenient" position on the subject's skull without the effect on the length of the lever arm. The band was connected axially with the ratchet of the torque wrench, which was firmly fixed to the highest horizontal arm. Adjustment of the distance of the wrench from the wall allowed for the axial adjustment of the subject's head. The head was positioned so that the movement axis went through the ratchet and its projection fell on the atlantoaxial joint i.e. during assessment of the subject's head position in the sagittal plane, the line from the centre of the ratchet and the external auditory meatus formed a right angle with respect to the ground, which was evaluated by means of the spirit level. Furthermore, the line connecting points on the skull: nasion-opisthion was parallel to the ground. Both lines intersected at the height of the atlantoaxial joint (Ylinen et al. 1999). A support was placed under the subject's chin. The chin support represented one of the horizontal arms of the measurement stand (the second arm from top), which caused that this position was maintained in a passive manner and eliminated muscular activity of this body part (Figure 3, Figure 4).

Both position and method of body and head stabilization in the subject was carried out according to the description contained in the publication by Ylinen et al. (1999) and Salo et al. (2006).

Before the measurement, the subject had an opportunity to make several trials which helped them to get used to a relatively uncomfortable position and adjustment of head position. Next, the subject was asked to perform a test of slight rotation of the head to one of the side in order to eliminate the skin play and, after the command "Attention, turn!", they performed the test of head rotation with maximal voluntary force for 5 seconds. The display on the wrench indicated the maximal moment of force measured during the test. Next, the same methodology was used for the measurement on the opposite side.

During the test of bending the head in the sagittal plane, the subject was in the same position as above, but additional stabilization of the head was needed. However, the attention was paid to setting the head in the neutral position. The force meter was fixed to a horizontal arm on the frame (the same arm that was previously used as the chin support), with the tip of the force meter arm touching the subject's forehead just above the nose, on a line connecting supraorbital ridges. Figure 5, figure 6). Before the measurement, the subject had also the opportunity to perform several trials in order to get used to the feeling of pressure of the force meter arm on the skull. Next, after the command "Attention, push", the subject pushed with
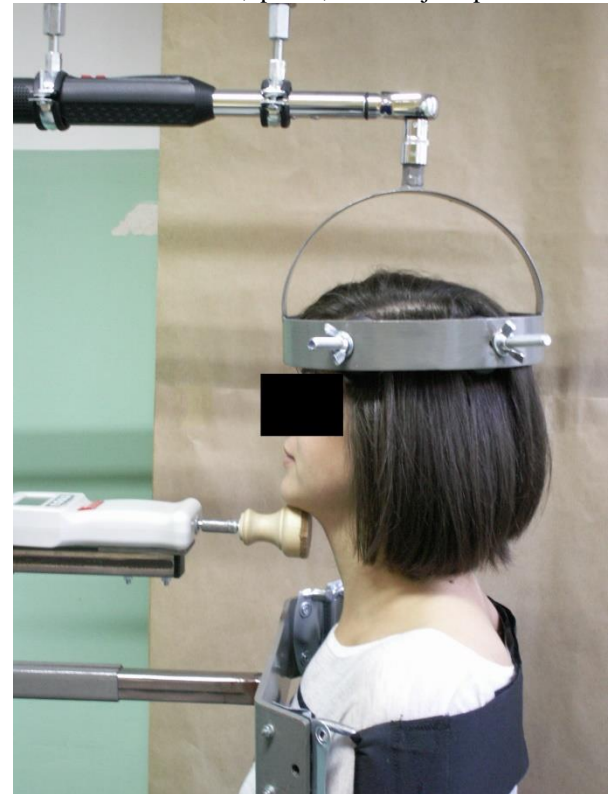

Figure 3. Passive body stabilization of the examined person.

Figure 4. Passive shoulder girdle stabilization of the examined person.

Figure 5. Measurement of cervical spine bemding force.

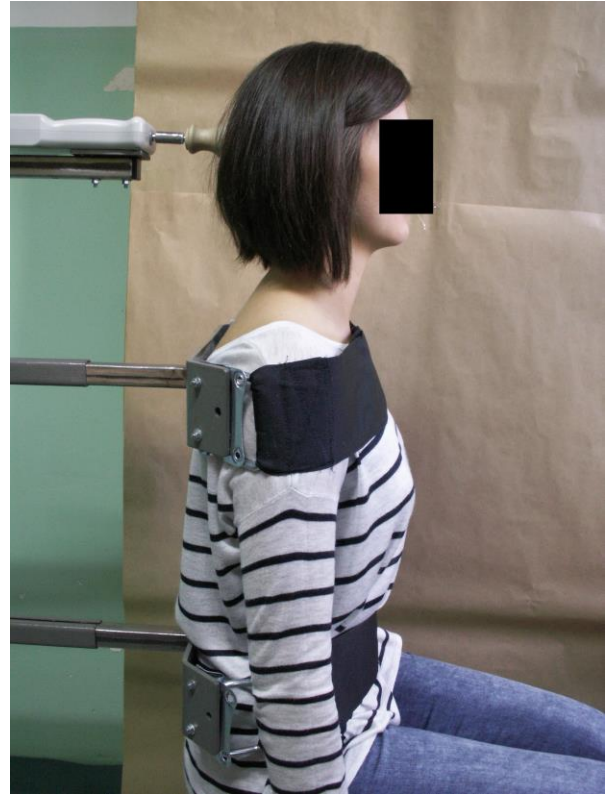**Figure 7. Measurement of force during extension of the cervical spine.**

the head on the tip of the force meter with maximal voluntary force for 5 second. The display on the force meter indicated the maximal force measured during the test.

Force measurement during the test of head extension in the sagittal plane was performed in the same manner, but the subject was sitting with their back facing the equipment and the force meter arm tip was applied to their head above the external occipital protuberance (Figure 7).

Measurement of the maximal force of isometric contraction in the cervical spine muscles during the attempted movements of lateral bend was also performed in the sitting positions, but with the body facing the measurement stand with the body side.

Figure 6. Position of the sensor during the cervical spine bending.

Figure 8. Measurement of force during lateral flexion of the cervical spine

The tip of the force meter arm was in contact with the subject's head above the external auditory meatus (Figure 8). The subsequent procedures were similar to the measurements performed in the sagittal plane. The methodology of measurements in the sagittal and frontal planes was developed based on the publications by Ylinen et al. (2004), Strimpakos et al. (2004), Salo et al. (2006) and Strimpakos (2011).

Statistical Analysis

Validation of the equipment consisted in the calculation of the intraclass correlation coefficient (ICC).

Three measurements were performed for each movement in three planes: initial measurement (I), second measurement after 15 minutes (II) and the third measurement after a week (III). The ICC coefficient was calculated based on the methodology discussed in the study by Shrout and Fleiss (1979). The following ranges were adopted for the ICC coefficient: 0.00 to 0.50 - weak, 0.50 to 0.75 - moderate, 0.75 to 0.90 - good, and, above 0.90 – excellent (Portney and Watkins 2000)

Subjects

A group of 13 women was examined to validate the device. The criteria for inclusion into the study group were adult age, no back pain and head pain syndromes. Subjects' biometric data are contained in the Table 1.

Tabele 1. Biometric data for the subjects (*n*=13), mean value ($\overline{x}$), standard deviation (SD), minimal value (min) maximal value (max) ,body mass index (BMI)

parameter	$\overline{x}$	SD	min	max
Age (years)	39.53	8.15	27	58
Weight (kg)	66.92	9.19	53	82
Height (cm)	169.46	7.93	158	181
Body mass index	23.63	3.56	17.72	28.57

RESULTS

The results of the measurements reached the

"excellent" level of the ICC coefficient between thefirst and the second test. In the case of the first and the third tests, the ICC coefficient reached the "good" level for the movements in the sagittal and transverse planes and the "excellent" level for the movements in the frontal plane. The results are presented in Table 2

DISCUSSION

The studies concerning measurements of force and/or moment of force for the isometric contraction of the cervical spine muscles have reported on methodological problems faced by researchers. The biggest challenge in these studies was stabilization of other body segments to ensure that the contraction concerns only the muscles in the cervical spine region and no compensatory muscle contraction occurs in the area of other segments. From the physiological standpoint, the isolated work of the cervical spine muscles is nearly impossible since myofascial chains cause that the work of the muscles in one segment is connected with contraction of the muscles in other body segments, which are often far from each other. However, this study is not aimed at analysis of tensegration mechanisms, especially because they have been thoroughly discussed in e.g. study by Myers (2009). Since these mechanisms are similar in all people, it can be adopted that they have the same effect on the results of measurements of force/moment of force of the isometric contraction of the cervical spine muscles. Therefore, comparison of measurements of e.g. two study groups or results of measurements performed for the same person e.g. before and after a therapy, tensegration mechanisms should not influence the final outcome of the study.

Nevertheless, the findings published in the scientific papers show substantial variability in measurements of force/moment of force, even if they were performed in similar population (e.g. age, gender and lack of pain syndromes). For example, the isometric contraction during the flexion test ranged from 41N (±14) for female to 72N (±18) for male subjects aged from 20 to 30 years (Kumar et al. 2001). In the age group from 19 to 63 years, these values were 101N (±24) for women and 229N (±50) for men (Strimpakos et al. 2004). The same studies have also found extreme values for the measurement of the extension force. In a study by Kumara et al., (2001) this value was 72N (±20) for women and 100N (±28) in men.

Tabele. 2. ICC coefficient for subsequent tests for individual movements, mean values ($\overline{x}$) and standard deviation (SD),

Direction of movement	Measurement I		Measurement II		Measurement III		ICC I vs II	ICC I vs III
	$\overline{x}$	SD	$\overline{x}$	SD	$\overline{x}$	SD		
Flexion (N)	54.58	12.78	57.10	13.48	60.75	13.89	0.94	0.88
Extension (N)	103.43	32.34	101.06	27.49	109.81	35.23	0.93	0.88
Lateral bend to the left (N)	78.45	25.19	79.50	29.87	83.09	28.41	0.96	0.92
Lateral bend to the right (N)	76.89	23.71	77.26	24.05	83.04	20.99	0.98	0.92
Rotation to the left (Nm)	3.24	0.99	3.40	1.01	3.39	1.13	0.95	0.83
Rotation to the right (Nm)	3.02	0.75	3.06	0.87	2.29	0.81	0.94	0.82

Furthermore, Strimpakos et al. (2004) obtained the values of 178N (±36) for women and 302N (±63) for men. The examinations in both groups were performed using the measurement systems designed by authors. Even greater differences have been documented in studies of maximal isometric contraction during the attempts to perform movements in the frontal plane. The findings presented by Chiu and Sing (2002) demonstrated the values of 40N (±14) for the right side and 52N (±19) for the left side in women and 46N (±18) for the right side and 76N (±26) for the left side in men. Furthermore, a study of Strimpakos et al. (2004) found that these value ranged from 123N (±27) for women and 233N (±46) in men. The measurements performed for the attempted movement in the transverse plane showed substantial differences between the results obtained by various authors. They range from 7.4Nm (±2.3) (Ylinen et al. 2004) to 15Nm (±5) (Strimpakos et al. 2004).

The results of measurements obtained in the present study, concerning the measurements in the sagittal and frontal plane are consistent with the above range. However, for the rotational movements, our results are lower compared to those cited in the literature (see Tab. 2). These differences can be explained by the "imperfectness" of the subject's stabilization system. This problem concerns not only the previously published results (cited above) but also the findings obtained in the present study. Although patient's stabilization during attempts to perform movements in the sagittal and frontal planes seems to be relatively simple, the proper axial head position and elimination of additional movements during the tests in the transverse plane cause a number of difficulties. They results mainly from the shape of the head, play between subject's head skin and head band, amount of hair and subjective feeling of danger during the study as a result of uncomfortable immobilization of the person studied. It is extremely difficult to design an immobilization device to hold the head during the rotation test with maximum force that would not cause any pain in the subject or at least a feeling of discomfort.

In the device analysed in this study, this was undoubtedly the weakest point. The attempts to compare the results of the measurements of force/moment of force during isometric contraction of the cervical spine muscles lead to the conclusion that it is impossible to obtain reliable reference values for individual measurements (Dvir and Prushansky 2008). Therefore, it is impossible to conclude whether the results obtained by evaluation of this parameter by means of a single device are consistent with the standards for a specific population. The same conclusion should be drawn with respect for the device used in our study.

It is also essential for evaluation of validity of the device to analyze the value of the ICC coefficient, which in the present study ranged from 0.82 to 0.98, depending on the plane and direction of movement and the intervals between the measurements. Obviously, lower values of the ICC coefficient (from 0.82 to 0.92) were obtained for comparison between the measurement I and III, that is, performed after a week rest. The measurements carried out at 15-minute intervals were characterized by higher values of the ICC coefficient (from 0.94 to 0.98). These results are comparable with the results obtained by other authors. Validation of the device designed by Strimpakos et al. (2004) showed values of the ICC coefficient ranging from 0.84 to 0.90 for the measurements performed at several-day intervals and from 0.93 to 0.97 for the measurements performed after several minutes. The ICC values published by other authors cited above showed similar ranges: from 0.94 to 0.98 (Ylinen et al. 1999), from 0.74 to 0.98 (Ylinen et al. 2004), from 0.87 to 0.95 (Salo et al. 2006) and from 0.90 to 0.96 (Rezasoltani et al. 2008).

Part of authors also took into consideration the statistical analysis used for calculation of the ICC coefficient. Ylinen et al. (2004) employed the Pearson's methodology. Validation of the device designed by Strimpakos et al. (2004) used repeated measures ANOVA test. Furthermore, Rezosaltoni et al. employed one-way ANOVA.

In the present study, Statistica 12 software was used, featuring the one-way or two-way ANOVA, according to the methodology contained in a study by Shrout and Fleiss (1977).

CONCLUSION

The measurement system used in the measurement stand designed by the authors of the present study can be successfully used for comparative studies of several groups or repeated examinations of the same study group after application of a specific therapeutic procedure.

The stand cannot be used for evaluation whether the results obtained are consistent with the standards for specific populations or for comparison with the results obtained from other devices.

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