COMPARISON OF THE REPEATABILITY AND DIAGNOSTIC OBJECTIVITY OF TWO METHODS OF MEASURING THE RANGE OF MOTION IN THE JOINTS

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Abstract

The objective of this study was to compare the repeatability and diagnostic objectivity of two methods of measuring the range of motion. 30 people took part in the study - 15 men and 15 women aged 21-26. In each person under the study, the range of motion was measured 4 times in the given joints of the upper and lower limbs. Two measurements were made with a goniometer and two with the Hippocrates Sensor, and the measurements were made by 2 physiotherapists. The goniometric test showed a smaller measurement error compared to the Hippocrates Sensor test. Both the universal goniometer test and the Hippocrates Sensor test were characterized by high repeatability of the measurement, independent of the person performing the test. However, the results of measuring the range of motion in the joints obtained by one therapist, but with different methods, were statistically significantly different. The universal goniometer test was characterized by greater measurement precision in relation to the standards compliant with the ISOM.

Key words*: range of motion, Goniometer, Hippocrates Sensor, shoulder joint, elbow joint, hip joint, knee joint*

Introduction

Proper diagnosis is a fundamental element of a comprehensive rehabilitation plan. Its purpose is to recognize the dysfunction, determine its type, and allows to assess the degree of its advancement and determine the nature of the changes. Information obtained by the therapist thanks to optimal and efficient diagnostics allows for the immediate initiation of targeted and effective therapy (Walaszek 2014),

Measurement of the range of motion in the joints is an essential element of physiotherapeutic diagnostics. Thanks to these measurements, both the therapist and the patient can observe the progress in therapy and assess the effectiveness of the therapeutic program. Additionally, measuring the range of motion in the joints as evidence of the progress achieved may motivate the patient at further stages of rehabilitation (Szczechowicz 2011).

There are many ways to measure your range of motion. This study can be carried out, among others by means of the orientation (visual) method, goniometer, plurimeter, measuring tape, radiographically, photographed or by video (Correll et al. 2018). A commonly used tool for this measurement is the goniometer. It is a cheap and easy-to-use device, but testing it is time-consuming and requires high precision, and additionally the measurement result may depend on the person performing it (Werner et al 2014). Therefore, therapists are constantly looking for new solutions that would help shorten the measurement time and facilitate its performance, while maintaining the precision and repeatability of the test.
Along with the development of technology, newer proposals of methods for measuring the range of motion appear on the market, e.g. devices utilizing laser or infrared beams. Testing with these devices is much less time-consuming and can be carried out more efficiently, but these devices are new on the market and in the available literature there are few reports discussing the accuracy and correctness of such an assessment of the range of motion in the joints (Stiler et al 2016; Ferriero et al. 2013; Keijsers et al. 2018). Therefore, the purpose of this study was to assess the repeatability and accuracy of measuring the range of motion in selected joints with the use of an infrared beam device (Hippocrates Sensor) in relation to the goniometer measurement.

Participants
30 people took part in the study - 15 men and 15 women aged 21-26 (see Table 1). All subjects had dominant right limbs, both upper and lower.

Exclusion criteria:

- Age under 21 and over 26
- No diseases of the locomotor system (incl. orthopedic, neurological, rheumatic)
- No injuries to the locomotor system during the whole life
- Lack of physical activity (recreational physical activity less than 1 hour a day)
- Weight-related disorders (underweight, overweight or obesity)
- Professional or competitive sports

Table 1. Characteristics of the persons under study

	Females				Males				All			
	$\bar{x}$	SD	Min	Max	$\bar{x}$	SD	Min	Max	$\bar{x}$	SD	Min	Max
Age (years)	22	0.57	21	23	23	1.4	21	26	22.27	1.2	21	26
Body height (cm)	164.2	7.33	175	152	181.5	4.7	175	189	172.23	7.1	152	189
Body weight (kg)	60.6	12.4	40.1	91	80.1	6.8	70	94.4	69.2	14.8	40.1	94.4
BMI	22.26	2.98	17.36	30	23.88	1.8	20.57	26.51	22.03	2.7	17.36	30

METHOD

In each person under the study, the range of motion was measured 4 times in the given joints of the upper and lower limbs. Two measurements were made with a goniometer and two with the Hippocrates Sensor. All measurements were made on the right side of the persons under study. The measurements were made by 2 physiotherapists who took the measurements without knowing the results obtained by the second person performing the test. Each of them performed two tests - one with the goniometer and the other with the Hippocrates Sensor. Each physiotherapist performed measurements on each person under study, on the same day, so that any differences in measurements resulting from greater stretching or warming of the soft tissues could be excluded. The test was conducted in the afternoon. Measurements were taken in 4 joints, two for the upper limb (shoulder joint and elbow joint) and two for the lower limb (hip joint and knee joint) using the SFTR (Sagittal, Frontal, Transverse, Rotation) method (Szczechowicz 2011). The obtained results were compared to the norms of ranges of motion for selected joints in accordance with ISOM (International Standard Orthopedic Measurements) (Kujawa 2011). Before examining the range of motion, body weight, height and BMI were measured.

Measurement of the range of motion with a goniometer

a) **device description -** the goniometer is a device for manual measurement of the range of angular motion in the joints. Each goniometer consists of two arms: a movable and a fixed one. The fixed arm takes the 0 point position, while the movable arm follows the motion. Additionally, the goniometer has a goniometer axis and division from 0 to 360 degrees. Motions are measured in four planes: sagittal, frontal, transverse and rotational (Szczechowicz 2011; Stiler et al. 2016).

b) **method of measurement -** in selected joints of the upper limb (shoulder and elbow joint) and the lower limb (hip and knee joint), measurements were made in all planes and directions (according to the SFTR method) characteristic for a given joint in accordance with the goniometer measurement methodology (Szczechowicz 2011; Bałachowski & Kowalewska 2014). In contrast to the Hippocratic Sensor measurement, the goniometer measurements were performed separately for each motion in each plane.

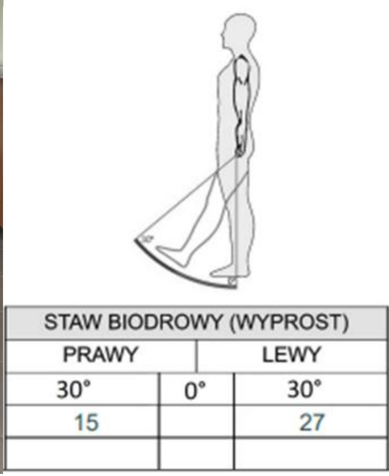
Measurement of the range of motion in the joints with the Hippocrates Sensor

a) **device description -** in selected joints of the upper limb (shoulder and elbow joint) and the lower limb (hip and knee joint), measurements were made in all planes and directions (according to the SFTR method) characteristic for a given joint. The Hippocrates Sensor is a device with a program for the analysis of joint mobility and faulty posture. The test carried out with the use of the Hippocrates Sensor consists in non-invasive directing of beams of infrared rays at the person under the study, in which the sensor captures specific measurement points located all over the body. The measurement is made with an accuracy of 1 degree, and the program description shows the starting positions for each motion. It is possible to repeat the measurement and stop it at any time. Each motion must be made five times. If any of the repetitions is not recorded, the program automatically extends the measurement and after recording five repetitions, it issues a message about the end of the test. During the test, it is important that motion takes place only in the part of the joint being tested. Motions in one plane are measured simultaneously, without stopping in the zero position (a patient starts a motion, e.g. bending, and smoothly moves to the extension motion). The Hippocrates Sensor software does not measure the extension motion in the knee joint.

b) **measurement method -** the person under the study stood at a distance of 3 meters from the sensor collecting data. Each patient assumed a specific starting position and positioned himself/herself in a specific direction relative to the Hippocrates Sensor. The tested limb was also set to a specific starting position and the patient was instructed to move only in the area of the tested joint during the measurement (see Table 2). When taking measurements in a standing position for the lower limb, the patient's position was stabilized (grasping the backrest of the chair standing next to the patient) so as to eliminate compensatory torso movements.

Table 2. Methodology of measuring the range of motion with the Hippocrates Sensor

Limb	Joint	Plane	Order of motion measurements	Patient's position	Starting position of the tested limb	Positioning the person undergoing a test in relation to the sensor
Upper	Shoulder	Sagittal	Extension → flexion	Standing	Hanging freely along the body	Facing sideways
		Frontal	Abduction → adduction	Standing	Hanging freely along the body	Facing forward
		Transverse	Horizontal extension → horizontal flexion	Standing	Hanging freely along the body	Facing forward
		Rotation	External rotation → internal rotation	Standing	Abducted in the shoulder joint up to 90° and flexed in the elbow joint up to 130°, palm facing the sensor	Facing forward
	Elbow	Sagittal	Flexion → extension	Standing	Abducted in the shoulder joint up to 90°, forearm in supination	Facing forward
Lower	Hip	Sagittal	Flexion → extension	Standing	Straightened in the knee joint	Facing sideways
		Frontal	Abduction → adduction	Standing	Straightened in the knee joint	Facing forward
		Rotation	External rotation → internal rotation	Sitting	Flexed in the hip joint to about 95°, flexed in the knee joint to 90°	Facing forward
	Knee	Sagittal	Flexion	Standing	Straightened in the knee joint	Facing forward, at a 45° angle towards the sensor
			Extension	Standing	Straightened in the knee joint	Facing forward, at a 45° angle towards the sensor



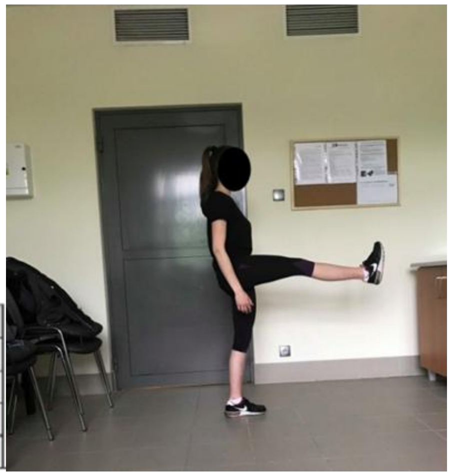


Figure 1. Hippocrates Sensor / Figure 2. View of the Hippocrates Sensor window for measuring the extension in the hip joint / Figure 3. The person under the study was measuring the range of motion in the hip joint using the Hippocrates Sensor.

Statistical methods

Statistical analysis of the gathered data was analyzed using Statistica 10.0 (StatSoft). The following parameters were used: mean average, minimal and maximal values and standard deviation. Statistical significance was determined by one way analysis of variance (ANOVA) followed by *post hoc* T-Tukey test and the differences were regarded as significant at $p<0,05$.

RESULTS

The results of the range of motion measurements were checked for both measurement methods in selected joints of the upper limb in relation to the norms. For most motions, the mean values of the range of motion obtained with the goniometer were closer to the norm. Only in the case of selected motions in the shoulder joint (abduction, adduction and horizontal extension), the mean values obtained with the Hippocratic Sensor were closer to the norms (see Table 3).

Table 3. Results of measurements of ranges of motion in selected joints of the upper limb.

Joint	Motion [°]	Device	Therapist I.				Therapist II			
			x̄	SD	Min	Max	x̄	SD	Min	Max
Shoulder	Extension 50 – 0	Goniometer	38.00	10.55	19	58	38.67	11.95	17	65
		Hippocratic Sensor	110.43	44.76	21	162	115.00	49.10	14	159
	Flexion 0 – 170	Goniometer	169.43	7.21	150	180	169.00	7.57	150	183
		Hippocratic Sensor	142.73	54.55	11	177	163.43	34.37	17	178
	Abduction 170 – 0	Goniometer	167.40	13.94	118	182	165.13	15.76	120	182
		Hippocratic Sensor	172.03	26.20	75	265	173.20	14.83	140	204
	Adduction 0 – 0	Goniometer	42.33	10.09	23	68	40.60	9.85	23	65
		Hippocratic Sensor	39.57	21.71	6	88	35.90	17.75	5	77
	External rotation (S90) 90 - 0	Goniometer	82.73	11.78	47	110	81.57	13.81	45	115
		Hippocratic Sensor	34.70	28.70	5	117	39.43	37.41	9	163
	Internal rotation (S90) 0 – 80	Goniometer	66.40	11.80	41	90	64.53	11.60	43	90
		Hippocratic Sensor	116.97	40.26	9	177	115.30	39.07	32	177
	Horizontal extension 30 – 0	Goniometer	36.60	8.53	17	53	35.90	9.19	17	58
		Hippocratic Sensor	31.67	14.62	11	81	31.77	14.76	14	83
	Horizontal flexion 0 – 135	Goniometer	134.10	11.01	108	158	134.63	12.21	110	160
		Hippocratic Sensor	152.77	17.02	107	178	151.63	19.58	84	176
Elbow	Extension 0 – 0	Goniometer	2.13	3.77	0	13	2.10	3.56	0	13
		Hippocratic Sensor	7.80	8.53	0	39	9.80	13.14	0	51
	Flexion 0 – 150	Goniometer	133.67	6.98	122	147	134.23	8.99	120	158
		Hippocratic Sensor	107.10	28.29	30	146	122.67	21.03	85	167

The results of the range of motion measurements for both measurement methods in the selected joints of the lower limb in relation to the norms were also analyzed. It was observed that in most cases the mean values of the range of motion obtained with the goniometer were closer to the norms. Only in the case of the adduction motion in the hip joint, the mean value of the range of motion measured with the Hippocrates Sensor was closer to the norm, and in the case of internal rotation in the hip joint, the mean values of the range of motion obtained via both methods were identical (see Table 4).

Table 4. Results of measurements of ranges of motion in selected joints of the lower limb.

Joint	Motion [°] and norm	Device	Therapist I.				Therapist II			
			x̄	SD	Min	Max	x̄	SD	Min	Max
Hip	Extension 15 – 0	Goniometer	24	7.5	13	42	23	6.4	10	37
		Hippocratic Sensor	51	34.8	12	108	55	35.8	12	105
	Flexion 0 – 125	Goniometer	118	15	85	155	116	12.3	90	150
		Hippocratic Sensor	42	17.4	16	78	43	18.8	12	80
	Abduction 45 – 0	Goniometer	50	10	25	84	50	9.7	25	80
		Hippocratic Sensor	77	31.6	19	161	77	21.4	37	113
	Adduction 0 – 25	Goniometer	35	9.1	17	49	34	8.6	15	45
		Hippocratic Sensor	25	5.3	13	30	25	10	6	62
	External rotation (S0) 45 – 0	Goniometer	40	8.1	26	65	41	7.3	28	66
		Hippocratic Sensor	32	18.5	11	117	28	9.7	9	55
	Internal rotation (S0) 0 – 40	Goniometer	38	8	7	50	39	7.5	7.5	48
		Hippocratic Sensor	38	21.1	12	129	37	21.6	13	129
Knee	Flexion 0 – 130	Goniometer	126	8.8	107	140	126	8.7	105	137
		Hippocratic Sensor	99	41.1	22	146	93	35.2	21	134

The repeatability of the measurement of both diagnostic methods was also checked for each of the therapists separately. In the upper limb, statistically significant differences were observed for most movements. The lack of these differences was noted only for the shoulder joint and only for some motions: in the case of the first therapist these were flexion and adduction motions, in the case of the second therapist these were abduction, adduction and horizontal extension motions. On the other hand, in the case of all motions in the lower limb, statistically significant differences were observed for the results obtained by each therapist. (see Table 5).

Table 5. Comparison of the repeatability of the measurement with the two methods for each therapist

Joint	Motion [°]	Device	Therapist I. (p value)	Therapist II (p value)
Shoulder	Extension	Goniometer	0.0001*	0.0001*
		Hippocratic Sensor		
	Flexion	Goniometer	0.2044	0.0115*
		Hippocratic Sensor		
	Abduction	Goniometer	0.0494*	0.448
		Hippocratic Sensor		
	Adduction	Goniometer	0.2175	0.536
		Hippocratic Sensor		
	External rotation	Goniometer	0.0001*	0.0001*
		Hippocratic Sensor		
	Internal rotation	Goniometer	0.0001*	0.0001*
		Hippocratic Sensor		
	Horizontal extension	Goniometer	0.002*	0.05*
		Hippocratic Sensor		
	Horizontal flexion	Goniometer	0.0003*	0.0001*
		Hippocratic Sensor		
Elbow	Extension	Goniometer	0.0001*	0.0001*
		Hippocratic Sensor		
	Flexion	Goniometer	0.01*	0.001*
		Hippocratic Sensor		
Hip	Extension	Goniometer	0.0001*	0.0001*
		Hippocratic Sensor		
	Flexion	Goniometer	0.0001*	0.0002*
		Hippocratic Sensor		
	Abduction	Goniometer	0.0001*	0.0001*
		Hippocratic Sensor		
	Adduction	Goniometer	0.0002*	0.0001*
		Hippocratic Sensor		
	External rotation	Goniometer	0.0277*	0.0208*
		Hippocratic Sensor		
	Internal rotation	Goniometer	0.0001*	0.0069*
		Hippocratic Sensor		
Knee	Flexion	Goniometer	0.0001*	0.001*
		Hippocratic Sensor		

*statistically significant

The differences in the goniometer and Hippocrates Sensor measurements between therapists were also checked. The analysis was performed for each tested motion, both in the upper and lower limbs. There were no statistically significant differences between the results obtained by the therapists performing the test for any measurement method, in any motion in any limb.

DISCUSSION

In the available literature, there are very few reports verifying the measurement reliability of modern devices for the range of motion diagnostics in relation to a traditional goniometer.

One of the few features that characterize measuring devices is the so-called measurement error. It is important that it is as small as possible, as it increases the precision of the measurement. Otter et al. (2015) measured the range of motion of the interphalangeal joint of the proximal first finger with a goniometer and a smartphone application. The average standard deviation during the measurement with the standard method was 12.2°, while in the case of the measurement with the smartphone application it was 11.3°. The authors concluded that the measurement with the use of the mobile application turned out to be more accurate. Similar studies were conducted by Ortiz et al. (2017) who analyzed the reliability of an iPhone application compared to the traditional method of measuring range of motion in the joints. The test consisted of four measurements of the degree of knee flexion in a randomly selected position: 2 measurements with a standard goniometer, and two with an iPhone application. The difference between the mean values within the group was 3.148º for the goniometer and 2.476º for the application. The obtained values turned out to be slightly more accurate in the case of the application than the goniometer measurement. Stiler et al. (2016) compared the ranges of motions in the shoulder joint measured with a classic goniometer and a proprietary smartphone application. The results of the measurements made with the goniometer were in each case characterized by a greater standard deviation than the measurement with the use of the application, which showed that the smartphone application turned out to be a more accurate tool for measuring the range of motion. Different results were obtained by Correll et al. (2018), who measured motions in the shoulder joint with a HALO laser goniometer and a traditional goniometer. The results of their tests showed smaller standard deviations in goniometer tests in all motions in the shoulder joint except for flexion. Depending on the movement, the standard deviation ranged from 6.9 to 21.1 degrees in the HALO goniometer test, while in the case of the universal goniometer, this interval was smaller and ranged between 6.8 and 15.1 degrees, which indicated a smaller measurement error of the universal goniometer. The own study confirmed the reports of Correll et al. (2018). During the measurements, in the vast majority of cases, lower values of the standard deviation were shown during the universal goniometer test compared to the Hippocrates Sensor test. These results related to the measurements taken by each therapist in both the joints of the upper and lower limbs.

Another feature that a professional measuring device should have is measurement repeatability. Repeatability makes the measurement independent of the person performing it and definitely increases its credibility. Milanese et al. (2014) examined whether there is a difference in the accuracy of the measurement of range of motion between beginners and experienced therapists. At the same time, the measurements via the standard goniometric method and the smartphone application were compared. The results of the tests showed no significant differences in reliability between therapists, both in goniometric measurement and measurement with the use of the application. Standard measurement error ranged from 1.56° for the goniometer and 0.62° for the application. Similar results were obtained in the own study, where the measurements of each movement in each examined joint between the therapists were analyzed and no statistically significant difference was obtained between the data. This would indicate a high reproducibility of the test results obtained both during the measurement with the universal goniometer and with the Hippocrates Sensor. An additional analysis was also performed through the own study to confirm the reproducibility of the obtained results. The results obtained during the goniometer test were compared to the results obtained during the Hippocrates Sensor test separately for each of the therapists. It has been shown that in the vast majority of cases there were statistically significant differences between the results obtained. This would indicate a very low repeatability of the measurement in a situation where one person measures with two different methods. Additionally, since during this analysis no significance was obtained for only selected motions in the scope of the shoulder joint in the case of each of the therapists, it can be assumed that the repeatability of the measurement may depend on the type of the examined joint.

The available literature lacks reports on the diagnostic objectivity of modern methods of assessing the range of motion in the joints, assessed in relation to the existing standards. This relationship was also checked in the own study. The mean values of the measured ranges of motion were compared to the standards compliant with the ISOM. It was found that the vast majority of the results obtained with the goniometer were closer to the norms, both when measured in the joints of the upper and lower limbs. This would indicate a greater precision of the goniometric measurement in relation to the measurement with the Hippocrates Sensor. Such results may be related to both the method of data collection (a different method of determining anthropometric points during measurements with the goniometer and Hippocrates Sensor) and the type of software used in the tested device.

Although few scientific reports show that the measurement with the universal goniometer is in many respects inferior in comparison to modern measuring devices, there is a need to more accurately verify the reliability and credibility of the measurement of the latter, so that the ease of measuring does not obscure its accuracy and repeatability.

CONCLUSIONS

1. The goniometric test contained a smaller measurement error compared to the Hippocrates Sensor test.
2. The test with the universal goniometer and the Hippocrates Sensor was characterized by high repeatability of the measurement, independent of the person performing the test.
3. The results of measuring the range of motion in the joints obtained by each of the therapists with different methods were statistically significantly different.
4. The universal goniometer test was characterized by greater measurement precision in relation to the standards compliant with the ISOM.

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