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# Validation and reliability of a new PC-controlled device for the evaluation of key pinch strength in healthy adults

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## Abstract

Objective: Hand muscle strength assessment is widespread and can be a useful marker in the evaluation and monitoring of subjects at different ages and health conditions. This study aimed at validating and determining the reliability of a new digital device for evaluation of hand pinch strength by comparing it with a well-validated hand strength assessment device, the Jamar hydraulic hand dynamometer.
Methods: In 65 healthy subjects, (males / females: 29 / 36), mean age 40.3±18.0 (range: 19.3 - 76.5) years, hand pinch strength and hydraulic hand dynamometer were used to assess hand strength following a testing protocol. Only the dominant hand was tested. Evaluations were performed considering gender, hand dominance, body mass index and age, according to the standardized testing protocol. The mean of three consecutive grip tests and lateral pinch tests was recorded.
Results: There was a strong correlation ($p<0.0001$) between the hydraulic hand dynamometer and hand pinch strength tests. Both mean strengths measured by hydraulic hand dynamometer and hand pinch strength in females were significantly lower than in males ($P<0.001$), the grip strength being 34.75% and the lateral pinch test 27.83% weaker than in males. Multivariate analysis indicated that the strength expressed by the hand pinch strength pinch test remained significantly associated with the results of hydraulic hand dynamometer ($p<0,001$), independent of age and body weight.
Conclusions: hand pinch strength and hydraulic hand dynamometer have been shown to be significantly correlated with each other in subjects of different ages, sex and body mass index. The hand pinch strength device has been proven to be a reliable tool for measuring maximal isometric strength by lateral pinch test. This device can be used for quick and inexpensive numerical evaluation of muscular strength in cases as the elderly in communities, bedridden patients, and during drug therapies presumed to be strength affecting.

## Key words

Hand muscle strength, pinch strength, grip strength, hand dynamometer.

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## Introduction

Hands, fingers, and particularly the thumb are extremely important for human beings. The quality of the hand grip characterizes hand functioning and daily living activities. The ability to manipulate objects is linked to the action of fingers that, thanks to the coordinated action of muscles, may be moved on the palm of the hand or onto an object held in one's palm. At the same time the hand's anatomy and especially the movements of the thumb allow us to exert a force on an object placed between the fingers and the thumb (Carmeli et al., 2003; O'Rahilly et al., 2008). These movements are a complex motor task due to the action of the extrinsic muscles working together with the intrinsic muscles (Carmeli et al., 2003; O'Rahilly et al., 2008; Angst et al., 2010).

For more than a century hand strength exerted through these movements (grip and pinch) has been used to evaluate a subject's condition (Fisher and Birren, 1946; Bechtol, 1954; Swanson et al., 1970; Thorngren and Werner, 1979; Kellor et al., 1971; Mathiowetz et al., 1984). There are several complex reasons that make the evaluation of hand muscle strength by lateral pinch strength and grip strength so important.

Grip and key pinch strength measurements are also useful for monitoring people during growth and aging (Bohannon, 2008; Werle et al., 2009; Puh, 2010; Hogrel, 2015; Kaya et al., 2013). These tests can be used to evaluate performance and the effect of training in several different sports involving the use of wrists and hands (Larsen et al., 2016; Gerodimos, 2012; Gerodimos and Karatrantou, 2013). In addition, these evaluations can be a prognostic marker for defining a patient's rehabilitation process in case of hand injuries, and a measurement for response to therapy (Nakamichi et al., 2010; Hwang and Ho, 2007; Sirola et al., 2008; Kilgour et al., 2013, Sultan et al, 2012).

These devices can predict nutrition status (Norman et al., 2011; Flood et al., 2014) and predict disease complications, disability risk factors, and death due to various causes in middle-aged and older adults (Bohannon, 2008; Shah et al., 2015; Ensrud et al., 2008).

Given the importance of these tests, there has been an increasing trend over the last century to validate and verify the reliability of different devices for hand strength evaluation (Bechtol, 1954; Swanson et al., 1970; Hogrel, 2015; Schreuders et al., 2004).

The Jamar hydraulic hand dynamometer (JHD) is a well-validated device which is considered the gold standard for the quantitative measurements of hand maximum isometric muscle strength, which has been reported to decrease in elderly subjects (Bechtol, 1954; Swanson et al., 1970; Mathiowetz et al., 1984, 1985; Fain and Weatherford, 2015). At the same time, many studies have verified the relationship between the JHD and devices for the lateral pinch test (Bechtol, 1954; Swanson et al., 1970; Puh, 2010; Mathiowetz et al., 1985; Fain and Weatherford, 2015). Especially for the lateral pinch test, the possibility to use a simple, non-invasive, and quick assessment can be a key element for physicians and therapists (Mathiowetz et al., 1985; Villafañe and Valdes, 2014; Raymond et al., 2015). Moreover, the possibility of having a PC-controlled device to perform this test allows for storage of results in addition to timely data processing and analysis. The present study has the aim of verifying the reliability and validity of a new device for carrying out the lateral pinch test, as evaluated in a large population of adult subjects. The results are then compared with those obtained with the JHD.

## Materials and Methods

### Participants

A total of 65 subjects, 29 males and 36 females, ages ranging from 19.3 to 76.5 years, attending the University of Florence and Blue Clinic Center of Bagno a Ripoli, Florence, Italy, were recruited to evaluate their hand grip and pinch strength. Only the dominant hand was evaluated. Participants were full-time students, subjects attending the Blue Clinic center and personnel of the two Institutions. Detailed demographic characteristics of the study participants are shown in Table 1.

Study exclusion criteria were: presence of current hand problems, neuromuscular, orthopedic and/or surgical complications at baseline. The physical examination included hand inspection, while history of upper extremity pathology/injury or recurrent pain were also evaluated before including participants in the study. All participants received instructions, completed a questionnaire to provide demographic information, and written consent was collected before beginning the study.

Data were collected on age, sex, weight, height, while body mass index (BMI) was expressed as body weight in kilograms divided by the square of height (in meters: $kg/m^2$). Participant recruitment was non-randomized.

Hand strength was evaluated in each subject included in the study by the widely validated Jamar hydraulic hand dynamometer 0-90 Kg (model J00105, Lafayette Instrument Company, USA) while a tailor-made e-dynamometer, PC-controlled, was used to assess the pinch strength. All participants to the study gave their informed consent and the study was approved by the ethics committee of our hospital.

### Description of the PRD dynamometer

The electronic dynamometer is a small, disk-shaped sensor housing a Wheatstone bridge, where a resistor of the bridge is a strain gauge (Fig. 1). The strain gauge type is the current model used commercially in scales, with a range of approximately 0 to 50 Kg. The action of squeezing the sensor between the upper and lower surfaces warps one of the strain gauges. The gauge's resistance varies, so it causes the exit from the balance conditions and a voltage appears between the output connectors. This signal is directed to an analog-to-digital converter whose output is processed by a Raspberry processing board.

The processing unit is connected to a personal computer (PC) by an USB interface and is controlled by tailor-made software. The monitor shows the force vs. time rela-

**Table 1** – Characteristics of the participants; mean ± standard deviation, range; n = 65.

| Variable | | | |
|---|---|---|---|
| Sex | Female (n = 36) | Male (n = 29) | Total (n = 65) |
| Age (yr) | 40.1 ± 17.9 (19.3 – 76.5) | 40.7 ± 18.5 (19.8 – 72.3) | 40.34 ± 17.99 (19.3 – 76.5) |
| Dominant arm (dx/sx) | 34/2 | 28/1 | 62/3 |
| BMI (kg/m2) | 22.5 ± 4.7 (18.0 – 37.6) | 24.0 ± 3.5 (19.6 – 37.4) | 23.1 ± 4.2 (18.0 – 37.6) |


**Figure 1** –. PRD electronic dynamometer.

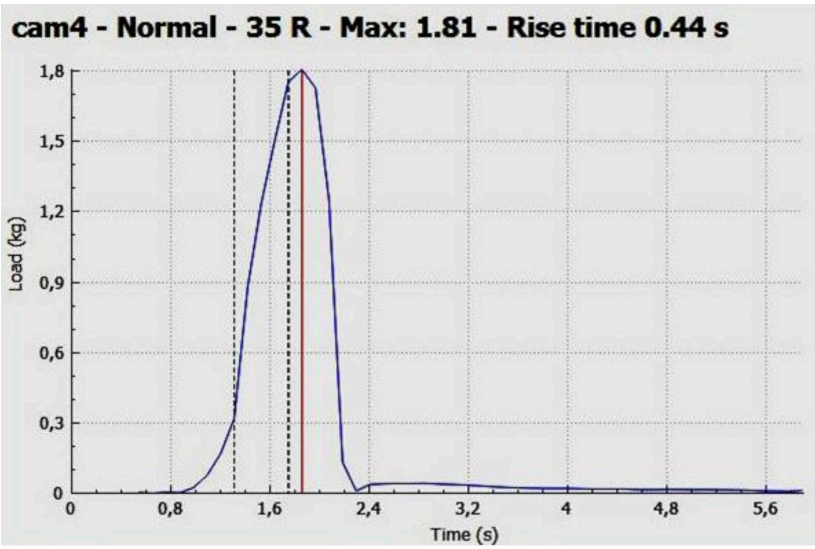


**Figure 2** – A sample of the "force vs time" diagram that appears on the monitor for a single pinch test.

**Figure 3** – Hand position for the measurement of pinch strength.

tionship (Fig 2) plus the rising time for the force to go from 10% to 90% of the maximum. An increase in time was a warning to the operator of the onset of the subject's fatigue and wandering attention during the long repetitive tests. This pinch gauge was designed for easy repositioning and low strain of the hand by Puglisi (engineer) and Romoli (medical doctor). It is referred to as the PRD from now on in this article.

The device has a large rest area on the medial part of the forefinger, plus a round thin positioning ring underneath to guide the same finger's flexion, and a total moderate thickness in order not to force the thumb in excessive flexion. The most comfortable total thickness in order to minimize fatigue in multiple testing of adult subjects was detected empirically. The geometry deemed most relevant to the purpose was elaborated in a series of preliminary attempts and the final choice is illustrated in Fig. 1.

We found that if the forearm rests on a horizontal position with elbow and wrist in contact with the table top, as illustrated in Fig 3, the involvement of muscles other than the thumb's and the forefinger's is minimal. We have not yet used electromyography to support this assumption, because other researchers may suggest more suitable arrangements.

## Device calibration

The manufacturer of the Jamar Hand Grip does not recommend that these calibrations be performed by the user. Therefore, we used a brand new device and checked the needle's zero position in the absence of load. We then secured the Jamar to the wall and loaded the gripping bar by hanging a weight of 10 Kg and 20 Kg in the middle of it, checking the needle indications. Regarding the PRD device, the software allows "point to point" calibration, with a linear interpolation between points. So we loaded the sensor with weights of 2, 5 and 7 Kg, adjusting the readings on the computer display.

## Experimental procedure

To measure pinch strength under controlled conditions, the subject was seated in front of a table and the sensor was placed between his/her thumb and forefinger with the hand safely supported on the table surface, as shown in Fig. 3. The angle between arm and forearm was about 90°. The operator gave the instruction: "Squeeze the button with your thumb with maximum force, but without hurting yourself. Stop if you feel pain". At the same time, the operator pushed a bottom on the PC keyboard, starting a measurement for 3 seconds. After a trial for getting familiar with the procedure, the subject repeated the test three times. The diagram of the relationship between force and time appeared on the monitor for each test (Fig. 2).

The subject was allowed to look at the monitor during the test. This may influence the level of force and must be considered among the test conditions. We made this decision because we did not want the force to be exerted for more than a couple of seconds, in order not to strain the hand. Visual feedback was found to be the best way to give the subject a rough idea of the time elapsed.

The maximum peak of force for each diagram was considered as a primary datum for this study. Then the average of maximum force was calculated and recorded for each set of three tests. After the pinch test, the subject stood up with the Jamar dynamometer in his/her dominant hand with the arm freely hanging down and slightly flexed. The bar in the handle was adapted so the subject felt comfortable. Grip strength was evaluated with patients in standing position and the elbow fully extended with the shoulder flexion at 0° (Su et al., 1994; Parvatikar and Mukkannavar, 2009; Roberts et al., 2011).

The examiner showed how to perform the test and then handed out the two dynamometers to the subject. The operator then gave the instruction: "Squeeze the handle with maximum force for three seconds, but without hurting yourself. Stop if you feel pain." A trial test was allowed for becoming familiar with the device. Then three tests were performed consecutively and the average of the values achieved was recorded. The interval between measurements was 30 seconds and that between the tests was 3 minutes (Roberts et al., 2011).

## Statistical analysis

Data are reported as mean ± standard deviation (SD) or as percentage, as appropriate. Muscle strength was expressed in kilograms and reported as mean ± SD. Comparisons among groups were analyzed by ANOVA, using the Bonferroni correction for multiple comparisons. Comparisons between PRD and JHD were achieved by the least squares method where y was PFD and x was JHD. Inter-assay repeatability was quantified by calculating inter-assay coefficients of variations. Multiple regression analysis was performed to test independent correlations using PRD pinch test results as the dependent variable and all variables which appeared to be significantly correlated with as confounding factors for univariate analysis. Statistical tests were applied two-tailed; and p values <0.05 were recorded and regarded as statistically significant. All calculations were performed using the SPSS system for Windows, version 16.0 (SPSS Inc, Chicago, IL, USA).

## Results

Men and women were well matched for age with 40.7 ± 18.5 yr. vs 40.1 ± 17.9 yr, respectively (Tab. 1). The mean results of each test were also considered separately for sex, and the variation coefficients (CV) are reported in Tab. 2 (Fig. 4). From this analysis inter-assay CVs were <5% for both devices and similar for all 3 challenges.

As shown in Figures 5-8, there is a strong correlation ($p<0.0001$) between the results obtained with the JHD and PRD tests, both when comparing the first, second and third test ($p<0.0001$) and the average of the three tests of either device ($p<0.0001$).

Among females the strengths exerted were 29.80 ± 6.96 kg at baseline and 5.47 ± 0.72 kg in the PRD test. The maximum strength with the two devices was 49.67 kg and 6.96 kg respectively while the minimum was 20.67 kg and 3.93 kg respectively, for JHD and PRD.

Among males the strengths exerted were 45.67 ± 11.10 Kg in the JHD and 7.58 ± 1.71 kg in the PRD test. The maximum strength with the two devices was 68.00 kg and 10.58 kg while the minimum 22.33 kg and 4.60 kg, respectively for JHD and PRD devices.

Mean strengths measured by both JHD and PRD were significantly lower in females than in males ($p<0.001$) with the grip strength and pinch test in women being 34.75% and 27.83% weaker than that of the men.

We performed a multivariate analysis of PRD as dependent variable and age and BMI as covariates of all the subjects investigated in both male and female groups.

**Table 2** – Results (mean ± standard deviation, range) and coefficient of variation of PRD and JHD tests on all subjects and in both sexes.

| | Females (n = 36) Kg | Males (n = 29) Kg | Total (n = 65) Kg | Coefficient of Variation (n = 65) |
|---|---|---|---|---|
| PRD - mean | 5.5 ± 0.7 (3.6 – 7) | 7.6 ± 1.7 (4.6 – 10.6) | 6.4 ± 1.6 | 3.92 |
| PRD - test 1 | 5.5 ± 0.7 (3.5 – 6.9) | 7.5 ± 1.7 (4.6 – 10.6) | 6.4 ± 1.6 | 3.95 |
| PRD – test 2 | 5.4 ± 0.8 (3.6 – 6.7) | 7.7 ± 1.7 (4.5 – 10.7) | 6.4 ± 1.7 | 3.78 |
| PRD - test 3 | 5.5 ± 0.8 (3.8 – 7.9) | 7.7 ± 1.7 (4.7 – 10.4) | 6.4 ± 1.7 | 3.79 |
| JHD - mean | 29.8 ± 7.0 (20.7 – 49.7) | 46.1 ± 11.2 (22.3 – 68) | 37.1 ± 12.2 | 3.04 |
| JHD – test 1 | 30.1 ± 7.4 (21 – 49) | 46.4 ± 10.8 (24 – 68) | 37.4 ± 12.2 | 3.07 |
| JHD – test 2 | 29.8 ± 7.3 (20 – 50) | 45.6 ± 11.4 (20 – 68) | 36.9 ± 12.2 | 3.03 |
| JHD – test 3 | 29.5 ± 6.6 (21 – 50) | 46.7 ± 11.7 (21 – 72) | 37.2 ± 12.6 | 2.96 |

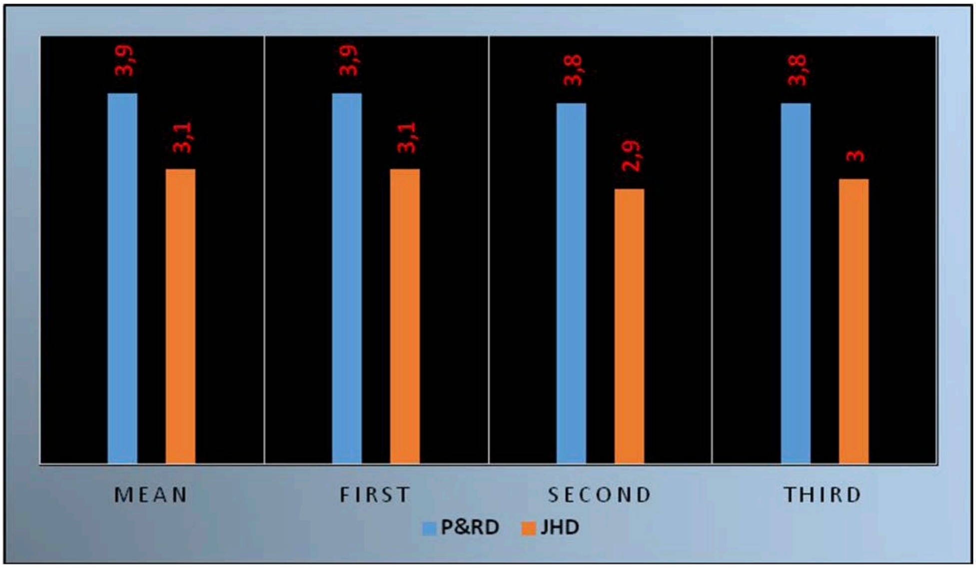


**Figure 4** – Variation coefficients of PRD pinch test device (blue) and JHD: Jamar hydraulic hand (orange). Data are the first, second and third tests and the means.

**Table 3** – Multivariate analysis considering the strength expressed by PRD (expressed in Kg) as dependent variable, and strength expressed by JHD, age, and BMI as independent variables in all subjects investigated and in males and females separately.

| PRD | ß – Regression Coefficient | p-Value |
|---|---|---|
| *All subject* | | |
| intercept | 2.04 | 0.009 |
| JHD | 0.10 | <0.001 |
| Age | -0.0056 | NS |
| BMI | 0.027 | NS |
| *Females* | | |
| intercept | 4.11 | <0.0001 |
| JHD | 0.059 | 0.0006 |
| Age | -0.001 | NS |
| BMI | 0.000 | NS |
| *Males* | | |
| intercept | 0.84 | NS |
| JHD | 0.10 | 0.0003 |
| Age | -0.001 | NS |
| BMI | 0.093 | NS |

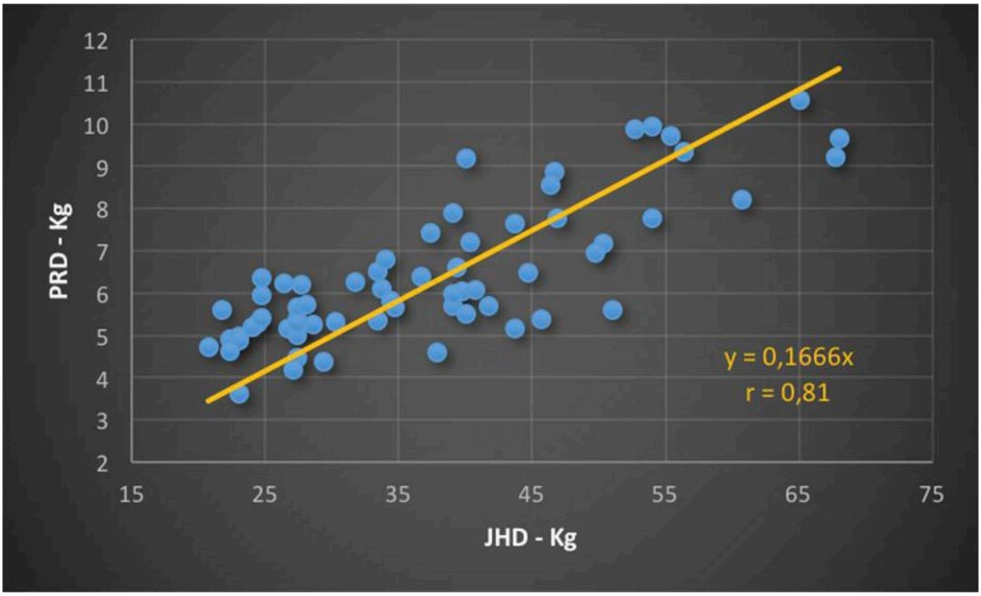


**Figure 5** – Relationship between the mean results of PRD device and (JHD) Jamar dynamometer measurements of all subjects investigated.

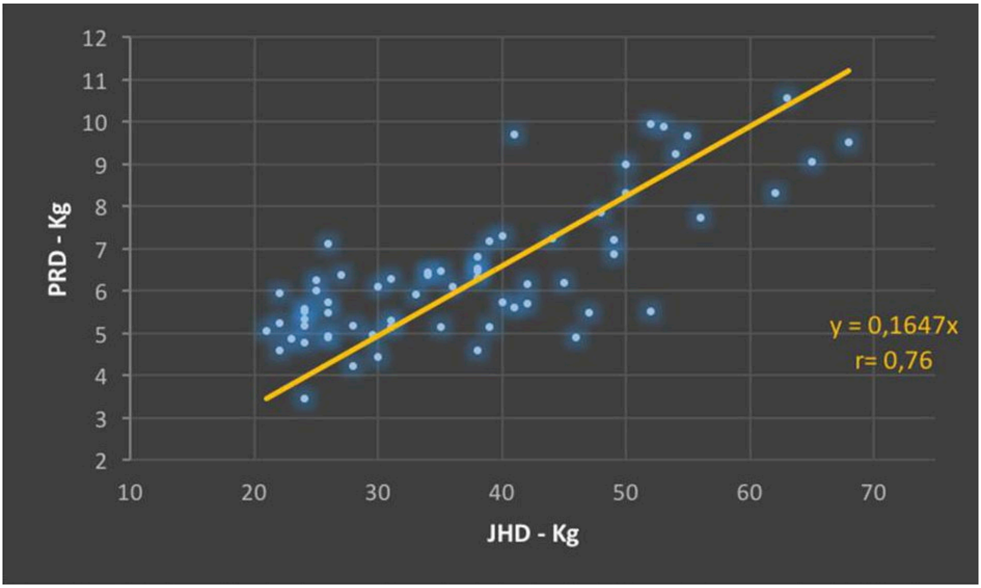


**Figure 6** – Relationship between the first test of PRD device and (JHD) Jamar dynamometer of all subjects investigated.

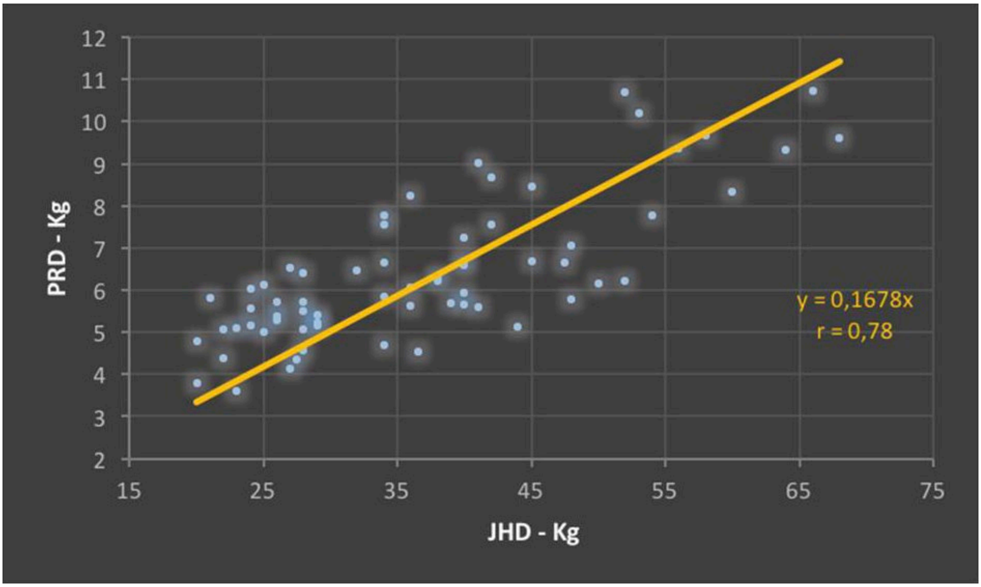


**Figure 7** – Relationship between the second test of PRD device and (JHD) Jamar dynamometer of all subjects investigated.

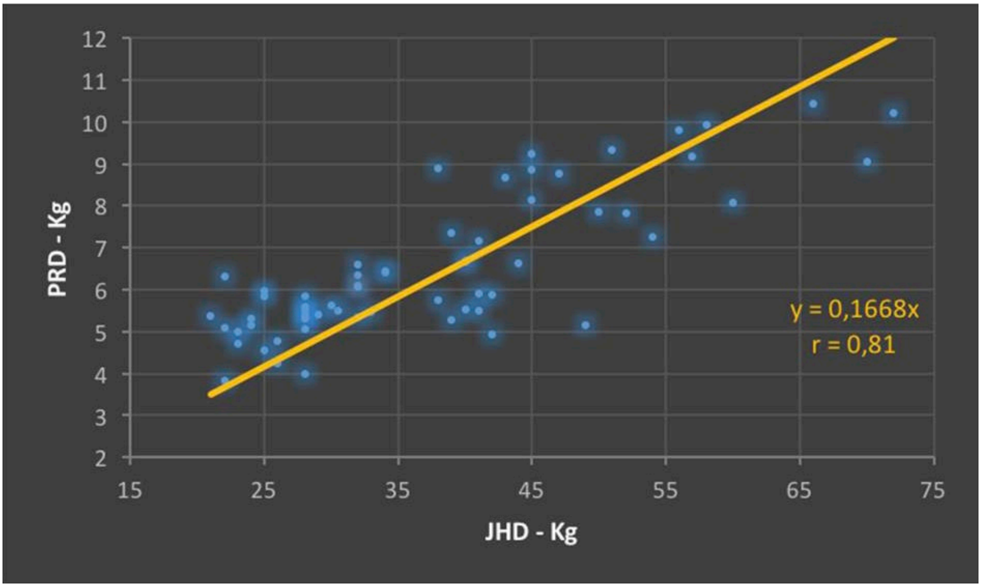


**Figure 8** – Relationship between the third test of PRD device and (JHD) Jamar dynamometer of all subjects investigated.

From this analysis, the strength expressed by PRD pinch test remained significantly associated with the results of JHD, independent of age and body weight (Tab. 3).

However, when considering the 41 subjects under 50 years (m / f: 18 / 23) compared with the 24 older subjects (m / f: 11 / 13), the correlation between the two devices was respectively ($r = 0.86$: $r = 0.64$; $p < 0.001$).

No attempt was made to normalize the results against the subject's weight or height, because the study was aimed at finding a correlation between PRD and JHD measurements, and not to establish normative data. The age and BMI of the subjects investigated was not related to the strength exerted as evaluated by the two devices both for all patients and for females and males separately.

## Discussion

This study aimed at verifying the reliability and validity of PRD for the evaluation of the lateral pinch test. This objective was achieved by comparing the PRD with the Jamar hydraulic hand dynamometer grip device, that has been widely validated and used for the assessment of grip strength since the second half of the last century (Kellor et al., 1971, Mathiowetz et al., 1985; Massy-Westropp et al., 2011). The comparison of the results achieved in a large group of subjects by the PRD device and JHD underlined a strong correlation between the two devices.

The two devices showed a comparable trend when investigating strength of the dominant hand in healthy subjects, and the relationship between the two devices was independent of variation in age and sex as indicated by the multiple regression analysis.

The evaluation of the single tests performed showed a significantly high correlation between the two devices for what concerns the amount of strength exerted. Test-retest quality with three repetitions indicated similar values of CVs for both devices, showing good inter-assay repeatability for both instruments.

We designed this new dynamometer for the evaluation of the lateral pinch test because this test may be used to evaluate various conditions in many individuals. The ease of using an instrument of the size and dimensions of the PRD makes the carrying out of the test easier in individuals who have difficulty grasping objects with their hands, by providing special support. The PRD also makes it possible to store data on the test performed, which can then be processed. Thus the force expression curve provides a further important assessment tool in real time and in digital form.

The availability of simple devices can further promote the transfer of such tests into the clinics or the practice of sport (Clerke et al., 2005; Hillman et al., 2005). In this sense, the PRD has been proven to be user-friendly and safe. No adverse events have occurred in the evaluated subjects. Use of the device and associated software was timely and none of the subjects enrolled reported difficulties in making the measurements.

There are many contexts in which the evaluation of the force expressed at the hand level is a useful measurement, such as in patients suffering from neuromuscular disease, chronic fatigue or diabetic neuropathy (Chiu et al., 2014; Francia et al., 2014; Neu et al., 2014; Raymond et al., 2015). Such tests can be easily performed at low cost to monitor healthy subjects and patients at all ages, including those in conditions of reduced autonomy or under therapy. Hand strength evaluation by the lateral pinch test can be particularly useful in this sense, making an easy-to-use and rapid device such as the PRD a welcome addition to this field.

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