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ORIGINAL ARTICLE

Isometric abdominal wall muscle strength assessment in individuals with incisional hernia: a prospective reliability study

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Abstract
Purpose To determine the reliability of measurements obtained by the Good Strength dynamometer, determining isometric abdominal wall and back muscle strength in patients with ventral incisional hernia (VIH) and healthy volunteers with an intact abdominal wall.
Methods Ten patients with VIH and ten healthy volunteers with an intact abdominal wall were each examined twice with a 1 week interval. Examination included the assessment of truncal flexion and extension as measured with the Good Strength dynamometer, the completion of the International Physical Activity Questionnaire (IPAQ) and the self-assessment of truncal strength on a visual analogue scale (SATS). The test–retest reliability of truncal flexion and extension was assessed by interclass correlation coefficient (ICC), and Bland and Altman graphs. Finally, correlations between truncal strength, and IPAQ and SATS were examined.
Results Truncal flexion and extension showed excellent test–retest reliability for both patients with VIH (ICC 0.91 and 0.99) and healthy controls (ICC 0.97 and 0.96). Bland and Altman plots showed that no systematic bias was present for neither truncal flexion nor extension when assessing reliability. For patients with VIH, no significant correlations between objective measures of truncal strength and IPAQ or SATS were found. For healthy controls, both truncal flexion (τ 0.58, $p = 0.025$) and extension (τ 0.58, $p = 0.025$) correlated significantly with SATS, while no other significant correlation between truncal strength measures and IPAQ was found.
Conclusions The Good Strength dynamometer provided a reliable, low-cost measure of truncal flexion and extension in patients with VIH.

Keywords Incisional hernia · Ventral hernia · Dynamometer · Abdominal wall function · Reproducibility of results

Introduction

The cumulated incidence of ventral incisional hernia (VIH) after abdominal surgery reaches 29 % in some publications [1]. VIHs are more common in smokers and in obese patients, and following postoperative wound complications [2]. VIH is associated with decreased quality of life and impairment of body image [3] and elevated risk of intestinal incarceration [4]. Surgical repair of a VIH improves the quality of life [5], whereas other changes, such as truncal muscle function following hernia repair, are largely unknown. Recently, it has been proposed that patients with VIH exhibit impaired function of the abdominal flexor muscles, and that this deficiency may be partly corrected by reconstruction of the abdominal wall [6]. It is unknown to what extent hernia patients present impairment of abdominal muscle strength capacity.

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Isometric muscle strength assessment using the very costly Biodex System-4 showed high reliability in patients with giant ventral hernia [7] or rectus diastasis [8]. However, it is yet unknown whether dynamometric determination of isometric force is reliable in hernia patients. Furthermore, the variability of abdominal wall function might be higher in patients with VIH due to pathologic diversity, as is the case with results from hand grip strength tests in patients with rheumatoid arthritis [9]. There are both clinical and scientific needs for a reliable tool for monitoring changes in abdominal wall function, and thus we found it of value to determine the reliability of a simple, low-cost isometric strength measurement to be used in future studies of patients with VIH.

The current study was conducted with the aim to evaluate the Good Strength dynamometer (Version 3.14 Bluetooth; Metitur Ltd, Finland) for use in patients with VIHs and healthy volunteers with an intact abdominal wall serving as controls.

Materials and methods

Participants

This was a prospective study including patients with VIH and healthy volunteers without a hernia diagnosis or previous abdominal surgery. Inclusion criteria for both groups were age above 17 years and American Society of Anesthesiologists' score 1–3. Exclusion criteria were pregnancy, systemic corticosteroid treatment, New York Heart Association class III–IV, and severe pulmonary or musculoskeletal disease. Patients were identified on the waiting list for VIH repair at our institution, and healthy participants were recruited through bulletins in the hospital area.

Test program

All participants underwent the same test program, which was adopted from previous validation trials in a similar setting evaluating isometric strength measurement equipment [7, 8]. After retrieval of oral and written consent, patients were asked to complete two questionnaires: International Physical Activity Questionnaire (IPAQ), which grades the patient into either 1 (inactive), 2 (minimally active) or 3 (health enhancing physical activity) [10], and self-assessed truncal strength on a visual analogue scale (SATS). Patients were then instructed in use of the Good Strength dynamometer (Fig. 1). Briefly, the Good Strength dynamometer truncal device fixated the pelvis of the patient which allowed for isolated evaluation of truncal flexor and extensor muscle function. An

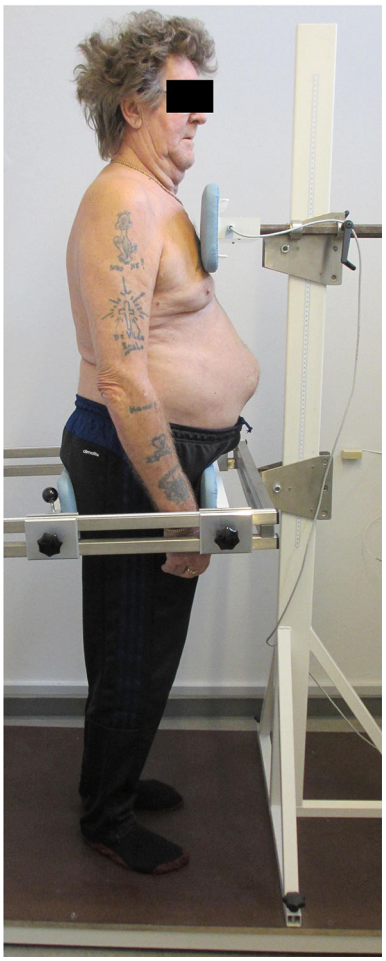

Fig. 1 Good Strength dynamometer

isometric maximal voluntary contraction (truncal flexion) was performed by applying maximal pressure with the chest against a plate placed at a height corresponding to the inferior angle of the scapula, thus generating a force measured by a dynamometer inside the plate. The measured pressure against the plate was transmitted to the computer software (Version 3.14 Bluetooth; Metitur Ltd, Finland) by a rate of 100 measurements per second, and digitalized and transformed into Newton (N). Thus, the registered outcome was the force exerted onto the plate by the patient.

Patients and volunteers were instructed to perform one tentative maximal truncal flexion. After this, the test regimen of truncal flexion was initiated with a maximal truncal flexion lasting 6 s followed by 30 s of rest. This was repeated twice, and the best performance of these three trials was used for analysis. Finally, truncal extension was similarly performed, although pressure was applied to the dynamometer by truncal extension at the same height as described above. This completed the baseline examination. Repeated examinations of truncal flexion and extension

(second examination) were executed 6–8 days after the baseline examination, with patients receiving exactly the same instructions as on the first testing day. All examinations of the patients with a hernia were carried out prior to surgical repair. Patients were not allowed to wear an abdominal binder during the functional measurements.

Statistics

Numerical values were reported as median (range) and compared using Wilcoxon's test. Categorical values (IPAQ categories) were compared across groups by Pearson's Chi-squared test. The reliability (correlation between baseline and second examination) of truncal flexion and extension was assessed by the interclass correlation coefficient (ICC) [11]. An ICC above 0.75 was considered excellent [7]. To further assess the test–retest reliability, Bland and Altman graphs were plotted for both groups of participants [12]. This graph plots the difference between test and retest against the mean value of test and retest and is commonly used to assess test–retest reliability in sports medicine [11, 13]. The plot allows for the evaluation of systemic bias, for instance, if the second examination systematically generates higher values than the baseline. If a test–retest difference of zero is included in the 95 % confidence intervals, a systematic change in these subjective measures can be ruled out. The difference between each pair of observations divided by the mean of the pair of observations is used to calculate the 95 % limits of agreement, which is also plotted on the Bland and Altman graph and delineates the random variation of the measurements [14]. A potential coupling between the truncal strength and the subjective measures of IPAQ and SATS was assessed by Kendall rank test. All statistical analyses were carried out using R 3.2 (Foundation for Statistical Computing, Vienna, Austria).

The study was approved by the Ethics Committee of the Capital Region, Denmark (ref. H-1-2014-008) and the Danish National Data Protection Agency (ref. 2012-58-0004, local ref. BFH-2015-053). The study was registered at clinicaltrials.gov (NCT02321059).

Results

A total of 20 participants were included in the study, 10 patients with a VIH and 10 healthy participants with an intact abdominal wall. There were no dropouts in the present study. The median horizontal and vertical defect size of the patients with incisional hernia was 2.75 cm (range 1–15 cm) and 4.40 cm (0.9–15 cm). Patients with a VIH were older, more comorbid and had a higher body mass index compared with participants with an intact abdominal wall (Table 1). There was no difference in truncal flexion (488.3 vs. 429.2 N, $p = 0.481$) or truncal extension (611.6 vs. 570.2 N, $p = 0.970$) between patients with VIH and healthy controls. After adjustment for bodyweight, there was a tendency towards both decreased truncal flexion (5.8 vs. 7.2 N/kg, $p = 0.105$) and extension (6.9 vs. 8.7 N/kg, $p = 0.063$) strength in patients with VIH compared with healthy controls. There were no differences between patients with VIH and healthy controls when comparing SATS (median 3.5 vs. 4.7, $p = 0.344$) or IPAQ (median 3 vs. 3, $p = 0.766$).

Patients with incisional hernia

Baseline versus second examination in patients with VIH revealed no significant difference in truncal flexion (488.3 vs. 482.2 N, $p = 0.492$) or extension (611.6 vs. 601.2 N, $p = 0.106$, Table 2). There was an excellent test–retest correlation for both truncal flexion (ICC = 0.91, $p < 0.001$) and truncal extension (ICC = 0.99, $p < 0.001$). No statistically significant correlations between truncal flexion and IPAQ ($\tau = 0.45$, $p = 0.123$) or SATS ($\tau = 0.09$, $p = 0.788$) were found. Furthermore, no correlation was found between truncal extension and IPAQ ($\tau = 0.23$, $p = 0.470$) or SATS ($\tau = 0.25$, $p = 0.367$). For both truncal flexion and extension, Bland and Altman graphs revealed that zero was included in the 95 % confidence intervals, and that error did not increase with muscle function, indicating that no systemic bias was present (Fig. 2). The 95 % limits of agreement were remarkably wider for truncal flexion than extension.

Table 1 Participant demographics, median (range)

	Patients with ventral incisional hernia ($n = 10$)	Healthy participants ($n = 10$)
Age (years)	66.0 (31.0–70.0)	32.0 (26.0–65.0)
Body mass index (kg/m^2)	27.0 (22.4–38.2)	21.7 (18.9–26.0)
ASA score	2 (1–3)	1 (1–1)
Horizontal hernia defect size (cm)	2.8 (1.0–15.0)	–
Vertical hernia defect size (cm)	4.4 (0.9–15.0)	–

ASA American Society of Anesthesiologists

Table 2 Results of reliability tests

	ICC	Kendall's τ	p
Patients with incisional hernia, $n = 10$			
Truncal flexion test–retest	0.91		<0.001
Truncal flexion vs. IPAQ		0.45	0.123
Truncal flexion vs. SATS		0.09	0.788
Truncal extension test–retest	0.99		<0.001
Truncal extension vs. IPAQ		0.23	0.470
Truncal extension vs. SATS		0.25	0.367
Healthy control group, $n = 10$			
Truncal flexion test–retest	0.97		<0.001
Truncal flexion vs. IPAQ		0.37	0.213
Truncal flexion vs. SATS		0.58	0.025
Truncal extension test–retest	0.96		<0.001
Truncal extension vs. IPAQ		0.32	0.230
Truncal extension vs. SATS		0.58	0.025

ICC interclass correlation coefficient, *IPAQ* International Physical Activity Questionnaire, *SATS* self-assessed truncal strength on a visual analogue scale

Healthy control group

As was the case in patients with VIH, no significant difference was demonstrated between baseline and second examinations of either truncal flexion (429.2 vs. 461.8 N, $p = 0.431$) or truncal extension (570.2 vs. 606.4 N, $p = 0.322$). Test–retest analysis showed excellent correlation for both truncal flexion (ICC = 0.97, $p < 0.001$) and extension (ICC = 0.96, $p < 0.001$). No significant correlation was found between truncal flexion and IPAQ ($\tau = 0.37$, $p = 0.213$), while truncal flexion correlated significantly with SATS ($\tau = 0.58$, $p = 0.025$). Truncal extension showed no significant correlation with IPAQ ($\tau = 0.32$, $p = 0.230$) but correlated significantly with SATS ($\tau = 0.58$, $p = 0.025$). Bland and Altman plots for both truncal flexion and extension indicated no systemic bias (Fig. 2). The limits of agreement were narrow for both truncal flexion and extension, indicating high reproducibility.

Discussion

The current study found excellent reliability of both truncal flexion and extension measurements using the Good Strength system to determine isometric trunk strength in patients with VIH. A similar degree of reliability was observed in heathy control individuals. Furthermore, no systematic change in the measurements was present.

Two other studies have assessed the reliability and validity of truncal strength measurements using expensive equipment to determine isometric muscle strength in patients diagnosed with rectus diastasis or ventral hernia as part of a similar test protocol [7, 8]. One of the studies revealed no correlation between abdominal muscle flexion strength and IPAQ score in both patients with VIH and healthy controls [8], similar to the lack of correlation between truncal flexion and extension, and IPAQ score found in the current study. Previous studies have questioned the validity of the IPAQ questionnaire as a measure of physical activity, perhaps indicating that the correlation between IPAQ and trunk muscle strength is of low importance [15, 16]. Altogether our findings combined with those previously reported suggest that the subjective evaluation of physical activity as an expression of muscle strength has limited validity.

Usually, validation of a new measurement method implies correlation analysis against a gold-standard [17]. However, there is no gold-standard for the measurement of abdominal wall function. The method most often used for examination of abdominal wall function in hernia patients is the Biodex system, against which the Good Strength dynamometer optimally should have been validated. However, the Biodex system was not available in our institution. Consequently, we used the IPAQ and SATS questionnaires to further study any potential coupling between subjective and objective strength measures. Interestingly, the Bland and Altman plots showed wider limits of agreement for truncal flexion compared with truncal extension in patients with VIH. Healthy controls showed comparable limits of agreement for truncal flexion and extension. This indicates increased variation in truncal flexor function induced by the VIH, comparable to findings in patients with rheumatoid arthritis [9].

A visual analogue scale as was used for the assessment of SATS is easy to administer and understand. This method has been applied for numerous different purposes in studies [18, 19], and constitutes a valid and reliable instrument for self-assessment of muscular strength [20]. Interestingly, we found a significant correlation between SATS and truncal strength in healthy participants contrary to the results obtained in patients with VIH, indicating that these patients perceive their abdominal wall function differently than non-operated healthy controls. Whether this is due to the former operative trauma on the abdominal wall or the hernia is unknown. It has been reported that patients with a VIH have an impaired body image, which thus may also include altered perception of abdominal wall function [3]. The phenomenon that certain patients including diabetics tend to wrongfully estimate their own physical performance is well known [21]. The present results suggest a similar missing link between objectively assessed truncal strength and subjectively reported SATS in patient with VIH.

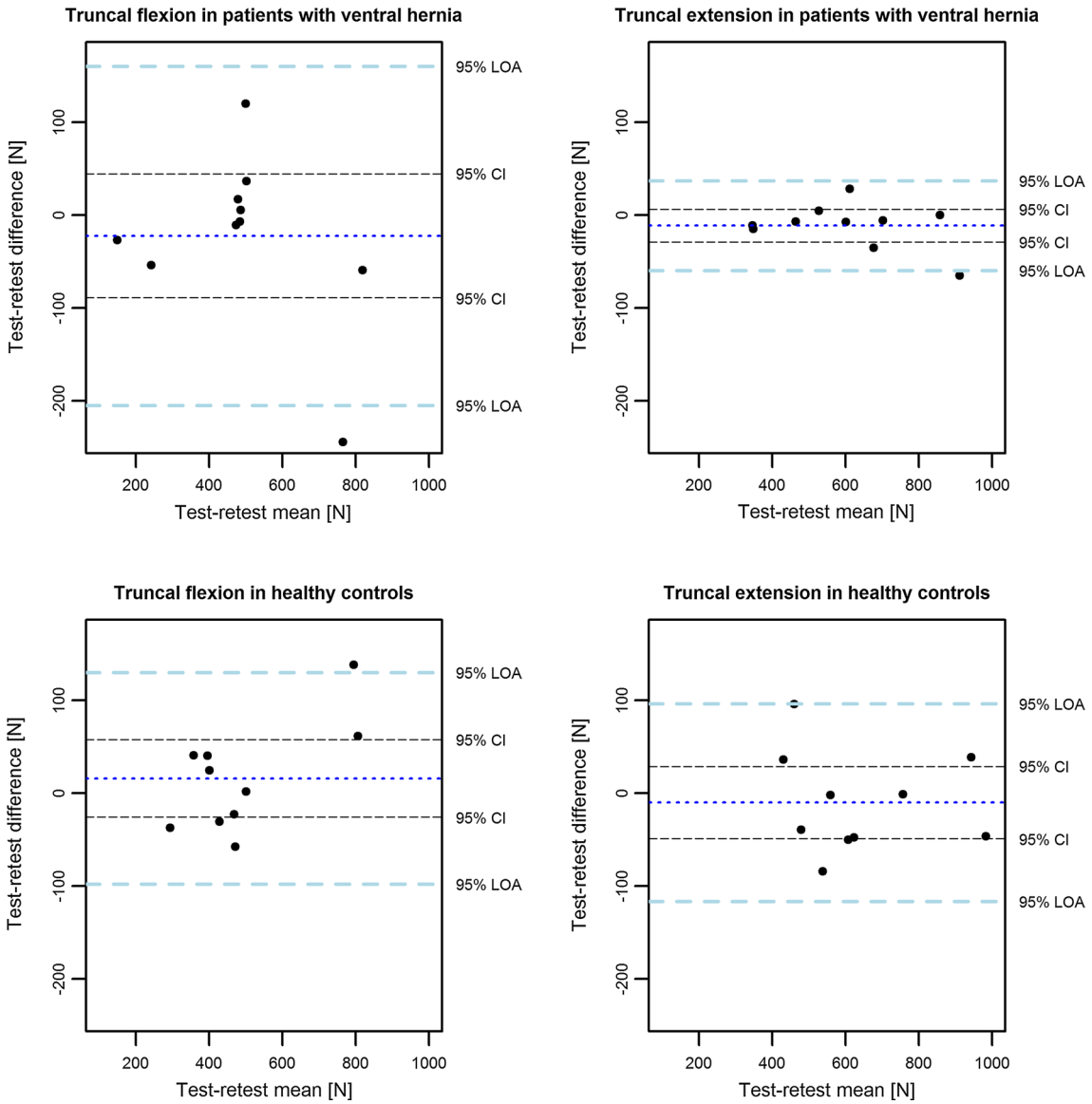

Fig. 2 Bland and Altman graphs of test–retest reliability of the Good Strength dynamometer in patients with incisional hernia and healthy controls. *95 % CI* 95 % confidence interval of test–retest difference, *95 % LOA* 95 % limits of agreement

A few other studies have assessed abdominal wall function in patients diagnosed with VIH, both pre- and postoperatively [6, 22]. These studies included few participants and different measures of abdominal wall strength. The Biodex system and the Abdominal Wall Strength Score are the only previously reported validated methods for the assessment of abdominal wall strength in patients with incisional hernia [7, 23]. To our knowledge, there is only one study in which abdominal wall strength both before and after VIH repair was addressed [6]. The results of that study were promising demonstrating significant improvement of abdominal wall function after VIH repair. If subsequent studies confirm these results, hernia surgeons may face a new consideration for surgical repair of incisional hernias. In the current study, there was no difference in truncal strength comparing patients with VIH and healthy controls. This may be due to the inclusion of patients with only small hernias and low statistical power due to limited study size. Although the comparison of truncal strength between patients with VIH and healthy controls was not an aim of the current study, we found it interesting that a tendency towards decreased abdominal wall function in patients VIH was found after adjusting for bodyweight. Future studies utilizing the Good Strength dynamometer are currently being conducted to further examine abdominal wall function in patients with VIH and compare this with patients who have no VIH.

The pathological mechanism behind muscular dysfunction of the abdominal wall in patients with incisional hernia has never been fully examined. Studies on an incisional hernia model in rat have shown atrophy and fibrosis in the external oblique muscle [24], which may be explained by the unloading of skeletal muscle, that occurs when the muscle is displaced from the original anatomical position. Interestingly, these alterations were reversed after repair of the hernia [25]. Even though the studies of this phenomenon only exist on rats, it may hold some of the explanation for the abdominal wall dysfunction in patients with a VIH. Although larger incisional hernias may cause greater loss of abdominal wall function, no cut-off for hernia size can be defined as to when a loss of muscular function sets in. It may be that even the slightest anatomical displacement of the rectus muscles along with scarring of tissue in the linea alba causes a decrease in abdominal wall function. Thus, we chose to include patients with incisional hernias of all sizes in the current study. Although the muscular dysfunction of the abdominal wall is thought to be a limitation for patients with VIH, it may not be the only factor affecting the mobility of these patients. Studies suggest pain to be present in more than 50 % of patients with a ventral hernia and this could account for part of the experienced abdominal wall dysfunction [26]. Furthermore, patients with larger lower abdominal wall hernias may have reduced mobility due to the large sac that hangs down over the pubic region, thus limiting truncal flexion.

In conclusion, we found that the Good Strength truncal device was a reliable measure of truncal flexion and extension in both patients with VIH and healthy controls. We aim to use these results for further examination of abdominal wall function in patients undergoing surgical repair of an incisional hernia.

Compliance with ethical standards

Conflict of interest KJ declares no conflicts of interest. MK declares no conflicts of interest. LJ declares no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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