ORIGINAL ARTICLE

Effects of abdominal surgery through a midline incision on postoperative trunk flexion strength in patients with colorectal cancer

I. Paiuk · I. Wasserman · Z. Dvir

Abstract

Background Abdominal surgery with bowel resection through a midline or transverse incision is performed in most cases of colorectal cancer (CRC). Both incisions affect abdominal wall function and may lead to differences in postoperative clinical outcomes. Although postoperative isometric trunk flexion strength (ITFS) has previously been investigated, the results were based on measurement tools distinguished by poor reproducibility and validity.

Objective To evaluate the reproducibility of and variations in ITFS following abdominal surgery using a dynamometer and explore the correlation between ITFS and the scar length.

Method The study group consisted of 22 consecutive patients (15 men and 7 women) referred for surgery. The outcome parameters included ITFS which was measured using a fixed dynamometer and a digital manometer, scar length, weight and pain. Test–retest measurement (3 h apart) of ITFS was taken 1 day before surgery to determine the instruments' reproducibility. Additional measurements of the outcome parameters were taken 1 and 6 weeks postoperatively.

Results Excellent test–retest correlations (ICC > 0.85) coupled with low standard error of the measurement for both the ITFS and the manometric findings indicated clinically acceptable reproducibility of the findings.

Significant pre- and postoperative differences in ITFS were noted using both techniques. Six weeks postoperatively, fair and significant correlations were noted between the dynamometry-based ITFS and both the scar length ($r = 0.452$) and age ($r = 0.498$). Of note, scar length and preoperative dynamometric ITFS predicted ITFS 6 weeks postoperatively ($F = 102.949$, $p < 0.001$, $R^2 = 0.92$).

Conclusions Measurements of ITFS using dynamometry in elective CRC patients are reproducible, sensitive to clinical changes and allow prediction of postoperative ITFS scores based on their preoperative counterparts.

Keywords Colorectal cancer · Abdominal muscles · Dynamometry · Maximal expiratory pressure

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Introduction

One of the common surgical approaches for abdominal cavity exploration in colorectal cancer (CRC) is a longitudinal incision which stretches from the xiphoid to the pubis [1]. This approach has a few short- and long-term implications for the patient's recovery reflected by a higher rate of respiratory dysfunctions during the first week [2–6], complications such as pulmonary collapse and pneumonia, postoperative ventral hernia (POVH) [3, 7, 8] and weakness of the abdominal wall muscles [9].

Compared to its transverse counterpart, the direction of the longitudinal incision is perpendicular to fascia and muscle fibers and consequently detrimentally affects recovery of the previous. In a study of the biomechanical properties of abdominal wall tissues in patients who underwent abdominal surgery using longitudinal incision versus matched healthy controls, a 30 % difference in favor of the latter group's ability to sustain loads was found. This

finding indicates a possible connection between the strength of abdominal wall tissues and POVH etiology [10]. Since recovery of aponeurotic tissue may last 200–300 days [11], incision of the linea alba may have a direct effect on abdominal muscle function [12].

Quantitative determination of abdominal muscle strength has been reported in previous studies using manometry- and strength-based measurements. Regarding manometry, this non-invasive technique for assessing abdominal muscles strength and monitoring changes has been applied in several medical conditions [13–15]. However, it should be emphasized that manometric measurements are predominantly intended to assess the expiration pressure and therefore their use for indicating the strength of the abdominals is problematic, at best. Significantly, the manometric results relate also to the integrity of the thorax and the diaphragm. Furthermore, comparison to invasive manometry, the standard in this domain revealed 95 % sensitivity but only 72 % specificity, indicating that the previous is not free of pitfalls in terms of diagnostic accuracy [16].

The use of dynamometry for assessing either the static (isometric) or the dynamic (invariably the isokinetic) strength is well indicated in case of muscular insufficiency [17]. Dynamometric measurements are distinguished by the fact that the device measures the combined force that a group of muscles exert against the force (or moment) sensor in a given direction and not the force output of an individual muscle within that group. Thus, in the case of trunk flexion weakness, the full scope of the compromise to the rectus abdominis cannot be estimated as it might be partly masked by other muscles such as the external and internal oblique that act as synergists in this movement. Dynamometric measurements of trunk muscles have invariably been reported in the context of normal subjects or patients impaired with chronic low back disorder [18–21]. The only study applying strength measurement to patients impaired with abdominal wall dysfunction described the use of isokinetic dynamometry in assessing incisional hernia outcome [22]. We are unaware of any previous study relating to patients following surgery for CRC. Consequently, we undertook to assess ITFS using a method which was previously applied in normal subjects [23]. However, a reproducibility (test–retest) study of isometric measurements of the trunk flexors, required in order to establish whether a recorded difference in muscular strength is within the error of measurement or reflective of a true clinically meaningful change, has, to the best of our knowledge, not been carried out.

Therefore the main objectives of this study were (1) to determine the intra-tester reproducibility of isometric trunk flexion strength, using a wall-mounted dynamometer, in CRC patients at the preoperative stage, (2) to examine the effect of longitudinal incision on the ITFS in these patients and (3) to explore a possible relationship between the length of the surgical scar and the ITFS in this patient group.

Method

Patients

Twenty-six consecutive patients with CRC (8 women and 18 men) were initially recruited for the study. Eventually, 2 patients were not available for the full series of tests, while another 2 had to start chemotherapy and hence the final study group consisted of 22 CRC patients: 7 women with mean age and weight of 62.6 ± 9.7 years and 78.9 ± 15.7 kg, respectively, and 15 men with mean age and weight of 63.6 ± 9.8 years and 78.3 ± 11.9 kg, respectively. There were two main reasons for choosing CRC patients for this study. First, most of the elective patients undergoing laparotomy in our department are diagnosed with CRC. Second, maintenance of uniformity in terms of pre- and post-op procedures, that is, fasting days, time with/out nasal gastric tube, hospitalization period, degree of mobility after the operation and return to daily activity, could be much better realized.

All patients underwent elective abdominal surgery using a longitudinal incision. A uniform protocol for stitching consisted of non-absorbable stitch, nylon loop 1 and Vicryl "0" single sutures every 2–3 cm.

The inclusion criteria included age (>18), a diagnosis of CRC, elective abdominal surgery using longitudinal incision, no other substantial medical history, no previous abdominal surgery and no steroid therapy during a period of 6 months prior to the operation. During their hospitalization and 6 weeks following the operation, patients have received all necessary treatments including physiotherapy but were not allowed to use abdominal belt or be involved in any strenuous exercise except walking. All operations were performed in Department of Surgery A, Assaf Harofeh Medical Center. The study was approved by the local IRB, and all patients signed an informed consent.

Instrumentation

For measuring abdominal muscle strength, we used a custom-made wall-mounted dynamometer (WMD) and a digital manometer (Micro RPM, Micro Medical Limited, UK). The WMD (Fig. 1) consisted of a compressive load cell (Vishay Israel) capable of measuring up to 30 kgf (kilogram-force) with a linearity of better than 0.5 % and associated electronics (amplifier, digital display), a plastic housing, a telescopic rod enabling adjustment to the

Fig. 1 Set-up of the wall-mounted dynamometer for ITFS measurements

individual patient's anthropometry and a holding frame (not shown in the illustration). The WMD displays the peak force developed during a maximal isometric contraction lasting 3–5 s. Its reproducibility validity is well established in normal subjects [24, 25] and select patient groups [26, 27]. The digital manometer measures the static pressure developed in the mouth cavity during maximal expiration following strong inspiration (total lung capacity). The expiration pressure is highly correlated with abdominal muscle strength [28]. The unit of measurement is cm H_2O (0–300 cm) with an accuracy of ± 3 %. The reproducibility and validity are well established in normal subjects [14, 16, 29] and select patient groups [15]. A digital caliper and digital weight were used to measure the scar length and bodyweight, respectively.

Procedure

All measurements were performed by a single, experienced physical therapist. All patients were measured 4 times: twice during the same day with a 3-h break a day before the operation, and 1 and 6 weeks following the operation. We decided to limit the post-op testing period to 6 weeks since at this point in time most participants started chemotherapy, which could affect study findings. Furthermore, the post-op course in the vast majority of CRC patients is without specific complications and largely unremarkable enabling a repeat (6w) examination without substantial drop-out rate.

The pre-op measurements were used to examine the reproducibility and determine the measurement error and included in addition to measuring ITFS, elbow extension strength (EES), weight and manometry. A week following the operation, measurements included weight, manometry and scar length, whereas at the final assessment (6 weeks post-op), ITFS, EES, weight and manometry were recorded. Each patient was familiarized with the test instrument prior to the criterion measurement.

The manometric measurement was performed with the patient seated. The results of individual 3 trials, 1 min apart, were recorded. Verbal encouragement was given during the test [13]. Dynamometry was performed with the patient seated in a well-standardized position: feet flat on the floor, knees at 90°, pelvis at neutral rotation and the trunk as erect as possible. Stabilization of the thighs and pelvis was enhanced by straps connected to the seat. Using the height and distance adjustments, the load cell was brought to touch against the xiphoid process. The patient was then asked to push against the load cell as forcefully as possible for up to 5 s without loosing contact between the feet and the floor or using the Valsalva maneuver. The results of 3 individual trials, 1 min apart, were recorded.

The objective of measuring EES was to ensure that the operation did not cause a general change of muscular strength, that is, that the adverse effect on trunk flexion strength could be attributed solely to the intervention. Measurement was limited to the dominant (writing) side and performed while the patient was lying prone with the arm and elbow abducted and flexed, respectively, at 90° and forearm in the neutral position (no pronation or supination). The load cell was then positioned against the styloid process. The patient was asked to push against the load cell as forcefully as possible for up to 5 s without losing contact with the bed. The results of 3 individual trials, 60 s apart, were recorded.

Data processing

We used SPSS version 16.0 for the statistical analysis. Correlation coefficients (Pearson's r and ICC) were computed for the paired t tests (pre- and post-op) and determination of the standard error of measurement (SEM), the latter being derived from the formula: SEM = SD*$\sqrt{(1-ICC)}$, where SD is the standard deviation of the scores in test 1 and test 2. The cutoff score for indicating a true clinical change at the individual level was defined as the smallest real difference: SRD = 2.77*SEM. Bland–Altman plots were used for the examination of test–retest bias, whereas the effect size was employed to assess the WMD and manometry-based changes. A stepwise regression was used for predicting ITFS from scar length.

Results

There were no significant inter-gender differences in terms of either age or weight. Table 1 presents the test–retest correlation coefficients, SEM and SRD for the functional

Table 1 ICC, SEM and SRD values for the preoperative tests (n = 26)

Parameters	Gender	ICC*	SEM	SRD
TFIS (kgf)	M	0.894	1.81	5.01
	W	0.881	1.33	3.67
EES (kgf)	M	0.928	1.66	4.60
	W	0.921	1.38	3.83
MEP (cm H$_2$O)	M	0.935	9.94	27.53
	W	0.957	7.51	20.80

SEM standard error of measurement, *SRD* smallest real difference—in the units of the outcome parameter, *ITFS* isometric trunk flexion isometric strength, *EES* elbow extension strength, *MEP* maximal expiratory pressure

* The *p* for all ICC values <0.001

parameters. As evident from the table, in order to establish a true individual clinical change at 95 % level of confidence, the cutoff values of the relevant outcome parameters, ITFS and MEP, were 5.01 kgf and 27.53 cm-H$_2$O in men and 3.67 kgf and 27.8 cm-H$_2$O in women, respectively. The mean length of the scar was shorter in men (18.9 ± 6.0 cm) than in women (23.4 ± 7.0) but not significantly (p = 0.133).

Table 2 outlines the post- versus pre-operative values of the functional parameters according to gender. As expected, men were significantly stronger than women on all 3 measures (ITFS, MEP and EES) at all test sessions save MEP at 1w, where men displayed a massive decrease in the expiratory pressure. In terms of the pre- and post-differences, weight did not change at either 1 or 6 weeks post-op and neither did the EES. In men, there was a significant reduction in both ITFS (at 6w) and MEP (at 1w) relative to the baseline, but at 6w, the baseline level MEP scores were on average regained. Significantly, at 6w post-op, there were 4 patients (2 women and 2 men) whose MEP was less than the baseline score—SRD, whereas the ITFS was

associated with twice as many patients (3 women and 5 men), making up more than one-third of the study group.

A correlational analysis revealed a moderate relationship between age and the pre- and postoperative difference in ITFS (r = 0.50, p = 0.018), and between scar length and post-op ITFS (r = 0.452, p = 0.035). There were fairly strong correlations between the pre- and postoperative values of MEP and ITFS: r = 0.70, p < 0.001 and r = 0.748, p < 0.001, respectively. There was also a moderate, r = −0.493, but significant (p = 0.025) relationship between the difference (pre-op−1w post-op.) in MEP and the difference in ITFS (pre-op−6w post-op.).

A stepwise regression for the prediction of ITFS from the other parameters yielded a highly significant relationship (F = 102.949, p < 0.001) with R^2 = 0.92. The following formula was thus derived: ŷ = 5.3 + 0.87 *mean ITFS before surgery−0.27*scar length, where ŷ is the predicted value of ITFS at 6w. Noteworthy, the preoperative weight, MEP and EES had no effect on the final ITFS. A parallel model for predicting MEP at 6 weeks was of the form: ŷ = 27.48 + 0.28 *mean MEP before surgery with a substantially lower R^2 (0.36). Scar length was not indicated as a factor.

Discussion

The main findings of this paper reveal that compared to its MEP counterpart, isometric assessment of trunk flexion exposes in a more accurate manner the residual weakness of the trunk flexors in patients with CRC 6 weeks after the operation while incorporating the effect of scar length on the postoperative ITFS score. These findings and other factors beg further elaboration.

With respect to the manometric measurements, as indicated in Table 1, the test–retest study yielded very high correlations. However, due to relatively high standard

Table 2 Pre- and postoperative scores of the outcome parameters

Outcome parameters	Women	Men	P values of gender differences within session	Diff (pre-post) > SRD
ITFS (po)	20.4 ± 4.6	35.0 ± 9.1	p < 0.001	–
ITFS (6w)	16.8 ± 2.9—NS	31.5 ± 9.4*	p < 0.001	3w, 5m (Deterioration)
MEP (po)	84.3 ± 33.3	115.4 ± 36.0	p = 0.017	–
MEP (1w)	60.3 ± 17.0*	56.3 ± 16.8**	NS	15/17 m, 3/7w
MEP (6w)	70.0 ± 28.3—NS compared to pre.o.	110.0 ± 30.7—NS compared to pre.o.	p = 0.009	2w, 2m (Deterioration)
EES (po)	21.4 ± 4.3	28.1 ± 5.9	p = 0.004	–
EES (6w)	18.2 ± 3.6—NS	29.2 ± 7.0—NS	p = 0.004	–

po preoperative, *w* women, *m* men, *NS* not significant

* *p* < 0.05; ** *p* < 0.01 significance of difference within gender between test sessions

deviations, the resulting SRDs were comparatively large, around 25 % of the mean value. Obviously, a much bigger sample could improve these scores. In terms of the absolute MEP scores (Table 2), the preoperative mean manometric values were 30–40 % lower than those found in normal subjects of the same age group [14]. This indicates a general lower motor capacity in these patients due probably to disuse of the muscles but may also be related to lung compliance. On the other hand, the difference between women and men—35 % in favor of the latter—is well in line with previous studies [14] and the general gender difference in strength [23].

As for the observed change scores, there was a significant decrease in MEP values after 1w with men suffering a massive 50 % reduction versus 30 % in women. This intergender difference was not statistically significant. Based on the SRD, this change was even more impressive: while 15/17 of the men have demonstrated true clinical deterioration, such an effect was apparent in only 3/7 of the women. However, at 6w postoperatively, the straightforward pre- and post-statistical analysis revealed that both women and men patient groups have largely regained their manometric scores together with restitution of the difference between genders. Nonetheless, using the SRD-based approach revealed that two women and two men were still suffering from significantly reduced MEP. It should be mentioned that the so-called relative SRD (SRD/mean pre-op value of MEP) was 25 and 24 % in women and men, respectively.

The difference between men and women, in terms of SRD, 1w post-op is a challenging issue. Whereas the mean reduction was 50 versus 30 % (men, women) and non-significant, the proportion of men presenting with MEP values less than mean-SRD is about 90 % in men versus approximately 40 % in women. Undoubtedly, the sample size is a factor. Furthermore, there may have been intervening factors like duration of anesthesia and of application of gastronasal tube or location of the scar in relation to the diaphragm, could contribute to the apparent difference between men and women but none of these factors have been monitored. On the other hand, if these were evenly applicable for both genders, our impression is that this difference has more to do with submaximal performance among men during the test at 1w following the operation driven probably by apprehension. This point requires further study. Of some significance is the finding that 6w after the operation, 4 patients (2 women and 2 men) were still presenting with a serious SRD-based MEP deficiency. This point will be discussed in the context of the ITFS. Interestingly, the two male patients had the highest pre-op MEP scores and therefore at 6w may have not regained the pre-op values. The same may apply to the female patients though both were of average performance.

The ITFS presents a different picture compared with that of the MEP with the qualification that this measurement was applied postoperatively only at 6w. Regarding the protocol, in the present study, testing was performed while the patient was seated ensuring that feet and thigh position and stabilization remain uniform.

Measurement of the abdominal strength may be performed in sitting or in supine lying positions [17, 18, 22]. The findings of the reproducibility testing performed in supine lying position were especially low with ICC and SEM of 0.25 and 60 N, respectively [18]. Furthermore, given the fragility of the scar tissue, for a period of 2–3 months, patients undergoing abdominal surgery are instructed to avoid situations which are associated with elevated intra-abdominal pressure. As a result, we decided to measure the strength in sitting, as this position is associated with better patient stabilization, lesser apprehension and lower potential risk.

As evidenced by the findings, the significant inter-gender differences in ITFS were 43 and 47 % in favor of the male patients, pre- and postoperatively indicating an almost identical recovery in strength. This further validates this measurement approach. Furthermore, similar to previous findings [6], age was a factor in ITFS namely older patients experienced a more severe weakness after the operation ($r = 0.498$, $p = 0.018$).

In order to determine the severity of trunk flexion weakness 6w following the operation, we used not only the relative reduction in strength but compared the post-op findings to those at baseline using the individual SRD [30]. In this context, it should be mentioned that the SRD is affected by both the test–retest correlation and the standard deviation of the scores, and consequently, the smaller the sample giving rise to the SEM (or SRD) the larger is the SRD. Thus, if following an intervention, a given parameter differs by $\sim$3SEM relative to the baseline score; then, by definition, the difference is outside the 'error belt' and can confidently be considered as representing clinically meaningful change, either improvement or deterioration. Of note, the relative SRD in this case was 17 and 14 % in women and men, respectively.

With respect to the SRD-based analysis, there were 8 patients, 3 women and 5 men who still presented with meaningful ITFS impairment at the 6w test session. This should be compared with only 4 patients (2 and 2) who were judged as presenting with meaningful expiratory deficiency at the same period. How should this gap be explained? One argument would base the difference on the relative SRD scores. Since the ITFS-related SRDs were lower than their MEP-related counterparts, the likelihood of classifying a score as indicative of meaningful deficit is higher for the ITFS. However, we suggest that an even more compelling argument is that the MEP is not as

sensitive an indicator as the ITFS for assessing trunk flexion weakness in this patient cohort. Although, as shown by the correlational analysis, ITFS and MEP were better than moderately correlated, their respective pre- and post-differences were in fact negative and therefore these outcome measures are not inter-changeable.

Equally of importance regarding the above contention is the significance of the regression model. The postoperative value of ITFS could be very well predicted by the preoperative ITFS score in conjunction with the scar length. A parallel model relating to the MEP failed to reach comparable predictive efficiency while excluding the possible effect scar length may have on the outcome measure. In this respect, it is worth emphasizing that scar length was measured externally while the effective the length of the fascial incision may be shorter or longer. Thus, a limitation of the study may be the expected error in reflecting the effect the scar has on the acting muscles. However, the surgical technique used in our department does not result in length differences of more than 1 cm, and therefore this error may be of limited, if any, clinical significance. Another limitation of this study was a relatively small cohort. Notwithstanding, the reproducibility of the outcome measures was clinically acceptable and there was also a clinically meaningful change in 8 of the patients, a finding that has rarely been previously reported.

Additionally, all our patients have undergone longitudinal incision, although there is evidence supporting transverse incision-based laparotomy. Therefore, we could not compare the findings between these two surgical approaches.

In this study, the clinical significance of the reduction in abdominal muscles strength 6w post-op was not examined. Consequently, given the present findings, POVH cannot be predicted from ITFS. However, in light of the study, we intend to invite all surviving patients for an examination, 2 years post-op, which will include clinical examination, as well as measurement of ITFS and weight.

In conclusion, abdominal surgery through vertical midline incision causes a selective weakness of abdominal muscles. ITFS measurements in patients undergoing elective colorectal surgery have proven to be both reproducible and sensitive to the resulting weakness at 6w postoperatively. Furthermore, preoperative ITFS with scar length may predict the postoperative ITFS score.

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