Functional outcome after laparoscopic and open incisional hernia repair

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Abstract

Background:

The debate about the advantages of laparoscopic versus open incisional hernia repair is still ongoing. The primary outcomes of already published studies are mainly recurrence, pain and quality of life. Data on postoperative abdominal wall function after these corrections is still lacking. In this single center study muscle strength and transverse abdominal muscle thickness were analysed with regard to open and laparoscopic techniques.

Methods:

Thirty-five patients that underwent open and laparoscopic midline incisional hernia correction were included. Approximation of the rectus muscles was included in some open procedures but never in laparoscopic correction. Twelve healthy subjects without any abdominal operation functioned as a control group. Trunk flexion muscle strength of all operated patients and 12 healthy subjects was studied with the Biodex® isokinetic dynamometer and conventional abdominal muscle trainers for the rectus and oblique abdominal muscles. All patients underwent ultrasound examination of the abdominal wall for analysing transverse abdominal muscle thickness.

Results:

The mean torque/weight (%) for trunk flexion, measured with the Biodex®, was significantly higher in the control compared with the total patient group. Comparing trunk flexion with the Biodex® after either laparoscopic or open incisional hernia repair showed a trend in favour of the open group after adjusting for gender. The muscle strength measured by the conventional abdominal muscle trainers showed no differences between the operation groups. The transverse abdominal muscle thickness difference between rest and contraction was significantly higher in the open repair group.

Conclusions:

The isokinetic strength of trunk flexor muscles is reduced after an operation for incisional hernia. There is some evidence that open repair with approximation of the rectus abdominis muscles results in higher muscle strength of the rectus muscles and higher thickness differences between rest and contraction of the transverse abdominis muscles compared to laparoscopic technique.

Introduction

Despite extensive research on the optimal closing technique for midline laparotomy, the risk for incisional hernia still remains about 5-20% [1, 2]. After abdominal aortic resection, the incidence of incisional hernia can be as high as 60% [2, 3]. Accordingly incisional hernia is the most frequently observed long-term complication in surgery, causing high morbidity and even mortality rates [4-8]. Complaints, such as pain, discomfort and respiratory restriction, subsequently lead to surgical repair in a large number of patients [9, 10].

Incisional hernias can be repaired by either open or laparoscopic techniques. As a rule laparoscopic correction is performed with a mesh. The open technique can be a simple hernioplasty (Mayo duplication or fascia-adaptation), component separation technique after Ramirez or a mesh repair with (Rives-Stoppa) or without approximation of the rectus abdominis muscles.

However, muscle strength studies of the trunk flexors after abdominal operations are rarely performed. Zauner-Dungl et al. studied trunk flexion strength after rectus abdominis muscle flap transfer in reconstructive surgery with an isokinetic dynamometer [11]. The same group studied trunk flexion strength comparing a laparoscopic with open cholecystectomy [12]. Using the Biodex® dynamometer muscle strength is measured during isokinetic movement, which is movement with a constant angular velocity (given by the dynamometer) within a certain range against a changing resistance given by the subject [13-15].

Another way to assess dynamic strength is to determine how much weight an individual can lift for one repetition. This one repetition maximum strength can be calculated from how many repetitions a person can perform with a certain sub-maximal weight [16]. Ultrasound of the abdominal wall can be used to measure the transverse abdominal muscle thickness in rest and during contraction. The change between rest and contraction can be used as a measure of abdominal wall muscle function [17-19].

The object of this study was to compare trunk flexion muscle strength between patients who underwent surgical repair for incisional hernia and a healthy control group. Secondary objectives were to compare trunk flexion strength and transverse abdominis muscle thickness after open and laparoscopic techniques for incisional hernia.

Materials and methods

This study consisted of 35 patients who underwent midline incisional hernia correction and 12 healthy subjects without any abdominal operation. All patients had undergone operations at an academic center. Twenty-one (53.3%) patients had operations with an open technique and 14 (46.7%) by laparoscopic access. In the laparoscopic technique, a mesh was used, and the hernia ring was left open. In the open repair, the fascia of the rectus abdominis muscle was closed after placement of a mesh in seven patients. The fascia was left open after placement of a mesh in fourteen patients. The mean follow-up time between the operation and the Biodex® examination was 5.8 years (1.8).

Biodex® measurements

Trunk flexion muscle strength measurements were conducted on a Biodex® isokinetic dynamometer (Model 2000, Multijoint System 3, Biodex® Corporation, Shirley, NY, USA). The dynamometer evokes a variable resistance with a fixed speed. Each subject was seated on a chair with the body strapped to the back of the chair. The mechanical stops were positioned with an amplitude of 60° to prevent the subject from working in non-conventional zones. One session of flexions and extensions was performed to get the subject accustomed to the exercise before testing. The second test session was used for collecting data measurements.

Trunk flexor muscles were assessed at 60°/sec angular velocities. The subjects performed six flexions and extensions and were encouraged to generate maximal effort through the entire range of motion for all repetitions. The peak torque was expressed in Newton meters (Nm) and was normalised to body weight (Nm/kg x 100%). Torque is proportional to power, and the peak torque is the highest value within the range of motion.

One repetition maximum measurements

To evaluate the maximum strength of the abdominal muscles, one maximum repetition test was performed. Two different devices were used for the exercises. One of the devices was designed to exercise the rectus abdominis and the other to exercise the oblique and transverse abdominal muscles (Enraf-Nonius, Rotterdam, The Netherlands). None of the patients had training experience and were instructed before doing the exercises. After measuring how many times patients could perform standardized exercises on the devices, the one repetition maximum (1RM) was calculated using the formula of Brzycki [16]. The formula is as follows: 1RM = weight lifted / (1.0278 – 0.0278 * number of repetitions). The maximum weight a person can lift is expressed in grams. The unit of the one repetition maximum is expressed in kilogram-force or gram-force, which is the magnitude of the force exerted on 1 kilogram (or gram) of mass by a 9.81 m/s^2 gravitational field (standard gravity).

Ultrasound imaging

Changes in muscle thickness during rest and after muscle contraction were assessed with ultrasound imaging. Unilateral measurements of the transverse abdominal muscle were performed using a portable ultrasound unit (SonoSite®, Seattle, USA). The measurements were performed by positioning the transducer at the level of the umbilicus horizontally and thereafter moving it laterally until the proximal edge of the transverse abdominal muscle was aligned to the left side of the onscreen display.

In the resting position, two images were taken from the transverse abdominal muscle to assess the rest thickness. Subsequently patients were asked to strain the abdominal wall at maximum strength. During contraction of the abdominal wall, two images were again taken after aligning the proximal edge of the transverse abdominal muscle to the left side of the onscreen display (Figure 1).

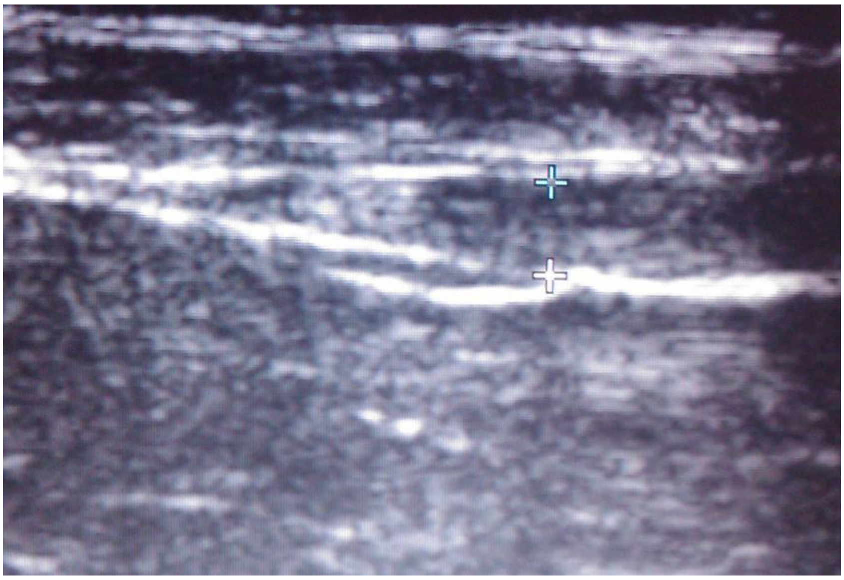

Fig.1. Example of an ultrasound still frame of the transverse abdominal muscle

The thickness of the transverse abdominal muscle was obtained using the measurement software of the ultrasound device. The proximal edge of the muscle was digitally callipered, whereupon the thickness of the muscle 25 mm laterally from this calliper was measured.

Every measurement was repeated two times to reduce intra-observer variability. The mean of these two measurements was calculated and used for comparison between the subjects.

Statistical analysis

Statistical analysis was performed with PASW Statistics 17.0 on a personal computer. All continuous data were given as means with standard deviations (SD).

The two-sample t-test was used to compare the control and operative groups for age, weight and length. The chi-square test was used to compare the control and operative groups for gender.

The two-sample t-test was used to compare the Biodex® measurements in the controls and patients after operative repair for incisional hernia. This test was also used to compare the measurements amongst themselves in patients after the three included operative techniques for incisional hernia: open technique with fascia closure, open technique without fascia closure and laparoscopic repair. A *P*-value <0.05 was taken as the threshold of statistical significance.

The relationship between the one repetition maximum lift and the operative technique (open or laparoscopic) was estimated using multiple regressions allowing for body weight, age and gender. Non-significant variables were removed one by one, removing the largest p-value first, until all remaining variables in the model were significant.

The strength of the relationship between the measurements of the different measurement techniques was estimated by the product-moment correlation coefficient.

Results

Fifty-five percent of the subjects were male, and their mean (SD) age, height, body weight and body mass index were 60 (13) years, 173 (10) cm, 83 (19) kg and 27 (5) kg/m^2, respectively. The mean age was significantly lower in the control group than in the patient group (50 versus 64 years, $P<0.01$). The patient groups were similar in age, sex ratio, mean BMI (body mass index) and recurrence rate.

Biodex®

A significantly higher peak torque/weight was found in the control group compared to the operated group (84 versus 202 nm, $P<0.01$). After splitting up the operated group in open and laparoscopic repair, the comparison with the controls remained significant ($P<0.01$, Table 1).

Table 1. Mean peak torque/weight in % (SD) in trunk flexion comparing three different operations for incisional hernia with the control group (n=12) measured with the Biodex® isokinetic dynamometer.

Peak torque/weight (%)	**Measure device**	**Operation group**	**Control group (n=12)**	**Confidence interval of the difference**	**P-value**
Total operation group (n=35) versus control	Biodex®	83.7 (46.1)	202.4 (88.6)	61.0; 176.4	<0.01
Laparoscopic technique (n=14) versus control group	Biodex®	71.4 (34.8)	202.4 (88.6)	72.6; 189.4	<0.01
Open technique with fascia left open (n=14) versus control group	Biodex®	97.0 (59.3)	202.4 (88.6)	45.2; 165.6	<0.01
Open technique with fascia closed (n=7) versus control group	Biodex®	81.9 (32.6)	202.4 (88.6)	60.1; 180.9	<0.01

The mean torque/weight was not significantly different between the open and laparoscopic groups. Comparison between patients in which the fascia was closed over the mesh with patients where the fascia was left open after open incisional hernia repair showed no difference in outcome (82 versus 97, P=0.54, Table 2).

Table 2. Mean peak torque/weight in % (SD) or maximum strength (gram-force) in trunk flexion comparing the three operations for incisional hernia with three different devices.

		Operation-	**Group**		
Peak torque/weight (%) or maximum strength (gram-force)	**Measure device**	**Group 1**	**Group 2**	**Confidence interval of the difference**	**P-value**

Open group (n=21) versus laparoscopic group (n=14)	Biodex®	92.0 % (51.5)	71.4% (34.8)	-11.5; 52.6	0.20
Open group fascia open (n=14) versus laparoscopic (n=14)	Biodex®	97.0%(59.3)	71.4% (34.8)	-12.1; 63.4	0.18
Open group fascia closed (n=7) versus laparoscopic (n=14)	Biodex®	81.9% (32.6)	71.4% (34.8)	-22.5; 43.6	0.51
Open group fascia closed (n=7) versus open group fascia open (n=14)	Biodex®	81.9% (32.6)	97.0% (59.3)	-65.8; 35.6	0.54
Open group (n=20) versus laparoscopic group (n=14)	Abdominal muscle trainer Rectus	560.5 (237.7)	423.9 (257.8)	-38.0; 311.3	0.12
Open group fascia open (n=14) versus laparoscopic (n=14)	Abdominal muscle trainer Rectus	576.7 (261.0)	423.9 (257.8)	-48.7; 354.4	0.13
Open group fascia closed (n=6) versus laparoscopic (n=14)	Abdominal muscle trainer Rectus	522.7 (187.5)	423.9 (257.8)	-147.6; 345.2	0.41
Open group fascia closed (n=6) versus open group fascia open (n=14)	Abdominal muscle trainer Rectus	522.7 (187.5)	576.7 (261.0)	-302.9; 194.8	0.65
Open group (n=19) versus laparoscopic group (n=13)	Abdominal muscle trainer	461.6 (208.7)	375.6 (162.3)	-54.8; 226.8	0.22

	Transverse				
Open group fascia open (n=13) versus laparoscopic (n=13)	Abdominal muscle trainer Transverse	444.9 (158.3)	375.6 (162.3)	-60.5; 199.0	0.28
Open group fascia closed (n=6) versus laparoscopic (n=13)	Abdominal muscle trainer Transverse	497.8 (307.3)	375.6 (162.3)	-102.0; 346.5	0.27
Open group fascia closed (n=6) versus open group fascia open (n=13)	Abdominal muscle trainer Transverse	497.8 (307.3)	444.9 (158.3)	-169.0; 275.0	0.62

After adjusting for gender, a trend could be observed with regard to the mean one-repetition maximum lift in favour of the open group (coefficient –136.6, [95% CI –284.9; 11.6], P =0.07, Table 4).

Abdominal muscle trainer

Analysis of the one repetition maximum strengths, measured with the abdominal muscle trainer for the rectus abdominis, showed no significant differences between the open and laparoscopic groups (561 versus 424, P=0.12, Table 2). Splitting up the open repair group in fascia closed or left open, showed comparable results between the two groups (523 versus 577, P=0.65). The same analyses were made for the one repetition maximum strengths measured with the abdominal muscle trainer for the oblique and transverse muscle. No significant differences were found between the open and laparoscopic groups or between the two different open techniques (Table 2).

Ultrasound measurement transversus abdominis (TrA)

Resting thickness of the transversus abdominis (TrA) was comparable between the open and laparoscopic techniques. The average thickness of the TrA was 4.4 mm for the open and 4.0 mm for the laparoscopic technique (P=0.40). Changes of the TrA muscle thickness after straining were significantly different between the open and laparoscopic technique, 3.3 mm and 1.7 mm, respectively (P=0.02), shown in Table 3. Comparing the open approximated fascia and the left open fascia groups with the laparoscopic patients, the TrA muscle thickness differences were significantly higher for both open groups (both P=0.05). The increase of the transversus abdominis muscle thickness was similar, whether the fascia was closed or left open in the open repair technique (3.3 mm versus 3.3 mm, P=0.98).

Table 3. Ultrasound measurements of the transversus abdominis muscle comparing the three operations for incisional hernia.

	Operation technique			
Changes of mean transversus muscle thickness (mm)	**Group 1**	**Group 2**	**Confidence interval of the difference**	**P-value**
Open (n=20) versus laparoscopic (n=10)	3.3 (1.8)	1.7 (1.4)	0.22; 2.9	0.02
Open fascia - open technique (n=13) versus laparoscopic (n=10)	3.3 (1.9)	1.7 (1.4)	0.04; 3.1	0.05
Closed fascia - open technique (n=7) versus laparoscopic (n=10)	3.3 (1.6)	1.7 (1.4)	-0.003; 3.1	0.05
Closed fascia - open technique (n=7) versus open fascia - open technique (n=13)	3.3 (1.6)	3.3 (1.9)	-1.8; 1.8	0.98

The Pearson’s correlations between the five different measurement techniques for abdominal muscle function are presented in Table 5. For the correlations, the Biodex® peak torque flexion was not corrected for body weight like in the other measurements.

Table 4. Regression coefficients of maximum strength with respect to gender measured by one repetition maximum measurement (rectus muscle).

Variable	Coefficient	95% CI	P-value	Standardised coefficient
Gender[1]	-263.2	-409.1; -117.3	0.001	-0.53
Laparoscopic versus open incisional hernia repair[2]	-136.6	-284.9; 11.6	0.07	-0.27

[1] Men is reference category.

[2] Open access is reference category.

Table 5. Pearson correlations (P-values) between five measurements of abdominal function.

	Biodex® (no correction for body weight)	1RM rectus	1RM oblique	Ultrasound in rest	Ultrasound during contraction
Biodex®	1.00				
1RM rectus	0.86 (<0.001)	1.00			
1RM oblique	0.54 (0.002)	0.65 (<0.001)	1.00		
Ultrasound in rest	0.22 (0.23)	0.40 (0.03)	0.54 (0.003)	1.00	
Ultrasound during contraction	0.24 (0.21)	0.40 (0.03)	0.35 (0.07)	0.58 (<0.01)	1.00

Discussion

In this study we compared the isokinetic muscle strength of the trunk flexor muscles measured with the Biodex® isokinetic dynamometer between patients who underwent open and laparoscopic correction for incisional hernia and a control group without any abdominal operation. The mean peak torque, as a measure of the isokinetic strength of trunk flexor

muscles, was significantly lower in the patients with incisional hernia corrections than in the healthy controls.
We also compared the abdominal wall function after the included three kinds of operative techniques for incisional hernia: the laparoscopic technique and the open technique with or without closure of the fascia. No difference was found between the different kinds of operations measured with the Biodex® dynamometer. A significantly higher maximum strength measured with the abdominal rectus muscle trainer was found in the open operations compared to the laparoscopic technique after adjusting for gender. All the open operations compared with the laparoscopic technique had higher thickness changes of the transversus abdominal muscle after contraction using ultrasound measurement.
Midline incisional hernias displace the rectus muscles laterally. This lateral extra-anatomical position might be the cause of weakened abdominal muscle strength. In a study comparing laparoscopic with open cholecystectomy, the open technique resulted in reduced muscle strength of trunk flexor muscles compared to controls and the laparoscopic approach [12]. The open cholecystectomy was performed subcostally with transection of the right rectus abdominis muscle. This is in contrast with the laparoscopic technique that is made through small incisions, leaving the rectus abdominis muscles intact. So a scarred rectus abdominis muscle lowers the muscle strength of trunk flexion measured with an isokinetic dynamometer. In contrast to the open repair with fascia closure for incisional hernia, in which the rectus muscles are medially positioned, in the laparoscopic mesh technique the rectus muscles remain in their lateral displaced position. In the open repair with the fascia left open, the abdominal muscle function is probably better than in the laparoscopic technique, because the fascia is put on tension in the open technique. In the laparoscopic technique, the hernia is enlarged by the pneumoperitoneum during the operation. After desufflation of the pneumoperitoneum, the risk of the mesh hanging floppy in the abdominal cavity is increased. The ultrasound measurements showed a significant increase of the transversus abdominis (TrA) muscle after contraction in the open techniques compared to the laparoscopic technique. Probably because of the better anatomical repair in the open technique, the TrA muscle does not become atrophic or even enlarges after the repair. In the open technique, the abdominal muscles remain on tension, which is necessary for a good muscle function.
The clinical relevance of a reduced isokinetic strength of the trunk flexors is not known, and correlations between strength, signs and symptoms were not studied. Significantly lower mean strength values have been found in patients with chronic back pain [15]. It will be interesting to study the relationship between the reduced muscle strength of trunk flexors in

patients with incisional hernia and the patients' symptoms before and after surgical repair. Overall, incisional hernia symptoms have not been systematically studied [20]. The reduced muscle strength of trunk flexors in patients after the laparoscopic technique for incisional hernia could cause a higher prevalence of back pain than in patients after open repair.

A good correlation was found between the Biodex® dynamometer and the one repetition measurement of the rectus muscles and also between the one repetition measurements of the rectus and oblique abdominal muscles. The measurements of the one repetition maximum tests and the ultrasounds at rest showed a moderate correlation. A moderate correlation was also shown with the measurements of the one repetition and the ultrasound at rest and during contraction. These correlations mean at least that these three techniques all measure abdominal function but at different levels. The Biodex® dynamometer measures the torque or moment of force, which is the tendency of a force to rotate an object about an axis. It is expressed in Newton meter (Nm), and it was corrected for body weight in our analysis. The one repetition maximum is a measure of maximal strength; representing the maximum amount of weight a person can lift in a single repetition. This lifted weight is expressed in kilograms or grams. The good correlation between the Biodex® and the one repetition rectus muscles indicates, that the Biodex® measures more rectus muscle function than oblique abdominal muscle function. The ultrasound examination yields a measure of the thickness of the transverse abdominal muscle before and after contraction and is expressed in millimetres. It has a low correlation with the Biodex®, because the ultrasound measured the transverse muscle, and the Biodex® mainly measures the rectus muscle function.

The statistical power for finding a significant difference between the three operative techniques was low and was caused by the small sample sizes of the groups. The small sample size of our study is a limitation for making strong conclusions. Measuring the same patients before and after the repair of their incisional hernia would increase the power of the study. Another limitation of our study is the use of healthy controls. A better and more interesting study group for comparison would be a patient group with a well-healed scar after a median laparotomy or patients with a large primary incisional hernia.

Moreover, it will be necessary to replicate the significant difference in abdominal muscle function between the laparoscopic group and the different open techniques with larger sample sizes. It is important and interesting to establish whether the difference in abdominal muscle function also exists in other open procedures, in which the fascia is closed and the rectus muscles are more or less approximated; this question should also be studied with larger sample sizes than those used in this study.

References

1. van 't Riet M, Steyerberg EW, Nellensteyn J, Bonjer HJ, and Jeekel J (2002) Meta-analysis of techniques for closure of midline abdominal incisions. Br J Surg 89:1350-1356
2. Wissing J, van Vroonhoven TJ, Schattenkerk ME, Veen HF, Ponsen RJ, and Jeekel J (1987) Fascia closure after midline laparotomy: results of a randomized trial. Br J Surg 74:738-741
3. den Hartog D, Dur AH, Kamphuis AG, Tuinebreijer WE, and Kreis RW (2009) Comparison of ultrasonography with computed tomography in the diagnosis of incisional hernias. Hernia 13:45-48
4. den Hartog D, Dur AH, Tuinebreijer WE, and Kreis RW (2008) Open surgical procedures for incisional hernias. Cochrane Database Syst Rev (3):CD006438
5. Anthony T, Bergen PC, Kim LT, Henderson M, Fahey T, Rege RV, and Turnage RH (2000) Factors affecting recurrence following incisional herniorrhaphy. World J Surg 24:95-100
6. Manninen MJ, Lavonius M, and Perhoniemi VJ (1991) Results of incisional hernia repair. A retrospective study of 172 unselected hernioplasties. Eur J Surg 157:29-31
7. Paul A, Korenkov M, Peters S, Kohler L, Fischer S, and Troidl H (1998) Unacceptable results of the Mayo procedure for repair of abdominal incisional hernias. Eur J Surg 164:361-367
8. Read RC and Yoder G (1989) Recent trends in the management of incisional herniation. Arch Surg 124:485-488
9. Frijters D (2002) Integrated health information system based on resident assessment instruments. Prismant, Utrecht, The Netherlands: National Medical Registration
10. Hoer J, Lawong G, Klinge U, and Schumpelick V (2002) [Factors influencing the development of incisional hernia. A retrospective study of 2,983 laparotomy patients over a period of 10 years]. Chirurg 73:474-480
11. Zauner-Dungl A, Resch KL, Herczeg E, and Piza-Katzer H (1995) Quantification of functional deficits associated with rectus abdominis muscle flaps. Plast Reconstr Surg 96:1623-1628
12. Balogh B, Zauner-Dung A, Nicolakis P, Armbruster C, Kriwanek S, and Piza-Katzer H (2002) Functional impairment of the abdominal wall following laparoscopic and open cholecystectomy. Surg Endosc 16:481-486

13. Kannus P (1994) Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. Int J Sports Med 15 Suppl 1:S11-S18
14. Newton M and Waddell G (1993) Trunk strength testing with iso-machines. Part 1: Review of a decade of scientific evidence. Spine 18:801-811
15. Newton M, Thow M, Somerville D, Henderson I, and Waddell G (1993) Trunk strength testing with iso-machines. Part 2: Experimental evaluation of the Cybex II Back Testing System in normal subjects and patients with chronic low back pain. Spine 18:812-824
16. Brzycki M (1993) Strength testing - predicting a one-rep max from reps-to-fatigue. The Journal of Physical Education, Recreation and Dance 64:88-90
17. Bunce SM, Moore AP, and Hough AD (2002) M-mode ultrasound: a reliable measure of transversus abdominis thickness? Clin Biomech 17:315-317
18. Kiesel KB, Underwood FB, Mattacola CG, Nitz AJ, and Malone TR (2007) A comparison of select trunk muscle thickness change between subjects with low back pain classified in the treatment-based classification system and asymptomatic controls. J Orthop Sports Phys Ther 37:596-607
19. Springer BA, Mielcarek BJ, Nesfield TK, and Teyhen DS (2006) Relationships among lateral abdominal muscles, gender, body mass index, and hand dominance. J Orthop Sports Phys Ther 36:289-297
20. Nieuwenhuizen J, Halm JA, Jeekel J, and Lange JF (2007) Natural course of incisional hernia and indications for repair. Scand J Surg 96:293-296