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Research article

The effect of core exercises on transdiaphragmatic pressure

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Abstract
Abdominal exercises, such as sit ups and leg lifts, are used to enhance strength of the core muscles. An overlooked aspect of abdominal exercises is the compression the abdomen, leading to increased diaphragmatic work. We hypothesized that core exercises would produce a variety of transdiaphragmatic pressures. We also sought to determine if some of the easy exercises would produce pressures sufficient for a training stimulus to the diaphragm. We evaluated the effect of 13 different abdominal exercises, ranging in difficulty, on transdiaphragmatic pressure (Pdi), an index of diaphragmatic activity. Six healthy subjects, aged 22 to 53, participated. Each subject was instrumented with two balloon-tipped catheters to obtain gastric and esophageal pressures, from which Pdi was calculated. Prior to initiating the exercises, each subject performed a maximal inspiratory pressure (MIP) maneuver. Resting Pdi was also measured. The exercises were performed from least to most difficult, with five repetitions each. There was a significant difference between the exercises and the MIP Pdi, as well as between the exercises and resting Pdi ($p < 0.001$). The exercises stratified into three Pdi levels. Seven of the exercises yielded Pdi ≥50% of the Pdi during the MIP maneuver, which may provide a training stimulus to the diaphragm if used as a regular exercise. The Pdi measurements also provide insight into diaphragm recruitment during different core exercises, and may aid in the design of exercises to improve diaphragm strength and endurance.

Key words: Abdominal exercise, diaphragm activation, gastric pressure, esophageal pressure.

Introduction

The diaphragm is the primary muscle of inspiration. As such, it is a chronically active muscle with as much as 65% Type I muscle fibers (Keens, et al., 1978). Its anatomical position, separating the thorax from the abdomen means that it is exposed to pressures exerted by muscles surrounding both body cavities.

During movements involving the core (thoracic and abdominal) musculature, diaphragm activity is increased both to overcome pressures opposing inspiration and for postural support (Hodges et al., 1997). Al-Bilbeisi and McCool (2000) reported increased diaphragm activation, evidenced by increased transdiaphragmatic pressure (Pdi), during several weight lifting activities that ranged from 20% of maximal Pdi (Pdi_{max}) for bench press to over 40% of Pdi_{max} for power lifts. They also measured increased Pdi during sit-ups and found values of over 40% of Pdi_{max}. In addition to abdominal exercises, other non-respiratory movements such as repetitive arm movements increase diaphragmatic activity (Hodges and Gandevia, 1999).

The fact that the diaphragm is activated during core exercises indicates a potential for these exercises to be used for diaphragmatic training. While only one study has addressed this possibility (De Palo et al., 2004), there is a large body of research on inspiratory muscle training through respiratory maneuvers (e.g. Clanton, et al., 1985; Hart et al., 2001; Pardy et al., 1988; Rohrbach et al., 2003; Wylegala et al., 2006). One traditional method of inspiratory muscle training is loaded inspiration, which improves inspiratory muscle strength (Clanton et al., 1985) and endurance (Wylegala et al., 2006) when the inspiratory resistance was sufficient.

While respiratory maneuvers may elicit training responses, they may not be comfortable or practical for some groups. Core exercises may represent a viable addition to a standard rehabilitation program. Such exercises, while increasing transdiaphragmatic pressure do not involve respiratory activity as the primary goal of the exercise. Given the relative lack of research relating core exercises to Pdi, and the possibility that this type of exercise may be useful for training the inspiratory muscles, we evaluated Pdi during thirteen core exercises. We hypothesized that core exercises would yield a variety of Pdi, some of which may be sufficient to elicit an inspiratory muscle training stimulus.

Methods

Six healthy subjects (3 male, 3 female; 22 - 53 years) were studied. All had performed the exercises previously. The experiment was approved by the Institutional Review Board at our institution and each volunteer gave informed consent. All exercises were supervised by a certified personal trainer. Subjects' characteristics are shown in Table 1.

Table 1. Demographics of the subjects used for the study.

Subject #	Sex	Age	Height (m)	Weight (kg)
1	M	53	1.91	93.2
2	M	22	1.83	81.8
3	M	26	1.79	65.0
4	F	27	1.65	68.2
5	F	24	1.60	52.3
6	F	28	1.68	61.4

Procedures

Data collection took place over two days. On day one subjects practiced the exercises and the MIP maneuvers. Data was collected on day two, which was separated by 24-48 hours from the practice session. Two esophageal

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balloon catheters (Cooper Surgical Company, Trumbul, CT) were inserted through the nose into the stomach and the esophagus by the investigators, who had performed this technique for more than one year. Proper catheter placement was confirmed by pressure swings during normal breathing. The subject then performed three maximal inspiratory pressure (MIP) maneuvers and three maximal sniff efforts, and proceeded with the exercises. The exercises were chosen based on the authors' experience and the level of difficulty was ranked by the investigative team. The assessment of difficulty by the investigators was done to allow subjects to perform the easiest exercises first to avoid fatigue during easy exercises resulting from the more difficult ones. Five repetitions of each exercise were performed except as described, with a 30-60 second break between exercises. All of the exercises were performed in time with a metronome set for 60 beats per minute. The subjects were instructed to inhale during the exertion phase in order to elicit a higher and more consistent Pdi (Al-Bilbeisi and McCool, 2000; De Palo et al., 2004).

Exercises

The exercises are described below in the order they were performed.

Sit and reach- The subject sat with legs extended and feet against a box, then leaned as far forward as possible while inhaling.

Single leg lift (SLL)- SLL was performed with the subject lying supine with arms at the sides. The subject then lifted the right leg perpendicular to the floor, held it for 2 sec and then brought the leg down to approximately six inches from the floor. This was performed five times with each leg.

Twist - The subject stood with feet shoulder width apart and held a broom stick across the shoulders. The subject rotated to the right for 2 sec, inhaling during the twist, and returned to the forward position then twisted to the left for 2 sec. The twist was performed to the point where the shoulders were perpendicular to a line formed by the feet or to the point of discomfort. This was performed for a total of ten repetitions, five each to the right and left.

Pelvic Tuck - This exercise was performed with the subject lying supine with the legs extended. The subject rocked the hips backward by contracting the abdomen to flatten the lower back against the floor. The subject inhaled while tucking the hips.

45^o Lean Back - The subject sat on a 36 cm box, with feet flat on the floor, then leaned back until the angle between the torso and seat of the box reached ~ 45^o. Then the subject returned to the starting position.

Pull in with ball assistance - While lying supine with arms behind the head, and feet resting on a 65 cm exercise ball, the subject brought the elbows toward the knees pulling the upper body off the floor and rolling the ball to bring the knees toward the elbows.

Bent knee leg lift (BLL) - BLL began with the subject lying supine on the floor; knees bent 90º and arms by the sides. The subject then lifted both feet off the floor until the thighs were perpendicular to the floor.

Crunch - This exercise had the subject lying supine with knees bent, feet flat on the floor and arms extended at the side. The subject lifted the shoulders off the ground while sliding the hands forward six inches along the floor.

Ankle Reaches - While lying supine in the initial position used for the crunch exercise, the subject lifted the shoulders off the floor and reached with the right hand towards the right ankle, then reached with the left hand towards the left ankle. This exercise was performed for a total of ten repetitions, five to each side.

Seated knee lifts - The subject was seated in a chair with feet flat on the floor and hands on the sides of the chair. The subject lifted the feet off the floor bringing the knees as far up to the chest as possible while inhaling.

Pull-ins - This was a modification of the pull-in with ball assistance, but without the ball. The subject started with legs straight out on the floor and hands behind the head, then pulled the elbows toward the knees by raising the legs (knees bent) and the shoulders off the ground. They then brought the shoulders back to the floor and legs down.

Sit-ups - In this exercise the subject started by lying supine on the floor with knees bent and arms folded across the chest. The subject raised the upper torso off the ground until the elbows touched the knees, while inhaling.

Double leg lifts (DLL) - Similar to the SLL, the subject lay supine with the legs straight and arms by the side of the body. While lifting both legs to about 90 degrees the subject inhaled. The subject then lowered the legs to approximately 15 cm (6 inches) off the floor.

The sit and reach, SLL, standing twist and pelvic tuck were grouped as the easy exercises. The 45^o lean back, pull in with ball assistance, BLL, crunches, ankle reaches and seated knee ups were all considered to be of moderate difficulty. The pull-ins, sit-ups and DLL were grouped as the difficult exercises.

Measurements and data analysis

MIP was measured by the technique of Black and Hyatt (1969) using a pressure monitor (S&M Instruments, Doylestown, PA) with a 1.00 mm hole in the end to prevent glottic closure. During the sniff procedure, subjects were asked to sniff maximally through the nose for one second while keeping the mouth closed. Esophageal and gastric pressures were measured via pressure transducers (MPX2050 DP, Motorola, Phoenix, AZ) calibrated prior to each trial with a mercury manometer. The signals from the pressure transducers were amplified (Grass 7P122 DC, Astromed-Grass, Quincy, MA), and A-D transformed (Biopac Systems MP 300, Santa Barbara, CA). Pdi was obtained as the difference between esophageal and gastric pressure for each effort.

Statistical analyses

The peak Pdi from each repetition of each exercise was obtained and the average of the peak Pdi for each exercise was used for analysis. One-way repeated measures analysis of variance was conducted to compare the Pdi across the exercises, MIP, sniff and rest. When a significant effect was found, Newman-Keuls post hoc test was used to test for differences between exercises.

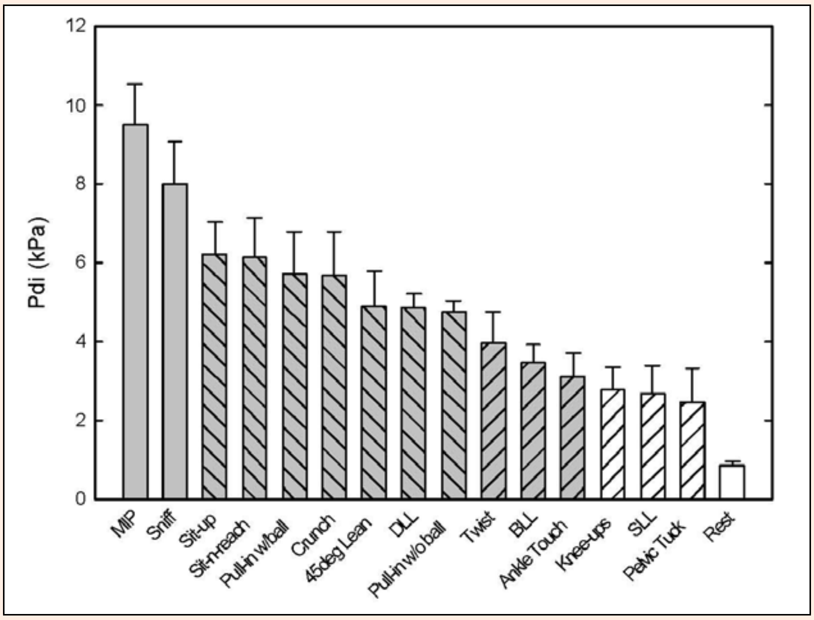

Figure 1. The Pdi of each of the 16 performed maneuvers, ranging from maximal pressures on the left to resting pressures on the right. Columns with similar in-fill were not significantly different from each other, the different in-filled columns indicate significantly different groups, ($p < 0.05$). Note: 1 kPa = 7.5 mmHg or 10.2 cm H_2O. BLL = bent-knee leg lifts, DLL = double leg lift, SLL = single leg lift.

Results

The subjects completed all exercises without difficulty. The overall main effect on Pdi was significant ($p < 0.001$). The post hoc test showed there was a significant difference between each of the exercises and the Pdi measured during the MIP or sniff, as well as between each of the exercises and resting Pdi ($p < 0.05$, Figure 1). The mean Pdi during MIP and sniff were not significantly different. Among the exercises, there were three categories of pressures. Seven of the exercises were not significantly different from one another. Those exercises were: The mean Pdi during MIP and sniff were not significantly different. Among the exercises, there were three categories of pressures. Seven of the exercises were not significantly different from one another. Those exercises were: sit-up, sit and reach, pull in with the ball, crunch, 45^o lean back, DLL, and pull in without the ball. The twist, BLL and ankle touch elicited significantly lower pressures than the above exercises ($p < 0.05$), but were not significantly different from one another. The pelvic tuck, seated knee ups and SLL were significantly lower than all other exercises ($p < 0.05$) but not different from each other. Figure 2 illustrates the pressures within each of the groups according to pre-established difficulty - easy, moderate and difficult. There was at least one exercise from each of the difficulty categories in the group of exercises that elicited the highest mean Pdi (Figure 2).

Discussion

The primary finding of this study was that core exercises elicited elevated Pdi compared to rest, some of which could be sufficient to provide a training stimulus for the respiratory muscles. Pdi provides an estimation of diaphragmatic activity elicited by a variety of abdominal exercises. Seven exercises yielded Pdi between 50 and 65% of the MIP Pdi (Figure 1). We also found that some exercises were easy to perform and could lead to a high Pdi - exercises such as the sit and reach and the twist produced pressures over 45% of MIP. There were also moderate intensity exercises that produced pressures well over 50% of the Pdi seen in the MIP maneuver. These exercises, in addition to providing relatively high Pdi, should be considered easy enough for less than healthy populations to perform.

To our knowledge this is the first investigation of Pdi produced during a range of non-respiratory activities. The work that has been done on non-respiratory maneuvers to strengthen the diaphragm demonstrated that it can be activated, and even trained, through non-respiratory activities, however that work used intense non-respiratory activities to strengthen the diaphragm. Depalo et al. (2004) performed a training study using sit-ups and bicep curls to strengthen the inspiratory musculature. Additionally, they demonstrated that during a sit-up Pdi increased to about 65% of max, a value that is comparable to our study's highest Pdi values of 50-65% of max, produced from seven of the exercises.

Several groups have also used non-respiratory activities to activate the diaphragm. Hodges and Gandevia (1999) examined the EMG activity of the diaphragm and found that continuous rapid movement of the upper limbs activated the diaphragm in a manner unrelated to respiration. Increases in intensity of arm movements increased diaphragm EMG. In a further study (Hodges and Gandevia, 2000) they found that EMG activity and intra-abdominal pressures were higher with inspiration during limb movement.

Creswell et al. (1992; 1994) measured intra-abdominal pressures during isometric trunk contractions, twists, Valsalva maneuvers and various lifting tasks.

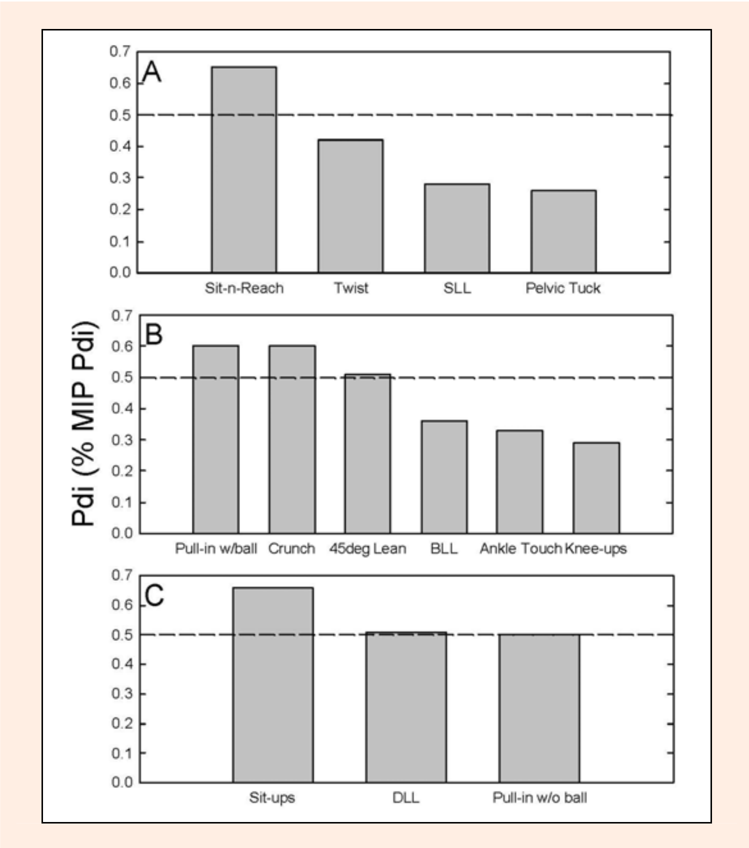

Figure 2 . Exercise groups divided by difficulty as assessed by the investigators, A) easy, B) moderate and C) difficult. The figure illustrates the percent of Pdi compared to the Pdi measured during the MIP maneuver for each of the exercises. The dashed lines represent a Pdi of 50% of that achieved during the MIP maneuver.

They also measured electromyographic activity and found that activation of the diaphragm and transverse abdominus were the main contributors to increases in intra-abdominal pressures in a trunk rotation task. They then set up a training program of trunk rotation against resistance and found a nearly 30% increase in trunk rotation strength and 11% increase in trunk extension strength, as well as strengthening of the transverse and oblique muscles in ten weeks.

There was a range in difficulty of the exercises performed. Core exercises need not be physically demanding to increase Pdi, stressing the diaphragm. For example, the sit and reach exercise was rated physically easy but produced a Pdi that was 65% of that measured during the MIP. The relatively easy exercises that produce high Pdi could be applied to clinical populations in addition to standard rehabilitation activities to aid in improving respiratory strength while not stressing the metabolic capacities of the subjects.

Conclusion

The evidence from this study supports our hypothesis that core exercises yield a variety of Pdi, some of which achieve pressures suitable for a training stimulus to the inspiratory muscles. The range of exercises provides diversity for populations of various physical abilities. The arrays of exercises tested include maneuvers that weaker individuals can perform. Future research is needed to evaluate the efficacy of training using one or more core exercises to strengthen the diaphragm and improve respiratory function and quality of life. It may be important to note that exercises performed with a closed glottis will lead to increased thoracic pressures, and potential complications of increased blood pressure. Therefore, it is recommended that subjects breathe while performing these or other resistance exercises.

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References

Al-Bilbeisi, F. and McCool, D. (2000) Diaphragm recruitment during nonrespiratory activities. *American Journal of Respiratory and Critical Care Medicine* **162,** 465-459.

Black, L.F. and Hyatt, R.E. (1969) Maximal respiratory pressures: Normal values and Relationship to age and sex. *American Review of Respiratory Disease* **99,** 696-702.

Clanton, T.L., Dixon, G., Drake, J. and Gadek, J.E. (1985) Inspiratory muscle conditioning using a threshold loading device. *Chest* **87,** 62-66.

Cresswell, A.G., Grundstrom, H. and Thorstensson, A. (1992) Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. *Acta Physiologica Scandinavica.* **144,** 409-418.

Cresswell, A.G., Blake, P.L. and Thorstensson, A. (1994) The effect of an abdominal muscle training program on intra-abdominal pressure. *Scandinavian Journal of Rehabilitative Medicine* **26,** 79-86.

DePalo, V.A., Parker, A.L., Al-Bilbeisi, F. and McCool, D. (2004) Respiratory muscle strength training with nonrespiratory maneuvers. *Journal of Applied Physiology* **96,** 731-734.

Hart, N., Sylvester, K., Ward, S., Cramer, D., Moxham, J. and Polkey, M.I. (2001) Evaluation of an inspiratory muscle trainer in

healthy humans. *Respiratory Medicine* **95,** 526-531.
Hodges, P.W., Butler, J.E., McKenzie, D.K. and Gandevia, S.C. (1997) Contraction of the human diaphragm during rapid postural adjustments. *Journal of Physiology* **505,** 539-548.
Hodges, P.W. and Gandevia, S.C. (1999) Activation of the human diaphragm during a repetitive postural task. *Journal of Physiology.* **522,** 165-175.
Hodges, P.W. and Gandevia, S.C. (2000) Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology* **89,** 967-976.
Keens, T.G., Bryan, A.C., Levison, H. and Ianuzzo, C.D. (1978) Developmental pattern of muscle fiber types in human ventilator muscles. *Journal of Applied Physiology* **44,** 909-913.
Pardy, R.L., Reid, D.W. and Belman, M.J. (1988) Respiratory muscle training. *Clinics in Chest Medicine* **9,** 287-296.
Rohrbach, M., Perret, C., Kayser, B., Boutellier, U. and Spengler, C.M. (2003) Task failure from inspiratory resistive loaded breathing: a role for inspiratory muscle fatigue. *European Journal of Applied Physiology* **90,** 405-410.
Wylegala, J.A., Pendergast, D.R., Gosselin, L.E., Warkander, D.E. and Lundgren, C.E.G. (2006) Respiratory muscle training improves swimming endurance in divers. *European Journal of Applied Physiology* **99,** 393-404.

Key points

- Please provide 3-5 bullet points of the study.The study examined the effect of different core exercises of varying difficulty on activation of the diaphragm.
- We found that the exercises yielded different pressures, some of which were greater than 50% of the pressures generated during a maximal inspiratory maneuver.
- The difficulty of the exercise was not always correlated with the magnitude of the pressure.
- Some of these exercises should be easy enough for subjects in rehabilitation programs to perform and still generate high enough pressures to help strengthen the diaphragm.

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