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The effects of walking speeds and carrying techniques on intra-abdominal pressure in women

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Abstract

Aims—To test the feasibility of monitoring intra-abdominal pressure (IAP) outside the laboratory environment and to compare IAP while 1) carrying 13.6 kg (similar to a 3-month old in car seat) in 6 different ways while walking 100 meters; and 2) walking 400 meters at self-selected slow, normal, and fast pace.

Methods—Forty-six healthy women between 19 and 54 years completed the walking and lifting activities; the order for each was randomized. IAP was monitored with an intra-vaginal pressure transducer that wirelessly transmitted pressure data to a portable base station. We analyzed maximal peak IAP and area under the curve (AUC) IAP.

Results—Monitoring IAP outside of the laboratory was feasible. Mean maximal IAP during walking increased as pace increased; 42.5 (SD 10.2), 50.5 (10.9), and 62.0 (12.1) cm H₂O for slow, medium, and fast speeds, respectively ($p < 0.0001$ by mixed model ANOVA). The corresponding AUC of IAP for walking decreased as pace increased. The ‘awkward carry’, ‘side carry’, and ‘front carry’ activities each resulted in higher mean maximal IAP (65.8 (10.6), 67.7 (12.8), 77.3 (13.1) cm H₂O, respectively) than the ‘carry in backpack’ activity (55.5 (11.4) cm H₂O; $p < 0.0001$).

Conclusion—Subtle variations in walking speed or method of carrying a toddler-size load can produce significant changes in IAP. Whether these increase the risk of pelvic floor disorders is not yet clear. However, these data suggest further inquiry into optimal methods and appliances to assist women in carrying may enable achieving a lower IAP profile.

Keywords

Intra-abdominal pressure; pelvic floor; lifting; carry; walking

Introduction

Pelvic floor disorders, including pelvic organ prolapse, urinary incontinence and fecal incontinence affect one in four women in the U.S [1]. Child birth, increasing age, and being of Caucasian race increase the risk of developing these conditions [1–4]. It is less clear how intra-abdominal pressure (IAP) during daily activities predisposes women to new or recurrent pelvic floor disorders. Despite this, many sources of information including the American Urogynecologic Society patient website recommend that women avoid heavy lifting, learn to use leg and arm muscles to lift, and avoid repetitive strenuous exercise to prevent pelvic organ prolapse and urinary incontinence [5]. These recommendations are based on the principle that repetitive straining and lifting cause detrimental changes to muscles, ligaments, and connective tissues that lead to pelvic floor disorders.

Studying the relationship between IAP and pelvic floor disorders has been limited by an inability to measure IAP non-invasively outside of a laboratory. For example, self-regulated,

ambulatory activities cannot be monitored in a urogynecology laboratory setting. Additionally, the standard fluid-filled rectal balloon catheter used in such urodynamics studies is not conducive to real-world settings due to their poor dynamic response and encumbered mobility [6, 7].

To overcome the limitations of currently available technology, our group developed a wireless intra-vaginal transducer (WIVT) which approximates IAP by measuring pressure in the upper vagina [6]. Data from the WIVT was found to correlate well with the simultaneous measurement of a rectal balloon catheter for coughing and Valsalva maneuvers in a clinical laboratory setting [8]. Using the WIVT, we recently monitored IAP in 57 women during standardized exercise sessions to describe maximal IAP, area under the curve, and first moment of the area of IAP during 31 activities performed in an exercise science laboratory [9]. Although this study provided the basis for wirelessly monitoring IAP, the base station transceiver required a laptop limiting the range of activity to within a 5 meter radius. Additionally, each activity was monitored for 30 seconds which inadequately represents normal movement outside a laboratory setting. Following this proof-of-concept study, we optimized the transducer and receiver to allow for greater portability.

The current study monitors IAP in women during real life activities outside of a laboratory environment. In addition to demonstrating the feasibility of using the WIVT for this purpose, we also specifically aimed to 1) compare IAP while women carried 13.6 kg (similar to a 3-month old in a car seat) in 6 different ways while walking 100 meters; and 2) determine whether IAP is associated with walking speed while walking 400 meters.

Materials and Methods

This study was approved by the University of Utah Institutional Review Board. All participants completed written informed consent. Participants were recruited by means of flyers on university bulletin boards. The protocol for this study was conducted in three locations: an outdoor track, an indoor track within an exercise facility, and a large indoor gymnasium. A standard walking distance of 400 m was used to examine differences in IAP associated with three self-selected walking speeds. The six lift-and-carry tasks required women to lift 13.6 kg and then carry the weight for 100 m in specific ways. Activity distances were confirmed by measuring wheel.

Each woman completed a session lasting about forty-five minutes including recovery breaks in between trials. Prior to exercise, each woman was asked to lie supine on a mat for 30 seconds and to stand quietly for 30 seconds to determine lying and standing baseline IAP. The order of lifting and walking conditions was randomly generated by a computer program prior to testing. After finishing baseline measurements, participants walked 400 meters slowly, normally, or fast based upon randomized order. A standard script was used to help the participant visualize and determine their walking rate. Prompts included: to walk slowly as though walking with a toddler or with an old dog, to walk at a medium speed that they considered normal, or to walk as fast as possible, without running, as though trying to catch a bus.

Maximal IAP and area under the curve (AUC) IAP were the dependent variables for the lift-and-carry trials; the manner in which the 13.6 kg was carried served as the independent variable. As women lift and carry items in different ways, six methods were used to assess this aim. We chose 13.6 kg (30 pounds) because 1) many clinicians restrict women with pelvic floor disorders from lifting more than this weight and 2) this approximates the weight of a 3-month old in a car seat (an internet search revealed that the best-selling portable car seats generally weighed 15 pounds, or 6.8 kg). Carrying the weight in the backpack was chosen a priori as the basis of comparison to other carrying methods (Figure 1). Because lifting up the load is a short activity, while carrying the load is a sustained activity, we chose comparing IAP during carrying as our primary comparison. With a backpack loaded to 13.6 kg, women were instructed to lift the pack from the floor, secure on the back using both straps, walk at self-selected pace for 100 meters, and then remove and set down the backpack. Other methods included double arm hang, in which 6.8 kg was placed into each of two reusable grocery bags; front carry, requiring women to hold 13.6 kg in a pack with both arms at the level of the waist; combination carry, with 6.8 kg held at the level of the iliac crest on the dominant hand side and 6.8 kg held in a grocery bag on the non-dominant side; side carry, with 13.6 kg held by the dominant hand, just above the iliac crest; and awkward carry, with 9.5 kg added to a car seat weighing 4.1 kg designed for an infant so that the total weight was 13.6 kg. For the awkward carry condition, women were instructed to carry the car seat in the manner which they would normally carry a car seat, but to avoid carrying the car seat in a way that would mimic front carry. All weights for these trials were confirmed by calibrated digital laboratory scale. Women walked 100 m using each of these specified methods in randomized order, but were allowed to change hands or sides (side carry, awkward carry) as necessary.

Walking and lift-and-carry exercises were timed and heart rate (HR, bpm) was recorded immediately after exercise. Between activities a rest period was observed to allow HR to drop to within 30 bpm of the resting HR in the supine lying position.

Healthy women between 18 and 54 years with a BMI of >19 and <30 kg/m² were recruited for the study. Potential participants were excluded if they responded positively to any question on the Physical Activity Readiness Questionnaire [10], indicating a potential health risk associated with vigorous exercise, were currently pregnant, within six months post-partum, had an injury in the previous 3 months that would prohibit completing the exercise protocol, or self-reported the sensation of a vaginal bulge.

Study procedures were conducted when women were not menstruating. Participants were first verbally instructed on how to properly insert the WIVT and where to place the chest strap for the heart rate monitor. After voiding, women inserted the sterilized WIVT into the upper vagina, secured the external antenna with tape to their abdomen, and affixed the chest strap for heart rate transmission. To stabilize pressure readings due to temperature changes, we then waited for 10 minutes while the WIVT equilibrated to body temperature after initial insertion. During this time, participants completed a demographic questionnaire and the self-administered short version of the International Physical Activity Questionnaire [11]. Upon completion of the questionnaires, participants were led to either the outdoor track (if no

precipitation and air temperature was between 15.6°C and 26.7°C), or indoor track or gymnasium.

The wireless remote abdominal pressure system consists of a WIVT and a portable base station. The WIVT is an assembly that includes a pressure transducer, signal conditioner, and wireless components encapsulated in an elastomeric capsule filled with silicone gel [6]. The base station is a custom designed portable electronics transceiver, worn by the participant, which wirelessly receives IAP data from the WIVT and stores the data on a microSD card. Data collection commences at 31Hz when the user activates an interface button located on the front of the base station. The interface button serves as an event marker that writes the event into the electronic record. Successful communication and data transmission are indicated by a green LED on the base station which flashes synchronously with the data transmission. If wireless communication is not successful the base station will flash a red LED every three seconds or until wireless transmission is reestablished. The study coordinator directed the participant to start the activity after observing the green indicator LED on the base station. Upon completion of the activity the study coordinator instructed the participant to stop the activity, and to press the base station event button after witnessing a green LED. Due to the indicator light delay, 1.5 seconds was trimmed from the beginning and end of the data to accurately bracket the performed activity.

A custom Matlab software (R2011a, MathWorks) program was used to analyze the raw data. Data for each walking activity were divided into 30-second segments. In each segment, the 10 highest peaks were identified. The IAP was measured from baseline (atmospheric pressure) and thus represents a total, not net, pressure. The maximal IAP for walking activities was determined by calculating the average of the 10 highest peaks obtained in each 30 second interval. Remainder data shorter than 30 seconds in length was excluded from analysis. As an example, an activity lasting 2 minutes 5 seconds consists of four 30-second intervals each containing 10 peaks with a remainder of 5 seconds. Mean maximal IAP in this scenario would be calculated by averaging all 40 peaks. The remainder interval, being 5 seconds in this scenario, would be discarded. Lifting activities were separated into three segments: 1) pickup-first 10 seconds, 2) carry, and 3) set down-last 10 seconds to adequately describe the change in pressure (Figure 2). For each pickup and set down, one single maximum IAP was recorded and the population mean calculated by averaging these single maximum peaks. Mean maximal IAP for the carry segment was calculated by averaging ten maximal peaks separated by at least one second apart. Area under the curve (AUC) was determined by trapezoidal approximation for the carry portion of the activity only.

Data collected by the base station during the protocol was assessed for completeness. An activity was considered complete if at least 80% of the pressure data were captured during the total activity time, monitored by stopwatch.

Sample size was based on comparing each of five carrying activities to carrying 13.6 kg in a backpack. We approximated the power of a mixed model analysis of variance, with multiple comparisons of 5 lifting activities versus this reference activity, using formulae for Sidak corrected t-tests at the 1% significance level, adjusted for intra-woman clustering assuming an ICC = 0.45. Based on our preliminary data in which the net (that is, the difference

between maximal and minimal IAP during a specific activity [12]) mean maximal IAP for lift-and-carry was (35.2 cm H₂O, SD 9.3), this calculation indicated that a sample size of 46 women would provide approximately 80% power to detect a difference of 20 cm H₂O (ie, net mean IAP of 30 vs 50 cm H₂O or total mean IAP of 50 vs 70 cm H₂O) in the comparison of one lifting activity versus the control. Therefore we planned to enroll up to 60 women to obtain a final complete dataset for 46. Additionally, this sample size provides 80% power at the 5% significance level to detect an increase in R-squared of 0.14 or more due to walking speed, in a regression adjusted for other covariates.

We compared mean maximal IAP between carrying 13.6 kg 100 m in a backpack and the other carrying activities (Figure 1) by random coefficients mixed model analysis of variance (ANOVA) adjusted for age and BMI. The effect of walking speed on mean max IAP was tested in a mixed model ANOVA of time intervals 1–6, adjusted for age and BMI. This allowed us to compare each woman's IAP during slow, normal, and fast walking regardless of the time it took to complete the activity. After observing an artifact of a decreasing average IAP, as faster women stopped the activity and only slower women remained, we limited the comparison of IAP by self-selected walking pace to time intervals including at least 80% of women, i.e., data through the 6th time interval. A spline function was used to rule out a non-constant trend in IAP over time and thus to determine IAP consistency during walking activities. This spline model for walking required a random intercept and a random slope to model the time trends. When necessary, we modeled time trends using linear splines with one knot, which were the best-fit splines [13]. All statistics were calculated using SAS software (SAS Institute Inc. v9.3).

Results

Out of 49 women enrolled, 46 women completed the exercise session. Their mean age was 33.7 years (range 19–54), mean body mass index of 22.8 (SD 2.5) kg/m² and 78% were nulliparous.

We found that, in this population, IAP could be monitored in an observational setting outside of a laboratory environment Using the portable base station and WIVT.

The mean IAP during supine and standing position was 11.7 (SD 6.5) cm H₂O and 31.9 (SD 9.6) cm H₂O respectively.

Mean maximal IAP during walking, displayed in Table 1, was progressively higher as self-selected pace increased from slow to fast ($p < 0.0001$ by mixed model ANOVA). The corresponding AUC of IAP decreased. Table 1 and Figure 3 show distinctive objective speeds during each walking activity, increasing linearly as self-selected pace increased. Mean maximal IAP was relatively steady during walking activities, after the random subject effects were adjusted, within the 6th time interval which included at least 80% of participants. As speed increased, the time to complete the activity shortened from an average of 465 seconds during slow walking, and 278 seconds during normal walking, to 206 seconds for fast walking. This decrease in time resulted in lower AUC measurements with

faster walking speeds; an inverse relationship. If AUC measurements were normalized to time (that is, reflecting mean IAP), an increase in AUC with walking speed would result.

The average slope of the time trend was not statistically significant once the random coefficients were taken into account. This means that IAP varied between subjects but tended to stay constant, on average, over time. There was no significant time trend for normal walking. Slow walking required a linear spline with one knot to model the time trend, but a plot indicated that the pattern it was modeling was on average less than 2 cm H₂O different from the model with no time effect. In general, IAP remained flat during these self-paced walking activities with no trend upward or downward in mean max IAP as the activity progressed.

Table 2 reports the carry comparisons of the lift-and-carry activities. The ‘double arm hang’ and ‘combination carry’ activities did not differ significantly from the ‘carry in backpack’ activity. However, ‘awkward carry’, ‘side carry’, and ‘front carry’ activities resulted in mean maximal IAP increasing from 65.8 to 77.3 cm H₂O on average (SD 10.6 to 13.1 cm H₂O), which were each significantly higher than in the control activity ($p < 0.0001$ by mixed model ANOVA).

The maximal 1-peak average and ranges of the pickup and set down segments of lift-and-carry activities are shown in Table 3. As we did not a priori plan to compare these, only descriptive statistics were done.

Discussion

This study demonstrated the ability to monitor IAP in a select population of women during activities outside of a laboratory environment.

Our results show that mean maximal IAP increases with walking speed, consistent with Grillner’s findings measuring IAP using an intragastric monitor [14]. In addition to the described statistical analysis of walking speeds, we used spline models for each walking speed to rule out any notable instability in IAP over time (for example, upward drift). We found that IAP varied between subjects but tended to stay constant, on average, over time. We also found that side, awkward and front carry positions---those used by postpartum women to carry their babies in car seats---were associated with significantly higher IAPs than backpack carry. These unequal load distributions most likely cause compensatory trunk muscle recruitment to stiffen the torso, thereby protecting the spine, but also increasing IAP during the pickup maneuver and carry. The lowest pressure observed when lifting the weight was in double arm carry in which participants squatted and grabbed the bag handles before lifting the weight rather than bending at the hip and lifting with the arms. In general, the highest pressures generated during lift-and-carry activities were found when the weight was picked up, followed by modest pressures when the weights were set down and the lowest pressures during the carry segment of the activity.

We observed large ranges in the mean maximal IAP during lifting, carrying and setting down of the weight. Some of this variability could be attributed to individual fitness, body

composition, and past or habitual carrying experience, which could influence the degree to which body mechanics compensated for the 13.6 kg load.

We chose backpack carry as the standard for comparison in the lift-and-carry trials, thinking that it would provide the least variability once the pack was secured to the back. This proved otherwise; range for mean maximal IAP was 50.8 cm H₂O for this technique. It may be that carrying such a weight was higher than normal for some, while normal for others, thereby accounting for some of the variability in mean maximal IAP. In contrast, given that nearly 80% of our participants were nulliparous, carrying an infant in a car seat, mimicked by the awkward carry condition, may have been a novel task to many. Yet the range for IAP in this position (43.0 cm H₂O) was similar. This may indicate that the position of weight above center of mass may contribute to IAP.

The pressures observed during walking and carrying are less than that occurring during coughing or hard straining. However, most women spend far more time walking with and without loads than they do in activities that produce short bouts of high pressures, like coughing. At this time, we do not know whether different patterns of IAP impact the pelvic floor differently, if at all.

We measured IAP in the upper vagina which has been shown to correlate with pressures measured with rectal and bladder transducers [8, 15–19]. The placement of the sensor in the upper vagina allows the tracking of the forces that are transmitted to the pelvic floor since the abdomen is a closed system. However, it is an indirect method which adds elements of uncertainty including forces from the viscera, vaginal smooth muscle contractions, and other unknown sources. Participants in this study were generally young, healthy and active women in order to decrease the risk of adverse events during exercise participation. Therefore, the pressures acquired during this study cannot be generalizable to older and less active women with chronic conditions or to women in the immediate postpartum period. Measurements of height and weight for BMI (kg/m²) calculation were collected during this study, which have been shown to influence IAP, but assessment of body density and composition as well as other measures of physical fitness was beyond our scope.

In interpreting these results, reproducibility of IAP measures should also be considered. We did not specifically test the test-retest reliability of IAP during walking around the track or carrying loads while walking longer distances. In previous work, we found that activities with higher maximal IAP tended to have greater variability between two sessions, though very few activities demonstrated a statistically significant difference in mean maximal IAP between sessions.[20] However, in two activities similar to that performed for the current study, the absolute limits of agreement for net mean maximal IAP were 5.6 cm H₂O for walking 4.8 km/hr at 0% grade and 11.5 cm H₂O for walking 4.3 km/hr at 0% grade carrying an 11.4 kg weight. If reproducibility is similar between conducting these activities on a treadmill versus a track (as in the current study), the differences seen between activities overcome the inherent test-retest variability of the measures.

Strengths of this study include randomization of walking and lifting and carrying trials, the use of spline models to determine whether IAP drifts over the time, and the use of valid,

novel technology to assess IAP in community settings. Because trials were randomized, the IAP values recorded are expected to be a function of the distinct tasks rather than a carry-over effect from previous trials. Further study will be required to determine whether longer duration walking or prolonged exercise results in drifts in IAP.

This study was intended to be an observational study to better understand the IAP profile of activities that women perform during their daily lives. This new pressure system has provided us with a deeper appreciation of how subtle biomechanical changes, as evidenced by slight variation in carrying a 13.6 kg, “toddler-sized” load, can alter IAP response. While increases in IAP with faster walking speed was observed previously in short bouts performed in a laboratory, we confirmed this observation in women who self-selected walking speed in typical fitness settings.

It is unlikely that a single threshold exists for IAP that increases risk for pelvic floor disorders. Whether the subtle variations in IAP seen with walking speed or method of carrying a toddler-size load actually increase the risk of pelvic floor disorders is not yet clear. However, during potentially high risk times, such as the postoperative or postpartum periods, it seems prudent, based on biologic plausibility, to limit time spent doing higher-IAP activities. Our results suggest that we can recommend to patients to evenly distribute their loads, when possible, and to limit fast walking in the immediate post-op period. Finally, research aimed to redesign heavy appliances that are regularly carried, such as car seats, is warranted in order to help postpartum women achieve a lower IAP profile.

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Figure 1.
Lift-and-carry conditions

Figure 2.

Graphs of typical lift-and-carry activities including: A) Weight in backpack and B) Carried on one hip. The lift-and-carry activities are separated into three segments: 1) Pickup 2) Carry 3) Set Down. For the pickup and set down segments, each lasting 10 seconds, the one-peak max values are averaged over the subject population. Maximal peak for the carry segments are calculated by averaging the 10 top peaks separated by a minimum of one second and averaged over the subject population.

Figure 3.
Mean max intra-abdominal pressure vs. walking speed

Table 1

Descriptive mean max and area under the curve (AUC) measures for baseline and walking

ACTIVITY	N	Speed (m/s) Avg (range)	Mean Maximal IAP (SD)	RANGE Maximal IAP	Median Maximal IAP (IQR)	Mean AUC(SD)	Range AUC	Median AUC (IQR)
Baseline Activities								
Lying	46	-	13.3(6.4)	5.7–45.5	12.1(9.2–16.2)	366.8(212.7)	127.6–1368.8	333.1(204.6–457.1)
Standing	46	-	34.5 (9.6)	9.4–70.0	33.6(29.5–39.0)	951.5(314.1)	176.2–2086.9	920.8(783.7–1114.2)
Walking Activities								
Slow Walking	46	0.9(0.4–1.3)	42.5(10.2)	13.8–78.7	42.7(36.3–46.0)	15512.0(5875.9)	5499.3–32867.8	13841.2(11577.1–17791.5)
Normal Walking	46	1.4(1.0–1.8)	50.5(10.9)	21.8–88.6	50.7(43.1–55.5)	9179.8(2976.0)	2462.8–21599.5	8790.6(7377.8–10382.3)
Fast Walking	46	1.9(1.5–3.0)	62.0(12.1)	39.8–109.5	60.6(54.8–64.4)	7816.1(2163.5)	3462.0–17190.7	7317.7(6575.5–8677.6)

Table 2

Descriptive measures of carry segment of lift-and-carry activities

ACTIVITY	N	Speed (m/s) Avg (range)	p-value BMI and Age adjusted	Mean Maximal IAP (SD)	RANGE Maximal IAP	Mean AUC (SD)	Range AUC
Carry In Backpack	46	1.2(0.9–1.8)	-	55.5(11.4)	34.4–95.2	2194.6 (685.0)	666.0–4983.9
Double Arm Hang	46	1.3(1.0–1.8)	0.2517	54.0(10.1)	32.1–89.6	1836.0(633.1)	600.0–4461.8
Side Carry	46	1.3(0.9–1.9)	< 0.0001	67.7(12.8)	46.9–104.4	2495.5 (866.3)	1141.6–5452.3
Front Carry	46	1.3(0.9–1.8)	< 0.0001	77.3(13.1)	49.8–122.9	2732.5 (857.0)	1282.9–5714.5
Combination Carry	46	1.3(0.9–1.6)	0.7093	55.9 (10.4)	37.0–96.0	2023.4(661.8)	501.5–4337.8
Awkward Carry	46	1.2(0.9–1.8)	< 0.0001	65.8(10.6)	43.8–96.8	2561.7(766.4)	1153.2–5500.2

Table 3
Descriptive measures of pickup and set down segments of lift-and-carry activities

ACTIVITY	N	Mean Single Max IAP (SD)	RANGE Single Max IAP	Mean Single Max IAP (SD)	RANGE Single Max IAP
Lifting and Carry Activities					
Carry In Backpack	46	84.1(21.7)	50.8–138.7	59.1(16.8)	35.5–133.0
Double Arm Hang	46	54.2(11.9)	32.4–88.7	53.2(10.0)	35.1–87.9
Side Carry	46	85.5 (20.6)	48.1–144.2	64.6 (14.3)	40.6–100.2
Front Carry	46	88.4(16.1)	62.1–132.6	75.0(15.1)	47.9–133.4
Combination Carry	46	62.3 (14.9)	37.5–102.7	54.0(11.3)	32.8–98.1
Awkward Carry	46	71.6(16.2)	41.6–116.5	64.6(12.7)	43.5–94.8