

Intra-abdominal pressure during Pilates: unlikely to cause pelvic floor harm

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Abstract

Introduction and hypothesis The objective was to describe the intra-abdominal pressures (IAP) generated during Pilates Mat and Reformer activities, and determine whether these activities generate IAP above a sit-to-stand threshold.

Methods Twenty healthy women with no symptomatic vaginal bulge, median age 43 (range 22–59 years), completed Pilates Mat and Reformer exercise routines each consisting of 11 exercises. IAP was collected by an intra-vaginal pressure transducer, transmitted wirelessly to a base station, and analyzed for maximal and area under the curve (AUC) IAP.

Results There were no statistically significant differences in the mean maximal IAP between sit-to-stand and any of the Mat or Reformer exercises in the study population. Six to twenty-five percent of participants exceeded their individual mean maximal IAP sit-to-stand thresholds for 10 of the 22 exercises. When measuring AUC from 0 cm H₂O, half the exercises exceeded the mean AUC of sit-to-stand, but only Pilates Reformer and Mat roll-ups exceeded the mean AUC of sit-to-stand when calculated from a threshold of 40 cm H₂O (consistent with, for example, walking).

Conclusion Our results support recommending this series of introductory Pilates exercises, including five Mat exercises and six Reformer exercises to women desiring a low IAP exercise routine. More research is needed to determine the long-term effects of Pilates exercise on post-surgical exercise rehabilitation and pelvic floor health.

Keywords Activity restrictions · Intra-abdominal pressure · Pelvic floor disorder · Pilates · Post-surgical exercise

Introduction

Nearly one in four women in the United States has a symptomatic pelvic floor disorder (PFD) [1]. About one in ten US women undergoes surgery for a pelvic floor disorder in her lifetime and up to 30 % return for surgical reoperation [2–4].

Because of the assumed relationship among physical activity, intra-abdominal pressure (IAP), and pelvic floor loading clinicians often recommend significant short- and long-term activity restrictions for women with existing PFDs or after surgical repair [5–7]. The restrictions are prescribed in an effort to minimize IAP, which is thought to increase the breakdown of surgical repair or further exacerbate the PFD [6]. Most of these post-surgical activity restrictions are based upon individual viewpoints and vary widely in strenuousness and duration [8]. To study IAP during physical activity, we developed a wireless remote intravaginal pressure system [9, 10].

While the relationship between IAP and progression or recurrence of PFDs is not clear, the fact remains that clinicians often restrict activity in the hope of minimizing the rise in IAP with strenuous activity, sometimes to the detriment of patients' health and wellbeing. We postulated that we could formulate a low IAP exercise routine in which IAP does not rise above a given threshold, thereby providing concrete advice to patients and clinicians. We chose to study Pilates exercise,

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based upon the Pilates Method Alliance teachings, because Pilates is easily accessible, has documented health benefits, and is used in rehabilitative settings [11].

Pilates exercise is largely performed on either a padded mat (Pilates Mat) or exercise apparatus (Pilates Reformer) and has evolved from the original teachings of Joseph Pilates in the early 1900s [11, 12]. The Pilates Reformer is highly adaptable to individual users and has gained use as a rehabilitative tool [13–15]. Pilates Mat exercises can be more challenging, but can be performed at home [14]. Regular participation in Pilates yields improved dynamic standing balance [16], increased abdominal and upper body muscular endurance [17], improved postural alignment [17], and improved strength of the pelvic floor after active cuing [18]. People who maintain or improve their flexibility are better able to perform daily activities, less likely to develop back pain, and avoid disability, especially as they age [19]. Therefore, it is in the best interests of women in the age group likely to have PFDs to be active, but at the same time, not subject a post-surgical or at-risk pelvic floor to substantial increases in IAP.

To compare IAP during Pilates exercises, and consistent with our previous work, we chose a commonly performed activity not typically restricted after surgery: standing from a seated position [5]. Our group also recently recorded IAP in 57 women during a standard exercise session that included sit-to-stand activity and found that this produced a moderate increase in IAP with significant variability [20].

Thus, the aims of this study were to describe IAP generated during specific Pilates Mat and Reformer activities, determine whether the mean group IAP (measured as both mean maximal IAP and area under the curve IAP) for any activity exceeds the mean group IAP during sit-to-stand, and to further determine the proportion of women whose individual IAP during any activity exceeds her individual IAP during sit-to-stand. The secondary aim is to compare IAPs during selected Mat and Reformer activities.

Materials and methods

Before the study each participant signed informed consent approved by the University of Utah Institutional Review Board. Participants were healthy women between the ages of 18 and 60 years, with body mass index between 19 and 30 kg/m², and with previous Pilates experience. To increase participants' safety, they were excluded if they responded positively to any question on the Physical Activity Readiness Questionnaire, which screens for heart, blood pressure, or bone or joint problems that could be exacerbated by exercise [21], if they were currently pregnant, if they were within 6 months post-partum, if they had an injury that would interfere with completion of the exercise protocol, if they had undergone pelvic surgery other than a hysterectomy, or if they

had responded “yes” to the question, “Do you have bulging beyond the vagina?”

Each participant was given written instructions describing the proper method of self-inserting the intravaginal pressure sensor after voiding. IAP was monitored by the wireless remote abdominal pressure system, which consists of the sensor and a portable base station. The pressure sensor contains a piezoresistive pressure sensor, microcontroller, and wireless transceiver that are sealed in an elastomeric capsule measuring 23.9 mm in diameter and 37.3 mm in length filled with silicone gel [9]. Data, captured at 31 Hz, from the pressure sensor was sent wirelessly to a portable base station located on the participant's hip that stored data on a microSD card. Each sensor was pre-heated to 37 °C and zeroed to atmospheric pressure, making all pressure readings described in this publication in relation to atmospheric pressure, before use. During the study the Pilates instructor directed the participants to press an interface button located on the base station at the beginning and end of each activity (22 activities in total) to start and stop data acquisition. The study coordinator confirmed the presence of a green blinking light on the participant's base station during each activity to indicate that wireless communication was proceeding.

We chose 22 Pilates exercises to closely resemble an introductory Mat and Reformer class [22]. During exercise, the instructor did not provide any verbal cues to contract the pelvic floor. Participants first performed five baseline activities: supine, side-lying, prone, quadruped, and standing, in addition to the threshold activity: multiple sit-to-stands with hands crossed on chest to a metronome of 40 bpm for 30 s. Next, all participants in a class, ranging from 1 to 4 participants, completed either the 11 Pilates Mat followed by 11 Pilates Reformer exercises (see Table 2) or vice versa depending on alternating study days. Each of the 22 Pilates exercises lasted approximately 1 min and consisted of 4–8 repetitions (depending on the exercise) with the entire protocol lasting approximately 1 h. For example, segmental bridging was repeated 4 times while femur arcs were repeated 6 times for every participant throughout the study. A sit-to-stand threshold can technically be only one repetition, but to best capture that data, we had participants repeat this activity for a minimum of 10 s (approximately 4 repetitions). To standardize the time of each sit-to-stand transition a metronome was set to 40 bpm. The flow of the exercise routine resembled a class environment and therefore rest periods were variable between exercises. If the pressure sensor was displaced during exercise, the participant readjusted the sensor in the restroom and then repeated the activity.

After concluding the exercise protocol, participants provided history information including age, weight, height, parity, number of Cesarean sections, number of vaginal deliveries, hysterectomy, length of Pilates experience, frequency in the last 6 months of using Pilates exercise, and whether the sensor fell out during the study. IAP data were then assessed for completeness.

Table 1 Baseline activities mean intra-abdominal pressure (IAP)

Activity	<i>n</i>	Mean IAP (SD) cm H ₂ O	Range
Supine	18	6.6 (3.2)	-3.3–10.7
Side-lying	18	1.2 (2.5)	-3.6–4.6
Prone	18	9.2 (3.5)	4.4–15.2
Quadruped	17	6 (6.8)	-5.5–18.7
Standing	18	28.9 (4.8)	21.8–37.2

Baseline and sit-to-stand activities were included in the analysis if the data length was greater than 10 s. A Pilates activity was included in the analysis if data were present for at least 75 % of the total activity time as monitored by a stopwatch. If these thresholds were not achieved, owing to deficient wireless communication or participant error in initiating the start of data acquisition, then the activity was considered incomplete and excluded from analysis.

A custom Matlab software (R2011A; MathWorks, Natick, MA, USA) program was used to evaluate the pressure data as previously described [23]. Maximal IAP was calculated by averaging the 10 maximal peaks in the waveform, each separated by 1 s. Mean maximal IAP statistics were calculated based upon the average of the subject population. In addition, each woman's individual mean maximal IAP for each exercise was compared against her mean maximal IAP during her sit-to-stand activity. Area under the curve (AUC) was calculated using trapezoidal approximation. We standardized the repetitions of each exercise, not the duration of each exercise, as each woman completed it at her own rate. In previous work, we standardized the time component of AUC (cm H₂O·s) in order to compare cumulative pressure between activities [23]. In the current study, we did not normalize AUC to time, as our goal was to measure the actual AUC of each prescribed activity. To highlight the degree to which the exercises elevated AUC over that achieved during walking slowly [24], we calculated the AUC over 40 cm H₂O, thereby minimizing the differences in activity duration.

Table 2 Descriptive measures for sit-to-stand, Pilates Mat, and Pilates Reformer exercises

Activity	Rael Isacowitz page number	<i>n</i>	Mean maximal IAP (SD) cm H ₂ O	Range maximal IAP	Mean AUC (SD) cm H ₂ O s	Range AUC
Threshold activity						
Sit to stand	–	18	56.2 (25.7)	35.9–144.3	835.5 (271.4)	331.2–1,459.8
Pilates Mat exercises						
Segmental bridging	45	16	12.0 (7.2)	3.9–30.4	673.4 (534.4)	112.9–2,105.4
Femur arcs	46	17	25.4 (12.3)	8.8–51.5	1,013.5 (465.6)	389.7–1,997.4
Chest-lift	48	16	23.0 (11.8)	5.8–52.1	944.0 (459.4)	222.3–2,143.5
The hundred	50	17	32.6 (14.9)	10.0–69.2	1,227.9* (609.2)	254.6–2,501.8
Roll up	52–53	15	51.1 (13.2)	33.2–75.7	2,240.3* (743.3)	1,016.4–3,441.8
Side kick	75	13	21.5 (11.4)	4.3–40.3	606.8 (431.4)	104.5–1,632.1
Leg circles	51	18	25.5 (10.6)	11.5–48.3	1,212.0* (496.2)	327.3–2,058.0
Swan	76	17	36.9 (13.3)	11.9–68.1	1,483.9* (627.5)	459.3–2,993.9
Quadruped	83	16	27.5 (12.6)	8.4–53.6	1,011.2 (470.2)	258.9–1,932.2
Plank	83	16	38.4 (11.7)	22.8–59.6	1,223.5* (326.1)	725.1–1,835.2
Standing leg raise	–	18	40.1 (10.4)	27.0–63.4	1,736.8* (569.0)	813.8–2,671.8
Pilates Reformer exercises						
Segmental bridging	142	17	11.1 (4.9)	4.1–21.3	479.2 (305.5)	64.3–1,051.1
Footwork	112	16	14.1 (5.1)	5.1–23.5	596.5 (289.7)	175.1–1,227.0
Supine arm work	168	17	21.3 (9.9)	10.8–44.8	876.9 (452.5)	314.5–1,967.1
Supine abdominals	123	16	31.1 (10.4)	11.1–45.8	1,095.9 (450.7)	353.3–1,938.1
Side-kick	75	16	17.2 (11.6)	2.4–34.2	493.5 (360.3)	25.90–1,088.3
Roll-up	210	16	49.6 (11.2)	29.1–74.2	3,400.7* (873.2)	1,664.7–5,020.2
Kneeling arm work	177	15	40.5 (9.2)	20.0–54.1	2,133.8* (590.4)	1,269.1–3,096.0
Swan	203	17	30.9 (12.5)	10.8–61.0	1,457.0* (706.6)	457.8–2,746.3
Feet in straps	136–137	17	24.1 (11.2)	9.5–54.0	1,024.9 (471.2)	389.6–2,253.8
Long stretch	164	17	33.9 (15)	1.6–69.0	1,270.6* (627.2)	55.3–2,858.7
Side split	191	18	35.6 (10.3)	6.9–50.5	1,875.2* (1026.3)	265.3–3,385.5

*Statistically greater than sit-to-stand threshold

Using the average and standard deviation of sit-to-stand mean maximal values from a previous study [20], we determined that a discernible difference of 10 cm H₂O could be detected in 20 people with two-sided tests, assuming $\alpha=0.05$ and power of 80 %.

To assess the normality of data a Lilliefors test was used [25]. A Wilcoxon signed-rank test ($\alpha=0.05$) was used to determine whether exercises were significantly different from the sit-to-stand activity. Likewise, a Wilcoxon signed rank test was used to make five comparisons between Reformer and Mat activities, which included side-kick vs side-kick, long stretch vs plank, feet-in-straps vs leg circles, supine abdominals vs the hundred, and roll-up vs roll-up respectively. A Spearman rank correlation was used to explore the correlation among BMI, age, and length of Pilates experience with mean maximal peak IAP during the Pilates Mat and Reformer exercises. All statistics were two-sided at the conventional 5 % significance level and were calculated using a custom Matlab program with a loaded statistics package.

Results

Twenty women were enrolled in the study. Their mean age was 43.1 years (range: 22–59), mean body mass index

22.6 kg/m² (SD 2.3) and 30 % were nulliparous. All 20 women completed the exercise routine. Two women were excluded from data analysis due to device retention failure as indicated on participant surveys as well as abnormally low pressure data.

Based upon a Lilliefors test for normality, results were generally consistent with normality, with the exception of three activities when analyzing mean maximal IAP, and one activity when analyzing AUC. For simplicity, we used Wilcoxon tests for all. The mean and range IAP during baseline activities are shown in Table 1. Sit-to-stand was performed on average 20 times during a mean duration of 28 seconds while the mean duration of each Pilates exercise ranged from 48 to 94 seconds.

Descriptive measures and comparisons of mean maximal IAP and AUC for the sit-to-stand activity vs the Pilates Mat and Reformer exercises are shown in Table 2 and in Figs. 1 and 2.

There were no statistically significant differences in mean maximal IAP of the group between sit-to-stand and any of the Mat or Reformer exercises.

We then analyzed the proportion of women exceeding their individual mean maximal IAP for sit-to-stand for each exercise (Fig. 1). In this graph, the proportion of women exceeding their personal threshold is shown below the bars. Six to

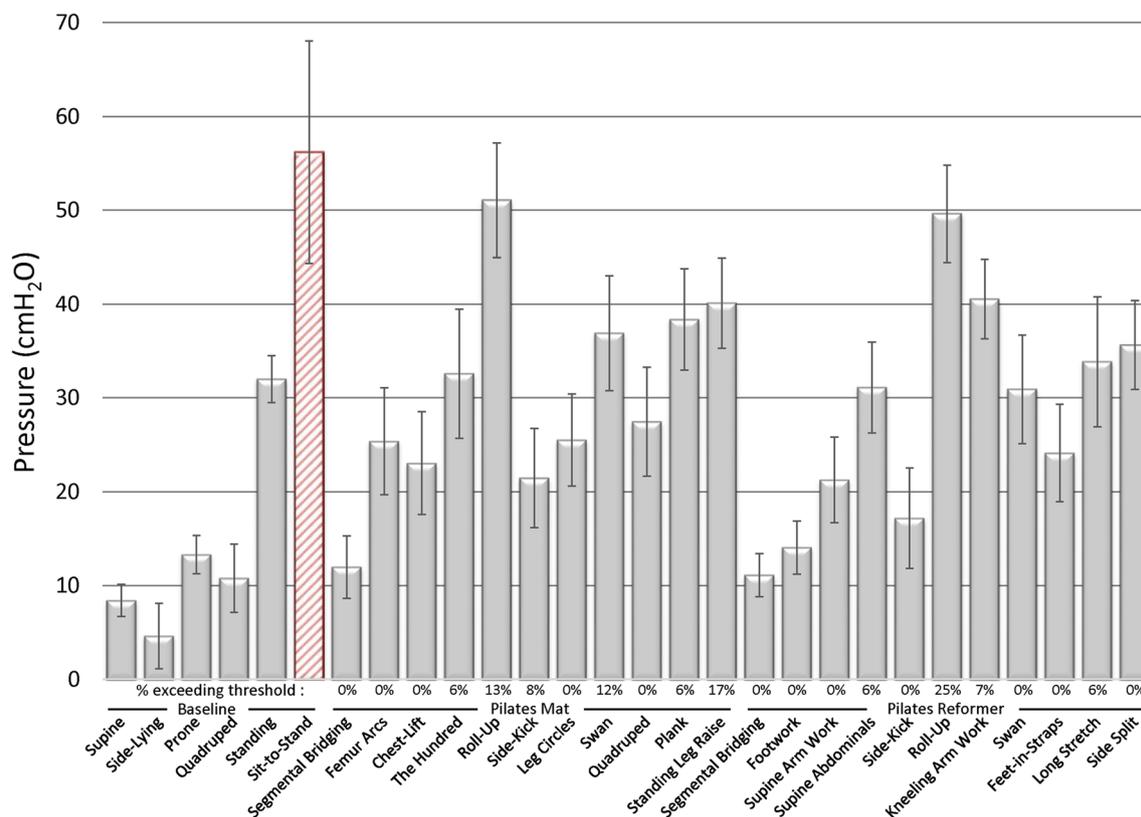


Fig. 1 Bar graph of mean maximal intra-abdominal pressure (IAP) \pm 95 % CI during five baseline activities, threshold, 11 Pilates Mat activities, and 11 Pilates Reformer activities. The percentage of

participants exceeding their individual mean maximal IAP for the sit-to-stand threshold on a particular exercise is shown below the graph

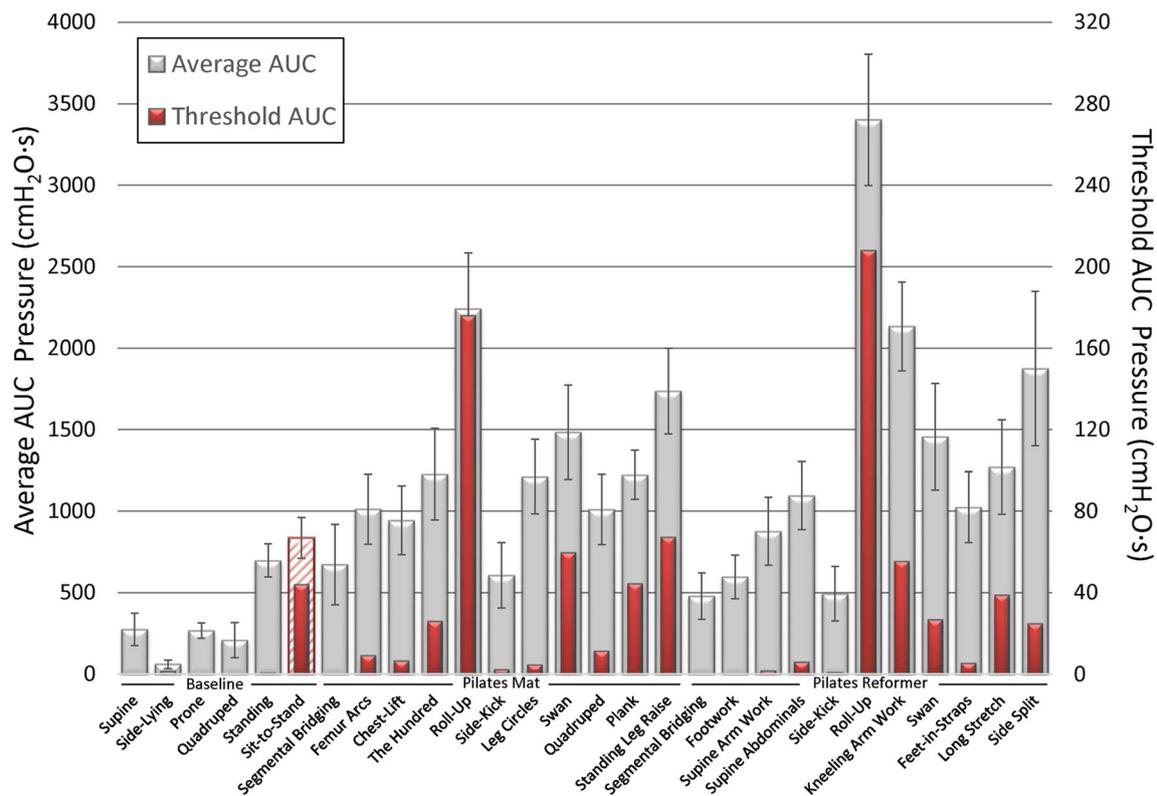


Fig. 2 Bar graph of average area under the curve (AUC)±95 % CI during five baseline activities, threshold, 11 Pilates Mat activities, and 11 Pilates Reformer activities. Also shown is the average AUC above a threshold of 40 cm H₂O for each baseline, threshold, and exercise activity

twenty-five percent of women exceeded their individual sit-to-stand thresholds for 10 of the 22 exercises (Fig. 1). Twenty-five percent of women exceeded their individual mean maximal IAP for the Reformer roll-up while 13 % did so during the Mat roll-up.

In Fig. 2, we present two ways of analyzing AUC comparisons. The first presents AUC measured from the atmospheric baseline (0 cm H₂O; Fig. 2: average AUC); the second demonstrates the AUC that falls above a 40 cm H₂O threshold (Fig. 2: threshold AUC). Comparison of AUCs measured from baseline revealed that compared with the mean AUC for sit-to-stand, the mean AUC was higher for “the hundred” ($p=0.011$), “roll-up” ($p<0.001$), “leg circles” ($p=0.010$), “swan” ($p<0.001$), “plank” ($p<0.001$), and “standing leg raise” ($p<0.001$) during Mat exercises, and higher for “roll-up” ($p<0.001$), “kneeling arm work” ($p<0.001$), “swan” ($p=0.003$), “long stretch” ($p=0.011$), and “side split” ($p=0.003$) during Reformer exercises. Comparison of AUCs measured above the 40 cm H₂O threshold found that only Pilates Reformer and Mat roll-up exerted significantly higher IAP ($p<0.05$) than the sit-to-stand activity (Fig. 2).

We chose a priori five comparisons between Pilates Reformer and Mat exercises, to include those activities that were similar in movement (side-kick vs side-kick, long stretch vs plank, feet-in-straps vs leg circles, supine abdominals vs the hundred, and roll-up vs roll-up). We found no statistically

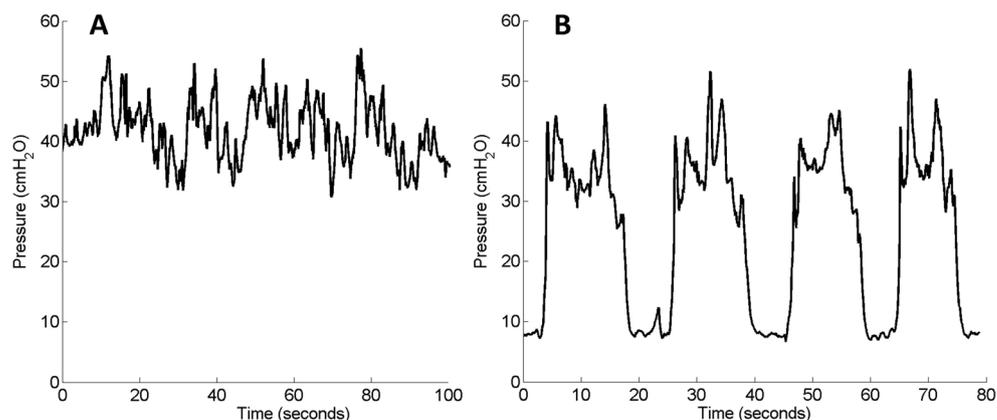
significant differences when analyzing mean maximal IAP. The AUC for the Reformer roll-up was significantly greater ($p<0.001$). Typical pressure curve comparisons for Reformer and Mat with regard to roll-up are shown in Fig. 3.

Spearman correlations between Pilates experience, measured in months, and age vs mean maximal IAP were generally not significant except for experience vs mean maximal Reformer roll-up ($\rho=-0.54$) and age vs mean maximal Mat roll-up ($\rho=0.69$). Correlations between BMI and mean maximal IAP were significant in 8 of the 22 Pilates exercises, with ρ values ranging between 0.49 and 0.68.

Discussion

In addition to the health benefits of Pilates, some exercises have been shown to increase pelvic floor muscle strength, although whether Pilates can reduce stress urinary incontinence has not been shown [18, 26]. Before our study, it was unclear how Pilates exercises influenced IAP. We found that mean maximal IAP for the population was not significantly higher during any of the exercises studied compared with sit-to-stand. Additionally, with few exceptions, women did not exceed their own sit-to-stand IAP threshold during either Mat or Reformer exercises. Mean AUC for the population was higher for 11 activities compared with the mean AUC for

Fig. 3 Typical intra-abdominal pressure measurement while the participant performs **a** Pilates Reformer roll-up and **b** Pilates Mat roll-up



the sit-to-stand exercise. However, only Pilates Reformer and Mat roll-up exercises were found to have significantly higher AUC than sit-to-stand activity when calculated above a threshold of 40 cm H₂O (typical of that seen with walking).

To place the AUC during the Pilates exercise routine into perspective, we calculated an estimate of AUC during a typical postoperative day, using data from a study of 46 women in which women walked 400 m at approximately 2 mph [24]. We conservatively estimated (best guess) that patients recovering from surgery transition from sitting to standing (including before and after voiding) 20 times per day and walk for 5 min three times per day. The estimated AUC for this hypothetical postoperative day (not including sitting, standing, and other activities that generate IAP) is 31,694 cm H₂O·s. As can be seen in Fig. 4, this AUC is greater than that for the Mat and Reformer Pilates sessions combined. AUC measurements describing IAP are rarely used in the literature [23, 27]. However, the AUC is commonly used in endocrinological and neuroscience research to reflect information that is contained in repeated measures over time, and in pharmacology to determine the effects of medication over a time period or to evaluate dose and response relationships [28]. The AUC reflects cumulative IAP over time, which may have a different impact on the pelvic floor than short bursts of peak pressure.

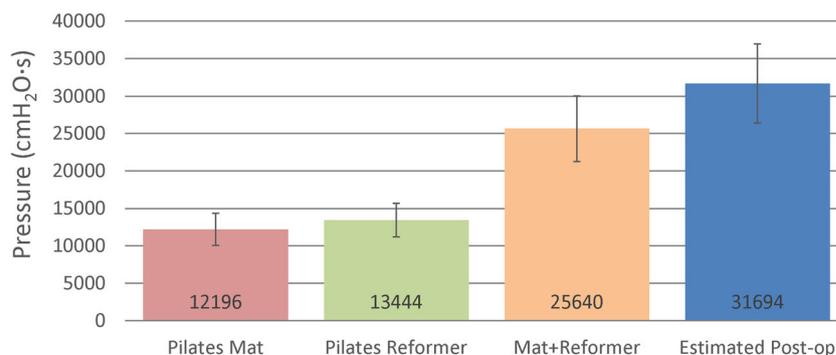
An AUC not standardized for time represents a different construct than an AUC standardized for time. If 2 women have identical maximal IAP during lifting, but one woman

takes 20 s to lift the load, while the other takes 2 s, the AUC for the first woman will be substantially higher. Thus, AUC represents the real-world situation of how women do a task. In contrast, an AUC standardized for time simply yields an average pressure over the activity and no longer reflects the sustained high IAP reflected by the AUC in the previous example. However, the variability in time increases the variability in AUC. Further research is needed to determine if this measure adds usefulness.

Rather than comparing exercises with varying durations we chose instead to highlight the additional AUC generated over a 40 cm H₂O threshold (the approximate maximal IAP generated during slow walking). By calculating the AUC over this threshold the time variability between exercises is reduced. We believe that this method will prove useful in the future in setting boundaries for activities of longer duration. Comparable exercises performed on the Mat or using the Reformer produced similar IAP values, with the exception of the roll-up performed on the Reformer, which produced a higher AUC. It is likely that the participants were unable to fully relax during the Reformer roll-up movement as spring tension continues to pull them upward at the bottom of the exercise. This spring-generated counterforce was not present in the Mat activity (Fig. 3).

The 22 Pilates exercises chosen to resemble an introductory class did not generate a higher mean maximal IAP compared with the sit-to-stand activity. However, many Pilates

Fig. 4 Total AUC±95 % CI profiles for Pilates Mat (30 min), Pilates Reformer (30 min), Pilates Mat and Reformer (60 min), and lower range activity profile of post-surgical patients consisting of 20 sit-to-stand exercises (including voiding periods) and walking for 15 min at a slow pace



methodologies exist and our results cannot be extrapolated to other exercises. In previous work, we demonstrated that most activities have substantial variability, including sit-to-stand; we chose this activity for comparison because of its clinical relevance. In addition to comparing mean results for the population, we also analyzed the difference between IAP during exercise and IAP during sit-to-stand for each individual [20].

Limitations of this study include the fact that, consistent with a real world setting, rest periods between activities were not controlled, which may have contributed to an additive effect on IAP during later activities. For logistical reasons, we did not randomize the order of Mat vs Reformer Pilates, but rather alternated this by study day so that 50 % of participants started with Pilates Mat. The exercise activities were not randomized, but rather reflected the standard Pilates routine where the early activities gradually warm the participant up before engaging in the more strenuous activities. Breath control, which has been shown to contribute to the magnitude of peak IAP, was cued during the exercise by the movement practitioner [29]. However, the synchronization of movement and breath was not verified and is a likely contributor to IAP variability. This study indirectly measured IAP in the upper vagina, which has been shown to correlate with urodynamic testing values [10, 30–32]. An indirect measurement of IAP rather than a directly measured IAP in the abdominal cavity adds uncertainty, including forces from the viscera, smooth muscle contractions, and others. However, placing the measurement device in the upper vagina subjects the sensor to similar forces that are present on the pelvic floor. In addition, because the transducer is located in the upper vagina, rather than the mid-vagina, in general, PFM contractions do not contribute to the pressure. In a previous laboratory-based study, IAP measured with this transducer during volitional PFM contraction remained low in most women [20]. However, it is possible that in some women, the transducer slipped into the lower vagina and thus did record reflex PFM contraction as well as IAP. Because all women in this study were healthy and had previous Pilates experience, we do not know whether inexperienced women demonstrate differences in IAP when first learning Pilates or how results might differ with women with pelvic floor disorders. We measured IAP, while in another study, perineal ultrasound was used to describe the position of the bladder neck during abdominal and pelvic floor maneuvers, suggesting an alternative method of assessing the impact on the pelvic floor [33].

We are not aware of any studies in women that directly assess the healing of the pelvic floor, or the effect of increased IAP on the rate of surgical wound healing and strength. Therefore, it is not possible to design a postoperative activity program known to protect the healing of the surgically repaired pelvic floor or to promote eventual wound strength [7]. Given that nonrestrictive recommendations do not seem to influence short-term subjective recurrence of prolapse [34] and that

most basic Pilates exercises do not appreciably raise IAP, we suggest that Mat exercises, including segmental bridging, femur arcs, chest lift, side-kick, quadruped, and Reformer exercises, such as segmental bridging, footwork, supine arm work, supine abdominals, side kick, and feet-in-straps, can be done in the postoperative period by women experienced in the techniques. More research is needed to determine the long-term effects of Pilates exercise on postsurgical exercise rehabilitation and pelvic floor health.

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Conflicts of interest None.

Authors' contributions Tanner J. Coleman: project development, exercise protocol development, data collection, data analysis, data interpretation, manuscript writing; Ingrid E. Nygaard: project development, data interpretation, manuscript writing/editing; Dannielle N. Holder: project development, exercise protocol development, data collection, manuscript editing; Marlene J. Egger: data analysis, manuscript editing; Robert Hitchcock: project development, manuscript editing.

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