GYNECOLOGY

Intraoperative cervix location and apical support stiffness in women with and without pelvic organ prolapse

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BACKGROUND: It is unknown how initial cervix location and cervical support resistance to traction, which we term "apical support stiffness," compare in women with different patterns of pelvic organ support. Defining a normal range of apical support stiffness is important to better understand the pathophysiology of apical support loss.

OBJECTIVE: The aims of our study were to determine whether: (1) women with normal apical support on clinic Pelvic Organ Prolapse Quantification, but with vaginal wall prolapse (cystocele and/or rectocele), have the same intraoperative cervix location and apical support stiffness as women with normal pelvic support; and (2) all women with apical prolapse have abnormal intraoperative cervix location and apical support stiffness. A third objective was to identify clinical and biomechanical factors independently associated with clinic Pelvic Organ Prolapse Quantification point C.

STUDY DESIGN: We conducted an observational study of women with a full spectrum of pelvic organ support scheduled to undergo gynecologic surgery. All women underwent a preoperative clinic examination, including Pelvic Organ Prolapse Quantification. Cervix starting location and the resistance (stiffness) of its supports to being moved steadily in the direction of a traction force that increased from 0-18 N was measured intraoperatively using a computer-controlled servoactuator device. Women were divided into 3 groups for analysis according to their pelvic support as classified using the clinic Pelvic Organ Prolapse Quantification: (1) "normal/normal" was women with normal apical ($C < -5$ cm) and vaginal (Ba and Bp < 0 cm) support; (2) normal/prolapse had normal apical support ($C < -5$ cm) but prolapse of the anterior or posterior vaginal walls (Ba and/or Bp ≥ 0 cm); and (3) prolapse/prolapse had both apical and vaginal wall prolapse ($C > -5$ cm and Ba and/or Bp ≥ 0 cm). Demographics, intraoperative cervix locations, and apical support stiffness values were then compared. Normal range of cervix location during clinic examination and operative testing was defined by the total range of values observed in the normal/normal group. The proportion of women in each group with cervix locations within and outside the normal range was determined. Linear regression was performed to identify variables independently associated with clinic Pelvic Organ Prolapse Quantification point C.

RESULTS: In all, 52 women were included: 14 in the normal/normal group, 11 in the normal/prolapse group, and 27 in the prolapse/prolapse group. At 1 N of traction force in the operating room, 50% of women in the normal/prolapse group had cervix locations outside the normal range while 10% had apical support stiffness outside the normal range. Of women in the prolapse/prolapse group, 81% had cervix locations outside the normal range and 8% had apical support stiffness outside the normal range. Similar results for cervix locations were observed at 18 N of traction force; however the proportion of women with apical support stiffness outside the normal range increased to 50% in the normal/prolapse group and 59% in the prolapse/prolapse group. The prolapse/prolapse group had statistically lower apical support stiffness compared to the normal/normal group with increased traction from 1-18 N (0.47 ± 0.18 N/mm vs 0.63 ± 0.20 N/mm, $P = .006$), but all other comparisons were nonsignificant. After controlling for age, parity, body mass index, and apical support stiffness, cervix location at 1 N traction force remained an independent predictor of clinic Pelvic Organ Prolapse Quantification point C, but only in the prolapse/prolapse group.

CONCLUSION: Approximately 50% of women with cystocele and/or rectocele but normal apical support in the clinic had cervix locations outside the normal range under intraoperative traction, while 19% of women with uterine prolapse had normal apical support. Identifying women whose apical support falls outside a defined normal range may be a more accurate way to identify those who truly need a hysterectomy and/or an apical support procedure and to spare those who do not.

Key words: apical support stiffness, cervix location, prolapse

Introduction

Pelvic organ prolapse is a common indication for gynecologic surgery, with the annual number of women undergoing these procedures projected to reach >190,000 by 2020.[1] While our understanding of the pathophysiology of pelvic organ prolapse has improved over the last decade—especially the importance of apical support[2,3] —much remains unknown regarding the biomechanical properties of the affected tissues and pelvic structures. A clinical evaluation of apical support is used to inform surgeons' decision-making as to whether a hysterectomy is needed as part of surgery for prolapse. However, there is a 50% disagreement rate among gynecologic surgeons about the level of apical support, assessed under traction in the operating room, that indicates the need for hysterectomy.[4] Moreover, evidence about how to integrate Pelvic Organ Prolapse Quantification (POP-Q) and intraoperative findings in this assessment do not yet exist. At the heart of this issue is the fact that surgeons use their own assessment of whether the apical supports are normal under traction to make decisions about whether or not hysterectomy and/or apical suspension should be considered. An *objective* assessment of apical support stiffness along with outcome data could provide better information on which to base these important clinical decisions.

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It is well established that the degree of uterine descent seen during maximal Valsalva in clinic is not as pronounced as that seen in the operating room under traction.[5,6] This difference may be partially explained by different environmental and loading conditions (eg, Valsalva vs traction, leg position, anesthesia) to which the apical ligaments are subjected. To gain a better understanding of this, we developed a technique to measure the intraoperative mechanical properties of the apical ligaments.[7] In pilot studies, we found that ligament stiffness only accounts for 19% of variation in POP-Q point C.[5] What is missing now is a quantitative understanding of how various properties vary in women with different types of pelvic organ support. For example, do women with normal apical support, but with cystocele or rectocele on POP-Q examination, have the same mechanical properties for the cardinal/uterosacral complex as do those with normal support in all areas on clinic POP-Q? Conversely, do all women with apical prolapse on POP-Q examination have abnormal ligament properties? The answers to these questions could have direct implications for deciding whether or not the additional morbidity of a hysterectomy and/or apical suspension is justified at the time of an operation for prolapse.

The aims of our study were to: determine whether: (1) women with normal apical support on clinic POP-Q, but with vaginal wall prolapse (cystocele and/or rectocele), have the same intraoperative cervix location and apical support stiffness as women with normal pelvic support (null hypothesis is that there is no difference); and (2) all women with apical prolapse have abnormal intraoperative cervix location and apical support stiffness (null hypothesis is that *all* women with apical prolapse have abnormal intraoperative cervix location and apical support stiffness). A third objective was to identify clinical and biomechanical factors independently associated with clinic POP-Q point C.

Materials and Methods

Women with a full spectrum of pelvic organ support were recruited from the gynecology clinics at the University of Michigan from September 2012 through September 2013. Informed consent was obtained for all participants under an approved University of Michigan Institutional Review Board protocol (HUM00056743). Inclusion criteria included women $\geq$18 years of age who were planning to have gynecologic surgery and willing to undergo intraoperative testing. Exclusion criteria included: pregnancy (either currently or within the past year), prior hysterectomy or surgery for pelvic organ prolapse, uterine fibroids >12 weeks in size or known pelvic inflammatory disease, chronic steroid use, prior pelvic radiation, current treatment for cancer, history of organ transplant, history of vasovagal syncope, neurologic diseases or impairments, and mobility issues that would prohibit leg positioning in high lithotomy.

Preoperatively, women were examined and their pelvic organ support measured using the POP-Q at inclination of 45 degrees. Intraoperative testing was conducted on the day of their scheduled gynecologic surgery. The technique for making measurements of cervix location and apical ligament response to traction in the operating room using a computer-controlled servoactuator device has been previously described.[7] To summarize, after induction of general anesthesia, the patient was positioned into high lithotomy and a short-blade Scherbak posterior-weighted vaginal speculum was placed. A single-tooth tenaculum was then placed across both the anterior and posterior cervical lips and the handle attached to the servoactuator device. Prior to activating the device, resting cervix location was determined by measuring the distance of the lateral cervical edge to the hymenal ring. The servoactuator then moved at a constant speed so as to apply an increasing tensile force (from 1-18 N) to the cervix while the position of the traction arm was simultaneously recorded, so that cervix locations at minimal (1 N) and maximal (18 N) force could then be determined. Because the pelvis does not move during testing, the location of the cervix was used as a proxy for ligament length. During early trials, a video recording of the hips from a lateral view was made to assure that the patient did not move on the table during traction. Change in cervix location was defined as the difference in cervix location (mm) from rest to either 1 N or 18 N, and the apical support stiffness was estimated by dividing the change in force (0-1 N and 1-18 N) by the measured change in cervical location.

Study participants were divided into 3 groups for analysis according to their pelvic support and cervix location as measured by a trained urogynecologist during the clinic POP-Q examination. We defined apical prolapse as $C > -5$ cm and vaginal wall prolapse as Ba and/or $Bp \geq 0$ cm based on population norms.[8] The normal/normal group included women with normal apical ($C \leq -5$ cm) and vaginal (Ba and $Bp < 0$ cm) support; normal/prolapse included women with normal apical support ($C \leq -5$ cm) but prolapse of the anterior or posterior vaginal walls (Ba and/or $Bp \geq 0$ cm); and prolapse/prolapse included women with both apical and vaginal wall prolapse ($C > -5$ cm and Ba and/or $Bp \geq 0$ cm).

The demographic and clinic POP-Q data were compared for the 3 pelvic support groups using simple linear regression models. Statistically significant differences between the groups were found for age and parity measures. A multivariable linear regression model that adjusted for age and parity allowed us to confirm that group differences in stiffness and displacement measures were not due to underlying differences in age and parity measures. After controlling for age and parity, cervix locations at the following traction forces were compared across and between groups: in clinic during maximal Valsalva and in the operating room at 1 N and 18 N of force. Normal range of cervix location during clinic examination and operative testing was defined by the range observed in the normal/normal group. The proportion of women in each group with cervix locations outside and within the normal range was then calculated for each of the 3 traction forces.

TABLE 1
Demographics and Pelvic Organ Prolapse Quantification values in 3 groups of women with varying degrees of pelvic support

Characteristics	Normal/normal, N = 14	Normal/prolapse, N = 11	Prolapse/prolapse, N = 27	Overall *P* value[a]
Age, y	47.1 ± 10.4	52.9 ± 13.8	59.0 ± 12.0	.013
Parity	1.5 (1–2)	3 (2–3)	3 (2–3)	.013
BMI, kg/m^2	30.1 ± 5.7	28.4 ± 5.4	27.5 ± 5.7	.378
POP-Q points, cm[b]				
Aa	−2.0 (−3.0 to −1.0)	0 (0 to 2.0)	1 (0 to 2.0)	<.001
Ba	−2.0 (−3.0 to −1.0)	1.0 (0 to 2.0)	2.0 (1.0 to 3.5)	<.001
C	−6.0 (−7.0 to −5.5)	−6.0 (−8.0 to −5.0)	−2.5 (−4.0 to −2.0)	<.001
Ap	−3.0 (−3.0 to −2.0)	−1.0 (−2.0 to 0)	−2.0 (−2.0 to −1.0)	.003
Bp	−3.0 (−3.0 to −2.0)	−1.0 (−2.0 to 0)	−1.0 (−2.0 to −1.0)	.044
GH	3.0 (2.0 to 3.0)	4.0 (3.5 to 5.0)	3.75 (3.0 to 4.0)	.087
PB	3.0 (3.0 to 3.0)	3.0 (3.0 to 4.0)	3.0 (3.0 to 3.5)	.663
TVL	10.0 (9.5 to 10.5)	10.0 (9.5 to 12.0)	9.75 (8.0 to 11.0)	.362

Data presented as mean ± SD or median (interquartile range).

BMI, body mass index; *POP-Q*, Pelvic Organ Prolapse Quantification.

[a] *P* values comparing group means were determined by simple linear regression models; [b] Reported in reference to hymenal ring (0 cm) and measured during maximal Valsalva, with exception of TVL.

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Pearson correlation coefficients were used to assess the association between POP-Q point C and the cervix location and stiffness measurements for all participants combined, as well as separately for each group. Multivariable linear regressions stratified by group were further used to assess the outcome of POP-Q point C as a function of cervix location at 1 N, stiffness, body mass index (BMI), age, and parity. The results of the regression models include r^2 and adjusted r^2 values that reflect the proportion of variance explained in POP-Q point C and are of primary interest. All analyses were conducted in software (Stata Statistical Software, Release 13; StataCorp LP, College Station, TX) Two-sided statistical significance was determined by an alpha value of 5%.

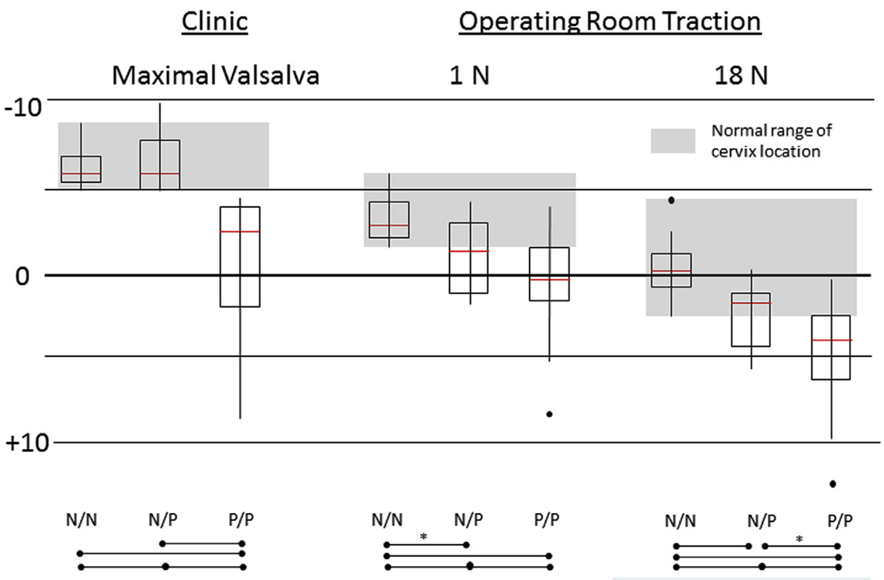
An a priori power calculation was not possible because the only prior data available did not have the relevant information regarding patient groupings. A post hoc power calculation based on group differences for ligament stiffness and cervix displacement demonstrated full (100%) statistical power when assuming the effect sizes presented in the "Results" section below.

Results

In all, 52 women were included in the study: 14 in the normal/normal group, 11 in the normal/prolapse group, and 27 in the prolapse/prolapse group. Data from 17 of these women were included in the description of the testing strategy.[7] Of the 14 women in the normal/normal group, 5 had a midurethral sling, 7 had a total laparoscopic hysterectomy, 1 had a colposcopy, and 1 had a vaginal hysterectomy, none of which were done for an indication of pelvic organ prolapse. Procedures for the 11 women in the normal/prolapse group were as follows: vaginal hysterectomy ± anterior repair, posterior repair, uterosacral or sacrospinous ligament suspension, midurethral sling (N = 7); anterior and posterior repair and midurethral sling (N = 3); and midurethral sling and endometrial ablation (N = 1). Women in the prolapse/prolapse group underwent the following procedures: vaginal hysterectomy ± anterior repair, posterior repair, uterosacral or sacrospinous ligament suspension, midurethral sling (N = 17); laparoscopic supracervical hysterectomy, colpopexy ± anterior repair, posterior repair, midurethral sling (N = 5); total abdominal hysterectomy ± anterior repair, posterior repair, colpopexy (N = 3); midurethral sling (N = 1); and total laparoscopic hysterectomy and midurethral sling (N = 1). Demographics of the 3 groups are shown in Table 1. Women in the normal/normal group were the youngest, had the lowest parity, and registered the highest BMI. By design, women in the normal/normal and normal/prolapse groups had similar cervix locations on POP-Q examination, while point C in the prolapse/prolapse group was closer to the hymen.

Figure 1 shows box plot comparisons of the cervix locations of the 3 groups during maximal Valsalva in the clinic, and at 1 N and 18 N traction forces in the operating room. During clinic examination, POP-Q values for point C in the normal/prolapse women were similar to those of the normal/normal women. By definition, point C measurements in the prolapse/prolapse group were all below

FIGURE 1
Cervix location under different traction forces



Boxes represent 25th-75th percentiles with median value (red line), values 1.5 times interquartile range (whiskers), and statistical outliers (dots). Differences between groups were determined using simple and multivariable linear regressions adjusting for parity and age. Groups defined as follows: normal/normal (N/N) is normal apex (C ≤ -5 cm)/normal vaginal wall support (Ba and Bp < 0 cm); normal/prolapse (N/P) is normal apex/prolapse of vaginal wall(s) (Ba and Bp ≥ 0 cm); and prolapse/prolapse (P/P) is prolapse of apex (C > -5 cm)/prolapse of vaginal wall(s). * *P* value not significant after controlling for age and parity; 0.1 at 1 N and 0.07 at 18 N; •——• *P* value < .05; •–•–• Comparison across three groups, *P* value < .05.

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the normal range. Raw data for Figure 1 are presented in Table 2.

By contrast, cervix locations in the operating room at 1 N and 18 N were lower in the normal/prolapse group compared with the normal/normal group, despite the groups having had similar locations on clinical examination. Cervix locations of women in the normal/prolapse group were between those of the normal/normal and prolapse/prolapse groups. The proportion of each group outside the range found in the normal/normal group is presented in Figure 2. During operating room traction testing, half of the women in the normal/prolapse group, who had normal cervix locations on POP-Q, fell outside the normal range at both operating room traction forces. In addition, 19% of cervix locations at 1 N and 26% at 18 N in women in the prolapse/prolapse group fell within the normal range. The proportions of women in each group with apical support stiffness within and outside the normal range was then determined (Figure 3). From 0-1 N of traction force in the operating room, only a small percentage of women in the normal/prolapse and prolapse/prolapse groups had abnormal apical support stiffness (10% and 8%, respectively). However, with traction force from 1-18 N, half of women in the normal/prolapse group had abnormal apical support stiffness as did 59% of the normal/prolapse group.

Table 3 shows the calculated stiffness of the cervical support complex from 0-1 N and from 1-18 N of traction force, by group with unadjusted *P* values. Stiffness was low in all groups. Apical support stiffness was lower in the prolapse/prolapse group compared to the normal/normal group from 1-18 N ($P = .006$), but none of the other comparisons were statistically significant. From 1-18 N, cervix displacement increased with advancing prolapse so that, on average, the cervix moved 1.3 cm more in the

TABLE 2
Data for cervix location under different traction forces presented in Figure 1 for 3 groups of women with varying degrees of pelvic support

				P values[a]			
	NN, N = 14	NP, N = 11	PP, N = 27	Overall	NN vs PP	NN vs NP	NP vs PP
Clinic POP-Q point C[b]	−6.0 (−7.0 to −5.5)	−6.0 (−8.0 to −5.0)	−2.5 (−4.0 to −2.0)	< .001	<. 001	.928	< .001
Operating room							
1 N	−2.9 (−4.2 to −2.2)	−1.4 (−3.0 to 1.0)	0.3 (−1.6 to 1.5)	< .001	< .001	.03[c]	.07
18 N	−0.2 (−1.3 to 0.7)	1.7 (1 to 4.2)	3.9 (2.4 to 6.1)	< .001	< .001	.01	.03[d]

Data presented as median (interquartile range).

NN, normal/normal; *NP*, normal/prolapse; *POP-Q*, Pelvic Organ Prolapse Quantification; *PP*, prolapse/prolapse.

[a] *P* values comparing groups were determined by simple linear regression models; [b] Reported in reference to hymenal ring (0 cm) and measured during maximal Valsalva; [c] $P = .11$ after adjusting for age and parity; [d] $P = .07$ after adjusting for age and parity.

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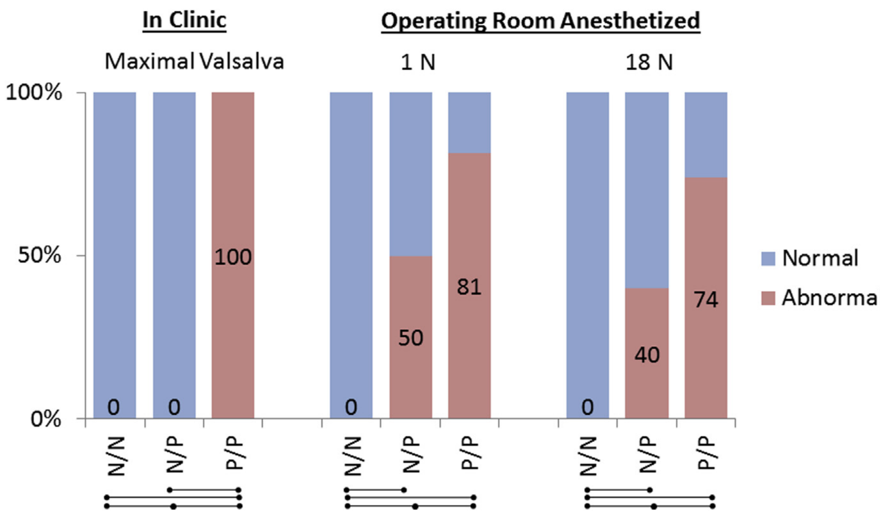
prolapse/prolapse group than in the normal/normal group, which was the only significant pairwise comparison ($P = .001$).

To assess the relationship between apical support stiffness and POP-Q point C, Pearson correlation coefficients were derived and are shown in Table 4. No significant correlations were observed between stiffness and POP-Q point C in any group. POP-Q point C and intraoperative cervix locations were only correlated in the prolapse/prolapse group. These correlations approached, but did not reach significance in the normal/prolapse group.

Finally, we developed multivariable linear regression models to identify factors independently associated with POP-Q point C for each group and to determine the proportion of variance explained by these factors (Table 5). In this model, while controlling for age, parity, BMI, and apical support stiffness, cervix location at minimal force remained an independent predictor of POP-Q point C in the prolapse/prolapse group. This model explains 65% of the variation seen in POP-Q point C in women with both apical and vaginal wall prolapse. However, in the other 2 groups, these factors did not have a statistically significant predictive effect.

FIGURE 2
Proportion of women with cervix location outside normal range



For 3 groups of women with varying degrees of pelvic organ support, proportion in whom cervix location is within and outside normal range under different traction forces. Groups defined as follows: normal/normal (N/N) is normal apex ($C \leq -5$ cm)/normal vaginal wall support (Ba and Bp < 0 cm); normal/prolapse (N/P) is normal apex/prolapse of vaginal wall(s) (Ba and Bp ≥ 0 cm); and prolapse/prolapse (P/P) is prolapse of apex ($C > -5$ cm)/prolapse of vaginal wall(s); P value $< .05$; comparison across 3 groups, P value $< .05$.

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Comment

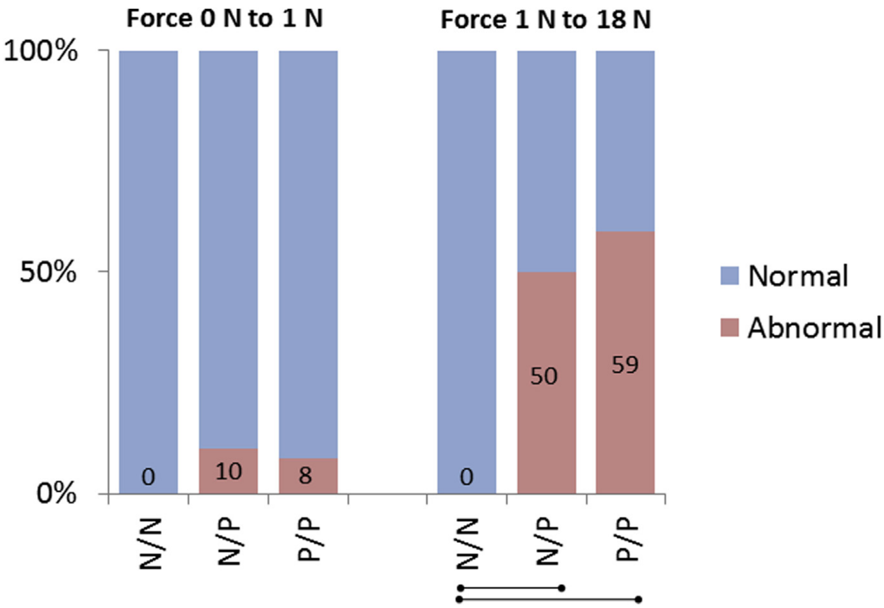
We reject the null hypotheses that women with normal apical support on POP-Q but vaginal wall prolapse (cystocele and/or rectocele) have the same cervix location and apical support stiffness as women with normal pelvic support in all areas. Approximately 50% of women with cystocele and/or rectocele but normal cervical support in the clinic had cervix locations that fell outside the normal range with intraoperative traction. Therefore, half of these women with a normal value for POP-Q point C had normal cervical support and half did not. Conversely, our data also show that a quarter of women who had prolapse of point C below the normal range on POP-Q actually have normal cervix locations and apical support stiffness under standardized traction.

Biomechanical studies clearly show that ligament properties interact with the pelvic floor closure caused by the levator ani muscles to determine pelvic organ support.[9] This helps show why measures of ligament properties do not explain all apical descent.[9] For example, only a small traction force (3 oz, or the weight of a large chicken egg) is needed to cause the amount of displacement seen physiologically during maximal Valsalva in magnetic resonance imaging.[10] This observation is consistent with the hypothesis that the levator ani muscles act to close the pelvic floor so that increases in intraabdominal pressure do not result in a downward force on the ligaments.[11,12] This is also consistent with a slack-cord paradigm, where movement of the uterus near its normal location is determined by the status of the pelvic floor, with the apical ligaments playing a larger role once greater degrees of descent occur.[13] Therefore, the substantial discrepancy between cervix locations during apical support testing suggests that some properties of cervical support are not captured well by POP-Q examination.

Another important relationship to consider is that of the anterior vaginal wall and uterine support.[2] Theoretically, the downward traction force created by a large cystocele may lead to cervical descent in a woman with otherwise normal apical ligament properties. In that scenario, repairing the cystocele alone may result in improved apical support even in the absence of hysterectomy or apical suspension. The future development of simplified apical support testing strategies, once validated, would help distinguish which patients need hysterectomy and/or apical suspension procedures as part of treatment for prolapse.

We recognize that anesthesia might affect apical ligament properties, so we used the measurements of women with normal apical and vaginal support to define a normal range of uterine location under each different testing condition. Defining what is normal is an important first step in being able to define what is truly abnormal, and to then use that information for clinical decision-making. The concept of what a surgeon

FIGURE 3
Proportion of women with apical support stiffness within and outside normal range



For 3 groups of women with varying degrees of pelvic organ support, proportion in whom cervix location is within and outside normal range under different traction forces. Groups defined as follows: normal/normal (N/N) is normal apex ($C \leq -5$ cm)/normal vaginal wall support (Ba and Bp < 0 cm); normal/prolapse (N/P) is normal apex/prolapse of vaginal wall(s) (Ba and Bp ≥ 0 cm); and prolapse/prolapse (P/P) is prolapse of apex ($C > -5$ cm)/prolapse of vaginal wall(s); *P* value $< .05$.

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believes to be normal has clinical implications. In a prior survey of gynecologic surgeons, 75% reported that if intraoperative cervix location with traction was at the level of the hymen at the time of anterior repair, they would also perform a hysterectomy.[4] However, in our study, 100% of women in the normal/prolapse group and 50% of women in the normal/normal group had cervix locations at or below the hymen with traction. Because some degree of cervix displacement is expected in the operating room, even among women with clinically normal pelvic support in all areas, using this group to define the normal range of cervix location takes into consideration unmeasured differences between the clinic and operating room conditions (eg, anesthesia, leg positioning, type of speculum used). Therefore, compared to simply having an absolute cervix location threshold for performing hysterectomy, identifying women whose apical support falls outside a defined normal range may be a more accurate way to identify those who truly need a hysterectomy and/or an apical support procedure and to spare those who do not.

Our final objective was to identify clinical and biomechanical factors independently associated with clinic POP-Q point C and to determine whether these factors vary among women in the normal/normal group, the normal/prolapse group, and the prolapse/prolapse group. The only variable that remained significantly associated with POP-Q point C was cervix location under the minimal traction force in the operating room for women in the prolapse/prolapse group. This finding can be partially explained by the fact that apical support stiffness was lowest in women in this group; therefore, it requires less traction force to move the cervix a certain distance and to reproduce POP-Q point C location in the operating room. However, we know that apical ligament stiffness only explains 19% of cervical descent seen with maximal Valsalva during clinic POP-Q examination,[7] so other factors, such as apical ligament length and the traction on the cervix produced by a cystocele, may help explain this finding.

Our findings add to, extend, and confirm information about our evolving picture of apical support mechanics. Prior research measuring apical ligament length using 3-dimensional stress magnetic resonance imaging has found that compared to women with normal support, the cardinal ligaments of women with prolapse are 20% longer at rest (71 vs 59 mm).[14] Additionally, the amount of elongation that occurs (change from

TABLE 3
Apical support stiffness and cervix displacement in 3 groups of women with varying degrees of pelvic organ support

	Normal/normal, N = 14	Normal/prolapse, N = 11	Prolapse/prolapse, N = 27	Overall *P* value[a]
Apical support stiffness, N/mm				
0-1 N	0.09 ± 0.62	0.12 ± 0.39	0.04 ± 0.79	.94
1-18 N	0.63 ± 0.20	0.50 ± 0.12	0.47 ± 0.18	.02
Cervix displacement, mm				
0-1 N	6.66 ± 5.42	11.85 ± 19.97	9.65 ± 9.32	.53
1-18 N	30.2 ± 7.20	37.29 ± 7.62	42.63 ± 13.24	.005

Data reported as mean ± SD.

[a] *P* values comparing group means were determined by simple linear regression models. Results did not substantively change after controlling for age and parity in regression models.

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TABLE 4
Correlations between Pelvic Organ Prolapse Quantification point C and cervix locations in operating room and apical support stiffness

Properties	Normal/normal	Normal/prolapse	Prolapse/prolapse	Overall
Apical support stiffness				
0-1 N	0.095	.184	−0.074	−0.058
1-18 N	−0.126	.195	−0.068	−0.247
Cervix location				
1 N	0.080	.626[a]	.819[b]	0.785[b]
18 N	0.137	.609[a]	.790[b]	0.793[b]

Pearson correlation coefficients used to assess association between Pelvic Organ Prolapse Quantification point C and cervix location and stiffness measurements.

[a] P value $< .001$; [b] P value = .05−.06.

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rest to maximal Valsalva) in the cardinal and deep uterosacral ligaments is twice as great in women with prolapse compared to those with normal support. Our results also support earlier findings that cervix location at maximal operating room traction (18 N) is a predictor of POP-Q point C.[7] However, data in the present report expand upon the prior study by comparing results between groups of women with different levels of pelvic support. Through this comparison we were able to show that the prolapse/prolapse group was the primary driving force behind this significant correlation, but that this was not true in the other 2 groups. Furthermore, we found that cervix location under 1 N of traction force was actually the greatest predictor, accounting for 67% of the variation seen in clinic POP-Q point C.

Our study is strengthened by the use of a servoactuator that can precisely measure cervix location, displacement, and traction force far more accurately than is clinically feasible. It also allows apical support stiffness to be quantified under different loading conditions. Furthermore, establishing a normal range of uterine movement under different conditions allows us to make the clinically important assessment of which cervical support properties are normal and which are not. We hope future analyses will be able to validate our findings and apply this concept in larger, comparative studies.

Limitations of this study include a small sample size, which may have been underpowered to detect some differences; however, the differences we have noted all reach statistical significance—indicating sufficient power to answer those questions. Now that these analytical strategies are established and effect size is known, power calculations and larger studies can be performed to examine other important relationships. We note that we could not measure the length or stiffness of the apical ligaments directly. We also had no way of measuring or accounting for cervical lengthening that may have occurred with traction. Because the origins of the apical ligaments are fixed to the bony pelvis that does not move during testing, we believed that tracking cervix location and changes in this location under the traction force was a reasonable proxy for length to estimate apical support stiffness.

Establishing an objective test that can measure relevant mechanical properties of cervical support could, once validated in clinical practice, provide important information to ensure that women who need surgery for apical support receive treatment, while those who do not are spared the morbidity of additional and potentially unnecessary surgery. ■

TABLE 5
Multivariable linear regressions for factors associated with Pelvic Organ Prolapse Quantification point C in 3 groups of women with varying degrees of pelvic support

Variable	Normal/normal, B (SE)	Normal/prolapse, B (SE)	Prolapse/prolapse, B (SE)
Constant	−3.21 (4.31)	−16.35 (7.20)	−4.83 (3.51)
Cervix location at minimal force [1 N]	0.01 (.04)	0.01 (.03)	0.12 (.02)[a]
Apical support stiffness, N/mm	−3.75 (4.64)	7.26 (7.94)	−4.71 (3.34)
Age, y	−0.05 (.06)	−0.02 (.05)	0.03 (.04)
BMI, kg/m^2	0.04 (.11)	0.12 (.11)	0.13 (.11)
Parity	0.34 (.54)	1.6 (10)	0.35 (.40)
Adjusted R^2	−0.45	0.23	0.65[a]

Performed as function of cervix location at minimal force, stiffness, BMI, age, and parity.

BMI, body mass index.

[a] $P < .001$.

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