Effects of Aging on Lower Urinary Tract and Pelvic Floor Function in Nulliparous Women

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OBJECTIVE: To evaluate the effects of aging, independent of parity, on pelvic organ and urethral support, urethral function, and levator function in a sample of nulliparous women.

METHODS: A cohort of 82 nulliparous women, aged 21–70 years, were recruited from the community through advertisements. Subjects underwent pelvic examination using pelvic organ prolapse quantification, urethral angles by cotton-tipped swab, and multichannel urodynamics and uroflow. Vaginal closure force was quantified using an instrumented vaginal speculum. Subjects were grouped into five age categories and analyses performed using *t* tests, Fisher exact tests, Kruskal-Wallace, and Pearson correlation coefficients. Multiple linear regression modeling was performed to adjust for factors that might confound the results of our primary outcomes.

RESULTS: Increasing age was associated with decreasing maximal urethral closure pressure ($r=-0.758$, $P<.001$) with a 15-cm-H_2O decrease in pressure per decade. Pelvic organ support as measured by pelvic organ prolapse quantification did not differ by age group. Levator function as measured by resting vaginal closure force and augmentation of vaginal closure force also did not change with increasing age.

CONCLUSION: In a sample of nulliparous women between 21 and 70 years of age maximal urethral closure pressure in the senescent urethra was 40% of that in the young urethra; increasing age did not affect clinical measures of pelvic organ support, urethral support, and levator function.

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LEVEL OF EVIDENCE: III

Pelvic floor disorders are common, costly, and distressing conditions for women.[1–4] These problems lead to over 300,000 operations per year, as well as considerable suffering from conditions not readily corrected with surgery.[5] Pelvic floor disorders such as urinary incontinence and pelvic organ prolapse are known to increase with age.[6,7] With the number of elderly women more than doubling in the United States between 2000 and 2050,[8] there will be an increased demand for services to care for female pelvic floor disorders.[9] Widely used clinical measures of pelvic floor function include the pelvic organ prolapse quantification system,[10] urodynamic testing, and the cotton-tipped swab (Q-tip, Unilever United States, Inc., Englewood Cliffs, NJ) urethral test.[11] These tests not only guide therapy for patients with pelvic floor disorders, but are also used as investigational tools for measuring pelvic support and urethral mobility and function.

There are a limited number of studies that have examined the effect of age on pelvic floor structure and function in the absence of disease.[12] Now that the adverse effects of parity on the pelvic floor have been elucidated,[6,13] most of the classic older studies of the effects of age on the pelvic floor[14,15] may be seen to be confounded by the inclusion of women of mixed parity. For this reason we sought to study the effect of age on pelvic support, urethral support and function, and levator function in a group of nulliparous women ages 21–70 years.

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METHODS

This was a cross-sectional study of age-related changes in urethral support and function, pelvic support, and levator function. Community-dwelling nulliparous women were recruited through local advertisements and professional referrals between March 2004 and December 2005. Women were eligible for participation if they were willing to undergo a physical examination regardless of race, continence, or prolapse status. Women with prior prolapse surgery, genital anomalies, radiation therapy, and hysterectomy within the prior year were excluded. In addition, women were screened and excluded from the study if they were currently being treated for cancer, had a history of any transplants, chronically used steroids, were human immunodeficiency virus–positive, had sickle cell disease, or had neurologic conditions, including multiple sclerosis, uncontrolled diabetes, stroke, Alzheimer's disease, or other dementias. A telephone interview included questions about medical and surgical history as well as symptoms of pelvic floor dysfunction. Because data concerning these characteristics in nulliparous women were not available, we planned to recruit at least 10 women per decade from 21–70 years of age, and the results of this study include a total of 82 women. To date, there is no preliminary data available in the literature for the purposes of forming a power analysis. We performed a post hoc power analysis when the total sample size across the five age groups was 82; a one-way analysis of variance will have 95% power at the 0.05 level to detect a moderate effect size of 0.25. Informed consent was obtained from each participant, and this study was approved by the University of Michigan's institutional review board.

A complete history was obtained including subject's age, race, obstetric, gynecologic, and surgical history by interview. Subjects who met eligibility criteria were scheduled for clinical evaluation. The standardized examination included height, weight, and pelvic organ support evaluation using the pelvic organ prolapse quantification system (POP-Q).[10] Urethral support was assessed by measuring mobility at rest and during Valsalva of a cotton-tipped swab inserted into the urethra,[11] and bladder and urethral function evaluated with postvoid catheterization for residual volume, multichannel urodynamics, and uroflow. Levator ani muscle function was assessed with a vaginal speculum specially designed to isometrically record the forces acting on the anterior and posterior bills of the speculum as the muscle acts to close the pelvic floor.[16] All examinations were performed by one of four urogynecologists.

For all subjects, the pelvic examination was performed with the subject seated in a birthing chair at a 45° angle. POP-Q measurements were then recorded at maximal Valsalva strain. The external urethral meatus was swabbed with povidone-iodine (Betadine, Purdue Frederick Co., Norwalk, CT) and the urethra filled with 1% lidocaine gel. An 8-F Mentor (Mentor Corp., Santa Barbara, CA) catheter was placed 3–4 cm into the urethra, and the postvoid residual volume measured. A small cotton-tipped swab was inserted within the catheter to straighten it for axial mobility measures and avoid the discomfort of cotton-tipped swab insertion directly into the urethra. The urodynamics chair was adjusted so as to assure that the subject's perineum was perpendicular to the floor, as judged by visual approximation. All urethral axial mobility measurements were made with a standard protractor placed near the subject's perineum. With the 0 degree mark held in a horizontal orientation the degree of the catheter in a resting position was designated as the mobility at rest. An additional measurement was made with maximal Valsalva strain making sure to keep the zero mark on the protractor intersecting the catheter. An 8-F microtip dual Gaeltec sensor catheter (Medical Measurements Inc., Hackensack, NJ) and 10F filling catheter were inserted, and the bladder was retrograde filled at 50 mL/min of normal saline. At a filling volume of 300 mL, Valsalva and cough leak point pressures were recorded. Maximal urethral closure pressures were measured by withdrawing a dual-tip catheter at a constant rate oriented at a 3 or 9 o'clock position. Three serial urethral pressure profile measurements were taken and an average of these measurements was used for analysis. A positive full bladder stress test was defined as urine leakage with cough or Valsalva seen during examination after filling the bladder to a volume of 300 mL.

The instrumented vaginal speculum was inserted, and vaginal closure force was measured both at rest and during maximal voluntary contraction. Augmentation of vaginal closure force was calculated as the difference between the force generated at maximal voluntary contraction and vaginal closure force at rest, that is, the amount of force generated above resting values. Specifics of this technique have been previously described along with its reliability.[17] Upon completion of the physical examination, the subject was asked to sit on a commode and complete the uroflow testing after the catheter had been removed.

Analysis was performed using SPSS 13.0 statistical software (SPSS Inc, Chicago, IL). Categorical variables were compared using Fisher exact tests.

Continuous variables were compared across groups using *t* tests or Kruskal-Wallace as appropriate. Pearson correlations were used to analyze relationships between continuous variables. Multiple linear regression was used to study the relationship between various outcome measures and age, body mass index, postmenopausal status, and history of hysterectomy.

RESULTS

A total of 82 women were enrolled. Body mass index, race, menopausal status, and history of prior hysterectomy are summarized in Table 1, stratified by age decade. Significant differences by age groups were observed for body mass index, menopausal status, and history of hysterectomy, but not for race. Two individuals were excluded from the study because of a history of prior surgery for stress incontinence. Overall, this was a healthy population, with 81.7% of women self-reporting "Excellent or Very Good" health. Medical conditions self-reported by subjects included hypertension (19.5%), diabetes mellitus (2.4%), lung disease (17%), heart disease (4.9%), arthritis (39%), and neurologic disease (2.4%). Seventeen percent of women self-reported losing urine at least 12 times in the past 12 months.

Increasing age was associated with a decreasing maximal urethral closure pressure ($r=-0.758$, $P<.001$) averaging a 15-cm-H_2O drop per decade (Fig. 1). Another way of characterizing the rate of decline over time is to observe that the maximal urethral closure pressure values of women aged between 60 and 70 years is only 40% of that observed in women between 20–30 years of age. The average maximal urethral closure pressure for each age group is summarized in Table 2. To evaluate the within-subject variability of maximal urethral closure pressure, we performed a one-way analysis of variance in which there were 82 strata (ie, subjects) and three determinations of maximal urethral closure pressures for each subject. We found that 98% of the total variance was explained by subjects and the mean square error of the model (ie, the average within-person standard deviation) was 4.62. This would suggest that the variance among repeated tests on the same individual was very small in comparison to the variance among subjects.

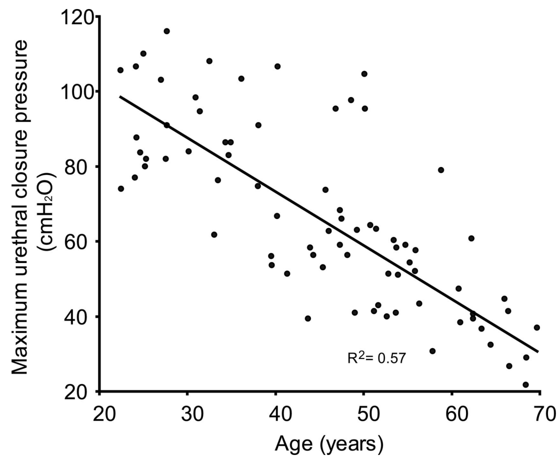

Fig. 1. Relationship between age and maximal urethral closure pressure.

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There was no difference in cotton-tipped swab angles at rest or at maximal strain with increasing age. Maximal flow (shown), average flow, and peak flow time (not shown) did not change with increasing age (Table 2). There was no correlation between maximal urinary flow and age ($r=0.07$, $P=.56$). Postvoid residual did not differ among the five age categories. A positive full bladder stress test was more common among older women, although this did not reach statistical significance. A total of nine of 82 women in the study leaked urine, and this small number precluded the analysis of the effect of age on leak point pressures.

Pelvic organ support, as measured by POP-Q, and levator function, as measured by resting vaginal closure force and augmentation of vaginal closure force, did not differ among the five age groups (Table 2). Perineal body length was the only POP-Q measurement that differed among the five age groups; however, there was not a linear relationship between perineal body length and increasing age. There was

Table 1. Patient Characteristics Stratified by Age Decade

Age decade	21–30 (n=15)	31–40 (n=14)	41–50 (n=19)	51–60 (n=20)	61–70 (n=14)	*P*
BMI (kg/m²)	20.4 (17–29)	28.1 (19–46)	25.9 (14–40)	28.1 (21–43)	25.3 (19–42)	.001
Race (% white)	100	92.9	84.2	95.2	92.9	.58
Postmenopausal (%)	0	0	15.8	80.0	100	.001
Prior hysterectomy (%)	0	0	15.8	0	42.8	.001

BMI, body mass index.
Data are median and (range).

Table 2. Urethral Support and Function, Pelvic Support, and Levator Function in Nulliparous Women Stratified by Age Decade

Age Decade	21–30 (n=15)	31–40 (n=14)	41–50 (n=19)	51–60 (n=20)	61–70 (n=14)	*P*
Urethral and bladder function						
MUCP (cmH_2O)	92.1±13.3	82.0±18.4	67.0±19.3	52.4±15.9	36.6±9.9	<.001
Maximal flow (mL/sec)	30.2±11.1	26.4±12.1	32.7±11.2	33.9±14.3	28.8±10.6	.42
PVR (mL)	16.7±28.0	30.0±41.2	35.1±29.5	35.6±36.4	18.3±13.7	.25
Positive SUI test (%)	0	0	15.7	20.0	14.3	.19
Urethral support (°)						
Cotton-tipped swab–rest	−19.7±12.2	−11.5±15.7	−12.6±12.1	−11.2±10.6	−15.6±14.9	.37
Cotton-tipped swab–strain	8.6±19.70	11.5±11.6	12.8±13.7	14.5±14.7	5.6±19.2	.50
Pelvic support (cm)						
Point AA	−2.3±0.7	−1.9±0.6	−1.8±0.7	−1.7±0.8	−2.1±1.0	.23
Point BA	−2.2±0.7	−1.9±0.5	−1.7±0.7	−1.7±0.8	−2.0±1.2	.42
Point C	−6.4±1.1	−6.9±1.5	−6.5±1.6	−6.7±1.5	−6.7±2.1	.91
Point AP	−2.7±0.6	−2.3±0.8	−2.1±0.6	−2.1±1.0	−2.1±1.0	.10
Point BP	−2.7±0.6	−2.3±0.8	−2.1±0.6	−2.0±1.1	−2.0±1.1	.08
Genital hiatus	2.0±0.8	2.5±0.6	2.0±0.6	2.0±0.8	2.1±1.1	.46
Perineal body	3.5±0.7	4.5±0.9	4.0±1.1	4.0±0.9	3.3±1.5	.03
Levator function (N)						
VCF, rest	4.4±1.5	5.2±1.5	4.7±1.3	5.0±1.2	4.8±2.5	.69
VCF, maximal	8.0±3.3	8.5±2.0	7.3±2.0	8.4±2.0	7.5±2.7	.51
VCF, augmented	3.5±3.2	3.3±1.6	2.7±1.3	3.5±1.9	2.7±1.6	.59

MUCP, maximal urethral closure pressure; PVR, post void residual; SUI, stress urinary incontinence; VCF, vaginal closure force.
Data are mean±standard deviation.

no correlation between age and point C (edge of cervix or vaginal cuff) of the POP-Q evaluation (r=−0.102, P=.36). There was no correlation between augmented vaginal closure force and age (r=−0.11, P=.35).

In building a linear regression model for maximal urethral closure pressure, we found that age alone explained 57.4% of the variance in maximal urethral closure pressure. When we added, in turn, race, body mass index, postmenopausal status, and history of hysterectomy to the model containing age, only race was significant. The R-square associated with this two-variable model was 62.2% indicating that race contributed an incremental R-square of 4.8%. In this model, the coefficient for age was −1.468 (standard error=0.142, P<.001) indicating a loss of 15 cm H_2O per decade. The coefficient for race (coded 0=African American, 1=white) was −20.827, indicating that African-American subjects had higher mean maximal urethral closure pressures.

There was also a significant relationship between age and posterior vaginal support as defined by point BP. The coefficient for age was 0.013 (standard error=0.006, P<.003). Age explained only 6.6% of the variance in posterior vaginal support.

DISCUSSION

In this study of nulliparous women, maximal urethral closure pressure decreased with increasing age, whereas pelvic organ support, urethral support, and levator function were not affected by increasing age. Maximal urethral closure pressure decreased linearly with increasing age, averaging 15 cm H_2O decrease per decade (Fig. 1). We did not observe changes in bladder function (postvoid residual, maximal, or average urinary flow) with increasing age.

Levator function, as measured by vaginal closure force with an instrumented vaginal speculum, also did not change with increasing age. This result is somewhat surprising given the well-known age-related loss that occurs in striated muscle cross-sectional areas[18] and strength[19] in the extremities, as well as the loss in the striated muscle of the urethral sphincter with age.[20] Part of the explanation for the lack of an age effect in augmentation of vaginal closure force could lie in the finding that the levator ani are predominantly populated by slow twitch (type 1) fibers (66%), while fast twitch (type 2) fibers (34%) constitute only a third of the fibers.[21] Because both the number and diameter of slow twitch fibers are largely unaffected by age,[22] and these constitute the majority of the levator ani muscle, the lack of an age effect on levator type 1 fibers may partly explain the lack of an age effect in augmentation of vaginal closure force. A second, complementary explanation for the lack of an age effect in augmentation of vaginal closure force may be a central activation failure in the maximal recruitment of levator ani muscle fibers in women of all ages. It is well known that women can have difficulty in correctly contracting their pelvic floor muscles, let alone maximally contracting them.[23] Since Henneman's size principle[24] dictates that in a volitional contraction the smaller motor neurons innervating slow type 1 fibers are recruited before the larger motor neurons innervating the fast type 2 fibers, the present results suggest that women across the age spectrum were able to recruit their slow fibers. But they may not have been able to recruit their largest and fastest fibers during the augmentation of vaginal closure force test, a fact that could only be confirmed by applying supramaximal electrical stimulation.[25] The explanation of why an age effect in augmentation of vaginal closure force was not found may be that, even although advancing age principally reduces the number of fast fibers due to loss of the largest motor neurons,[26] these women were unable to volitionally recruit their largest levator ani motor neurons and type 2 fibers at any age.

The age-related decrease in mean urethral closure pressure found in these nulliparous women corroborates and extends a similar finding in groups containing multiparous women.[14,15] These changes most likely reflect histologic changes seen in urethral striated muscle, blood vessels, and connective tissue. For example, a decrease with age has been found in the relative volume of striated muscle and blood vessels, but no change in the smooth muscle components of the urethra.[27] Similarly, Perucchini et al[28] reported a decrease in the number and density of urethral striated muscle fibers with increasing age. It should also be noted, however, that at any given age there are also large differences among individuals. In the figure, for example, at age 50 years there are women with pressures as low as 40 cm H_2O and as high as 110 cm H_2O. The reasons for these large individual variations remain to be explained. Although the traditional paradigm has considered stress incontinence to be primarily a problem of urethral support, there is strong theoretical[29] and clinical evidence for the importance of urethral closure pressure being involved as well.[14,30]

We observed a 19% higher mean maximal urethral closure pressure in nulliparous African-American women compared with white women in our study. These finding are similar to those of Howard et al[31] who also observed that African-American subjects had a 14% higher mean maximal urethral closure pressure.

There is a paradox between this lack of age-related changes in pelvic support, urethral support, and levator function as measured clinically as compared with epidemiologic studies that show a clear relationship between aging and an increased prevalence of pelvic floor disorders.[6,32] Our results suggest that epidemiologic findings are likely to describe disease-related effects rather than age-related effects in pelvic support, urethral support, and vaginal closure force. They also suggest that the increased incidence of prolapse with age may be related to changes in tissue characteristics not measured in this study. For example, a study of biomechanical properties assessing premenopausal and postmenopausal vaginal tissue reported a significantly higher elastic modulus in postmenopausal vaginal tissue.[33] The elastic modulus is the relationship between stress and strain (stress divided by strain). Thus, with a higher elastic modulus the strain-stress curve is steeper. The higher elastic modulus indicates that the older tissues are stiffer and that for a given tensile force, the older tissue will stretch less. But the fact that age did not affect vaginal closure force at rest suggests that age-related changes in vaginal tissue elastic modulus did not affect the speculum measurements.

Strengths of this study include a standardized and comprehensive clinical evaluation of pelvic support and function in a group of nulliparous women aged 21–70 years. Although this study was not designed or powered to estimate normal pelvic anatomic or functional characteristics for nulliparous women, our statistically significant findings suggests a strong association between increasing age and declining urethral function in the absence of parity. Prior studies evaluating nulliparous women have been limited by their inclusion of mostly young women with no comparison to older nulliparous women.[14,15] One limitation is that this cross-sectional study is only an approximation of the "natural history" of pelvic function in a group of subjects independent of parity. However, this study does provide reasonable approximations of pelvic floor function in the absence of longitudinal studies. Our small cohort also limited our power to observe differences among these five age categories.

Pelvic floor disorders impair the lives of a large number of women of all ages throughout the world. A lack of basic understanding of the mechanism involved in these conditions and their implication for treatment has impeded our progress in their treatment. This study adds to the growing body of information of the cause and underlying causes of pelvic floor disorders. Specifically, we describe a linear relationship between increasing age and mean urethral closure pressure. These findings suggest the importance of educating women's health providers about screening and seeking early treatment for urinary symptoms, because our study suggests a strong association between aging and a declining continence mechanism.

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