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ORIGINAL ARTICLE

Effects of delivery mode and age on motor unit properties of the external anal sphincter in women

Xuhong Li[1] · Chuan Zhang[2] · Nicholas Dias[2] · Jiaojiao Liu[1] · Fang Hu[1] · Shuo Yang[1] · Yanhua Zhou[1] · Yingchun Zhang[2]

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Abstract

Introduction and hypothesis This study aimed to assess the individual and interactive effects of delivery mode and age on the function of the external anal sphincter (EAS) by analyzing the motor unit properties with intramuscular electromyography (EMG). Results are expected to improve the understanding of delivery-related occult obstetric EAS injuries and its development over the aging process and further support early clinical detection and intervention.

Methods A total of 49 postpartum women were recruited into four test groups according to their age and delivery mode: young vaginal delivery (Y-VD), elderly vaginal delivery (E-VD), young cesarean section (Y-CS), and elderly cesarean section (E-CS) groups. Anorectal ultrasonography, manometry, and intramuscular EMG were employed for comprehensive evaluation of EAS function.

Results No significant difference in anorectal ultrasonography and most manometry measurements was associated with delivery age or mode. Intramuscular EMG, however, revealed a statistically significant difference in the characteristics of motor unit potentials (MUPs), including duration, turns, phases, and multiphase wave ratio between four subject groups. No significant interaction effect between age and delivery mode was found.

Conclusions Delivery mode and age have a significant effect on the neuromuscular function of the EAS, suggesting a potential protectiveness of cesarean section against impairment to the EAS. Our results do not provide significant evidence regarding the interaction effect of delivery mode and age; further investigations are needed to confirm this conclusion.

Keywords Aging · External anal sphincter · Delivery mode · Intramuscular electromyography · Motor unit potential analysis

Abbreviations

AI	Anal Incontinence
EAS	External anal sphincter
E-CS	Elderly cesarean section
EMG	Electromyography
MUP	Motor unit potential
Y-VD	Young vaginal delivery
Y-CS	Young cesarean section
E-VD	Elderly vaginal delivery

✉ Yingchun Zhang
yzhang94@uh.edu

[1] The Third Xiangya Hospital, Central South University, Changsha, China

[2] Department of Biomedical Engineering, University of Houston, 360 HBS Building, 4811 Calhoun Rd., Houston, TX 77004, USA

Introduction

Child delivery and aging have been evidenced as strong risk factors for pelvic floor disorders in women. Particularly, anal incontinence (AI), defined as involuntary leakage of gas or stool, negatively impacts the quality of life (QoL) of 25% of women during their first postpartum year or many years after delivery [1–3]. It is commonly accepted that mechanical tear to the external anal sphincter (EAS) is associated with weakened muscle force and an increased likelihood of anal or fecal incontinence (FI) [4]. Additionally, the fact that AI also presents in a considerable portion of women without recognized sphincter injury indicates an occult etiology [1]. Prior studies report evidence of impaired peripheral innervation in postpartum AI patients, with or without direct sphincter tear [5, 6], suggesting a dual pathology associated with the postpartum sphincter disruption [7].

Prior longitudinal studies have shown that the incidences of AI and anorectal functions deteriorate over time [1, 8]. It has been hypothesized that obstetric neurological injury may accelerate neuromuscular changes associated with the normal aging process, resulting in a rapid loss of EAS function [9]. However, there has been no effort to evaluate whether delivery mode and advancing age interact to increase the prevalence of EAS neuromuscular dysfunction in middle-aged or elderly parous women. The lack of pathophysiological understanding of neurological EAS injury further may impede early clinical diagnosis and proper postpartum management in the prevention of AI.

Despite recent technical advances in anorectal ultrasonography (US) and manometry, these methods are still limited to anatomical and functional evaluations of the anal sphincters. Pudendal nerve motor latency examination detects the properties of nerve conduction, yet its reliability has been questioned [10]. Intramuscular electromyography (EMG) has long served as a sensitive clinical routine for the diagnosis of neuromuscular diseases. This study aimed to assess the function of the EAS in postpartum women with different delivery modes and ages by systematically evaluating EAS function with US, manometric, and multi-motor-unit potential (multi-MUP) analysis technique.

Materials and methods

Participants

Forty-nine healthy parous women were recruited. Participants aged between 20 and 40 years were recruited into the young group and those >50 years into the elderly group. Women were then grouped based on their modes of delivery:

(1) Young women with vaginal delivery (Y-VD)
(2) Elderly women with vaginal delivery (E-VD)
(3) Young women with elective cesarean section (Y-CS)
(4) Elderly women with elective cesarean section (E-CS)

Participants were screened with a medical history check, questionnaires, and pelvic floor examination. A customized questionnaire was developed to collect demographic information, medical history, and health status, including obstetric history, presence of urinary incontinence (UI) or ,AI and neurological disorders. Exclusion criteria included history of neurological disorders, heart disease, prescribed anticoagulants, pelvic surgery, mixed delivery mode, or any other chronic diseases that may potentially complicate the neuromuscular function of EAS or data collection. Women presenting with AI or urinary tract infection (UTI) were also excluded. Specifically, in vaginal delivery groups, women who had undergone episiotomy and obstetric sphincter tear (third- or fourth-degree perineal lacerations) were excluded. Diagnosis of AI was by type and frequency of incontinence presentations. Forty-nine women were considered eligible for the study. The experimental protocol was reviewed and approved by the local Institutional Review Board. All women gave informed consent.

Anorectal ultrasound and manometry

Integrity and continuity of the EAS on the transverse section of the anal canal was observed under resting state using a GE Voluson P8 US system (General Electric, MA, USA). US images of the EAS were obtained as described by a previous study [11]. The presence of an anatomical defect and/or muscle atrophy was noted. After transperineal ultrasound (TUS), basal and squeezing pressures of the EAS were assessed with a Triton anorectal manometry system (LABORIE Corp., Toronto, Canada) attched to an air-pressured balloon. Manometric parameters of anorectal resting pressure (mmHg), maximum squeezing pressure (mmHg), functional length under contraction (cm), distension pressure (mmHg), first sensation to rectal filling (ml), first urge to defecate (ml), maximum rectal tolerance volume (ml), and rectal defecation pressure (mmHg) were acquired using a standard pull-through technique for group comparison.

Electrophysiology recording

All women were placed in the lithotomy position and after being given instructions on how to properly contract the EAS. Two Dantec disposable concentric needle electrodes (9013S0032, Natus Neurology Inc., WI, USA) were then inserted into both sides of the EAS [9]. Needle electrodes measured 37 mm in length with 25-gauge diameter. A fully soaked Velcro wristband was grounded to the right wrists. EMG was amplified and recorded at 48 kHz and analyzed by a Dantec Keypoint system (9033A07, Natus Neurology). Data were acquired in epochs of 300 ms and bandpass filtered at 5–3000 Hz. Signal quality was monitored via a display screen and audio feedback. Each woman was instructed to contract the EAS with mild effort. Proper insertion of needle electrodes was confirmed by visualization of motor unit spike signals and audio feedback [12]. At least ten distinct motor units were recorded for each woman. MUP features were extracted automatically by the recording system [13]. Features including amplitude (value between maximal negative and positive peak), duration (interval between defined MUP onset and offset), area (integral of rectified MUP), turns (amplitude changes of 100 μV threshold), phases (baseline crossing of one MUP), and multiphase wave ratio (percentage of multiphasic waveforms) were obtained for each recorded MUP and averaged for all detected motor units and compared between

groups [13]. Results are presented in form of mean [standard deviation (SD)].

Statistical analysis

Manometric and MUP features of the EAS were summarized using Microsoft Excel 2003 (Microsoft Corporation, WA, USA). Statistical analysis was performed using SPSS 23.0 statistical software (SPSS Inc., Chicago, IL, USA) and Matlab (R2017a, Mathworks Inc., Natick MA, USA). Differences in demographic, manometric, and MUP features were estimated with multiple comparisons between different groups using a two-sample Student's *t* test with Bonferroni correction. Fisher's exact test was used to compare categorical difference in the condition of perineal laceration in vaginal delivery groups only. The effects of delivery mode and age on manometric and MUP features were analyzed by factor analysis. Statistical significance was accepted at $p < 0.05$.

Results

Demographics of height, weight, age, parity, and frequency of bowel movements are listed in Table 1. No significant difference was observed between groups in weight, height, body mass index (BMI), gravidity, and parity after Bonferroni correction. Two of 15 women in the Y-VD group and three of 14 in the E-VD group were negative for obstetric perianal lacerations. Fisher's exact test was used to evaluate group differences regarding perineal lacerations in the vaginal delivery group, and results reveal no statistically significant difference between Y-VD and E-VD ($P = 0.65$).

Comparison of manometric features of the EAS between cohorts is summarized in Table 2. No statistical difference was found between groups regarding anorectal resting pressure, squeezing pressure, functional length under contraction, distension pressure, first sensation of rectal filling, rectal urge to defecate, and maximum tolerance volume. A significantly lower defecation pressure was found in the E-CS vs the Y-CS group. Additionally, no significant impact of interaction effect was observed in the aforementioned manometric indicators.

Comparison of EAS EMG features among cohorts is shown in Table 3. Compared with the elderly groups, young women tended to have significantly lower MUP durations, turns, phases, and multiphase wave ratio. Meanwhile, compared with women who had undergone cesarean section, women that have undergone vaginal delivery tended to show higher MUP duration and turns. In young women, women that have undergone vaginal delivery also showed lower phases and multiphase wave ratio; yet a similar difference was not observed between the elderly groups. No significant difference was found in MUP amplitude and area after applying the Bonferroni correction.

Using delivery mode and age as influencing factors, factorial analysis assessed the effects of both on six MUP features of all women. No significant difference was found in interaction effect between delivery modes and age factors and amplitude ($p = 0.99$), duration ($p = 0.31$), turns ($p = 0.05$), phases ($p = 0.09$), area ($p = 0.38$), multiphase wave ratio ($p = 0.08$), and satellite potential rate ($p = 0.92$).

Discussion

This study aimed to quantify the impact of delivery mode and advancing age on the neuromuscular function of the EAS. We incorporated clinical anorectal imaging, manometry, and intramuscular EMG approaches to provide a complete picture of EAS health. Our results suggest a significant difference in some of the multi-MUP features studied. Women with vaginal delivery tended to exhibit increased duration, turns, phases, and multiphase wave ratio compared with those who underwent elective cesarean delivery. Results suggest that occult neurological EAS defects detected by intramuscular EMG can be attributed to both vaginal delivery and advancing age in

Table 1 Demographic information and Student's *t* test results

	Group mean (SD)				Student's *t* test (*p* value)			
	Y-VD ($n = 15$)	E-VD ($n = 14$)	Y-CS ($n = 14$)	E-CS ($n = 6$)	Y-VD vs. Y-CS	E-VD vs. E-CS	Y-VD vs. E-VD	Y-CS vs. E-CS
Age (years)	29.5 (3.0)	56.0 (3.9)	32.3 (4.0)	53.8 (2.1)	0.0391	0.2231	<0.0001	<0.0001
Weight (kg)	56.2 (7.1)	59.9 (9.3)	58.7 (9.3)	61.4 (8.2)	0.4553	0.9525	0.1298	0.7026
Height (m)	1.6 (0.1)	1.6 (0.1)	1.6 (0.0)	1.6 (0.0)	0.5803	0.6927	0.1823	0.3213
BMI (kg/m^2)	21.8 (2.9)	23.9 (3.5)	22.5 (2.7)	24.1 (2.4)	0.6331	0.7558	0.0501	0.2957
Gravidity	2.1 (0.9)	2.6 (0.7)	2.7 (1.7)	2.3 (0.8)	0.2240	0.2864	0.1111	0.4704
Parity	1.4 (0.5)	1.8 (0.6)	1.5 (0.5)	1.4 (0.5)	0.6040	0.0577	0.0256	0.5181

Y-VD young vaginal delivery, *E-VD* elderly vaginal delivery, *Y-CS* young cesarean section, *E-CS* elderly cesarean section, *BMI* body mass index

Table 2 Manometric features and Student's *t* test results

	Group mean (SD)				Student's *t* test (*p* value)			
	Y-VD (*n* = 15)	E-VD (*n* = 14)	Y-CS (*n* = 14)	E-CS (*n* = 6)	Y-VD vs. Y-CS	E-VD vs. E-CS	Y-VD vs. E-VD	Y-CS vs. E-CS
RP (mmHg)	52.3 (11.0)	46.0 (8.0)	57.5 (8.2)	53.1 (19.2)	0.1082	0.8745	0.1106	0.0192
SP (mmHg)	119.3 (21.6)	104.5 (29.5)	126.0 (18.5)	120.0 (25.3)	0.3184	0.4672	0.1108	0.1620
FLUC (cm)	3.2 (0.2)	2.9 (0.5)	3.2 (0.2)	3.0 (0.8)	0.6156	0.9187	0.1416	0.5546
DisP (mmHg)	39.8 (9.0)	36.4 (6.8)	41.7 (7.4)	39.3 (10.7)	0.4828	0.6903	0.2835	0.3799
DefP (mmHg)	48.3 (10.2)	44.0 (9.9)	51.3 (9.0)	48.9 (23.1)	0.2702	0.3125	0.3482	0.0057
FSRF (ml)	22.0 (8.2)	27.7(15.8)	25.0 (10.0)	27.9 (8.6)	0.4489	0.9092	0.2722	0.4600
FUD (ml)	67.7 (15.3)	71.7 (14.4)	72.3 (20.3)	90.0 (42.5)	0.6140	0.6050	0.5473	0.6838
MTV (ml)	181.3 (46.4)	178.0 (41.3)	204.0 (39.6)	182.9 (37.4)	0.1579	0.7311	0.9362	0.1070

Y-VD young vaginal delivery, *E-VD* elderly vaginal delivery, *Y-CS* young cesarean section, *E-CS* elderly cesarean section, *RP* resting pressure, *SP* squeezing pressure, *FLUC* functional length under contraction, *DisP* distension pressure, *DefP* defecation pressure, *FSRF* first sensation of rectal filling, *FUD* first urge to defecate, *MTV* maximal tolerance volume

healthy women; elective cesarean delivery may be protective against this occult neurological injury. However, no significant results evidenced the interaction effect of either factor on the EAS neuromuscular functions.

Our results are consistent with previous electrophysiological findings on the existence of neurogenic injury in postpartum women. Prior evidence has suggested the existence of occult neurogenic injury to the EAS and levator ani muscles after vaginal delivery, with increased muscle fiber density, altered MUP properties, and prolonged pudendal nerve latency [9, 14–17]. Peripheral alterations in levator ani innervation were also reported using needle EMG, indicating that obstetric damage may not be limited to the pudendal nerve [16]. Alterations in EMG features studied can be largely explained by the remodeling process of peripheral innervation. Vaginal delivery can cause impairment to the peripheral nerve, resulting in axonal damage and muscle denervation. Orphan muscle fibers can be reinnervated by neighboring motor neurons. This pathological innervation remodeling process can result in an increased motor unit size and spatial territory and, consequently, an altered MUP interference pattern. This may be reflected by a more complicated appearance of MUP waveform, with increased average motor unit amplitude, area, duration, turns, phases, and, correspondingly, ratio of multiphasic MUP waveforms [18]. Interestingly, a significant difference between motor unit amplitude (defined by peak-to-peak values) following vaginal and cesarean delivery was not evident in our results. This can be explained by the fact that this injury is very subtle, especially in women with no or minor perineal laceration. However, the significant difference observed in other MUP features was adequate proof of the existence of a neurogenic obstetric EAS injury.

Elective cesarean section can be protective against obstetric anal sphincter injury [4]. Botelho et al. reported a significantly higher pelvic floor contraction strength and vaginal EMG amplitude in women who had a cesarean birth, suggesting preserved pelvic floor muscle neuromuscular function [19]. Our results further show a stronger sign of reinnervation in the EAS of women experiencing vaginal delivery, with higher turns, phases, duration, and multiphase wave ratio, indicating that elective cesarean delivery can, at least partially, help preserve motor unit function. It should be noted that our results

Table 3 External anal sphincter motor unit potential features and Student's *t* test results

	Group mean (SD)				Student's t-test (*P*-value)			
	Y-VD (*n* = 15)	E-VD (*n* = 14)	Y-CS (*n* = 14)	E-CS (*n* = 6)	Y-VD vs. Y-CS	E-VD vs. E-CS	Y-VD vs. E-VD	Y-CS vs. E-CS
Amplitude (μV)	325.5 (51.7)	279.7 (33.5)	341.3 (35.9)	295.7 (32.8)	0.2798	0.4340	0.0156	0.0127
Duration (ms)	11.1 (0.7)	13.2 (0.7)	9.1 (0.6)	11.6 (0.9)	<0.0001	0.0004	<0.0001	<0.0001
Turns	3.6 (0.3)	4.5 (0.2)	2.6 (0.2)	3.7 (0.2)	<0.0001	<0.0001	<0.0001	<0.0001
Phases	4.2 (0.3)	4.5 (0.3)	3.6 (0.2)	4.4 (0.2)	<0.0001	0.3496	0.0004	<0.0001
Area (μV·ms)	472.7 (86.2)	477.2 (64.2)	407.0 (31.9)	443.6 (25.5)	0.0169	0.1501	0.6667	0.0239
MWR	19.6 (6.3)	27.1 (1.3)	13.1 (1.8)	24.6 (3.5)	<0.0001	0.1943	0.0002	0.0002

Y-VD young vaginal delivery, *E-VD* elderly vaginal delivery, *Y-CS* young cesarean section, *E-CS* elderly cesarean section, *MWR* Multiphase wave ratio

do not exclude the effect of pregnancy. The increase in uterine weight and changes in hormone levels can also cause pelvic floor damage during pregnancy; therefore, cesarean delivery is not intended to be fully protective against neurological sphincter injury [20]. However, there is limited understanding as to what extent this injury is attributable to either pregnancy or delivery [19, 21]. Moreover, there is conflicting evidence regarding whether cesarean delivery is protective against postpartum AI [22–24]. Aging, on the other hand, is reported to have a significant impact on the strength of striated muscle; alterations in EAS strength and function associated with aging have been shown. Neill et al. and Laurenberg et al. reported an increased fiber density of EAS after 60 s using single-fiber EMG [25, 26]. Dias et al. revealed an increased innervation asymmetry in elderly healthy women using an intrarectal high-density surface EMG probe [27]. Our results further confirm signs of innervation remodeling in elderly women via MUP analysis, with increased duration, turns, phases, and multiphase wave ratio.

Prevalence studies suggest a higher rate of AI in women vs men, and women tend to be more likely to develop FI with advancing age [4, 28, 29]. This phenomenon is assumed to be associated with both recognized mechanical trauma and occult impairment to the pelvic floor during delivery. The correlation between UI and AI may also suggest the presence of an injury to the common innervating nerve [28]. Hypotheses suggest these occult injuries to the pudendal nerve and EAS innervation will result in a tendency to lose larger motor units because of innervation remodeling after occult obstetric neurological trauma [9]. Therefore, an accelerated loss of muscle function is expected with age. However, our study reveals no such interaction effect between delivery modes and age on manometric or electrophysiological features. Nonetheless, interaction close to significance level was observed for MUP turns ($p = 0.05$), suggesting that the effect of aging may depend on delivery mode. Although no significant interaction was observed in healthy women, whether the conclusion holds in conditions such as in women with third- or fourth-degree sphincter tear—where more severe neurological and mechanical injuries occur—requires further investigation.

Our results found a significant difference in EAS sensorimotor function between the four groups, except for defecation pressure between Y-CS and E-CS. This further suggests that neuromuscular EAS changes are subtle in women without direct sphincter tear and are not necessarily symptom related. Abnormal manometry features were observed in some elderly women, but overall, no difference was found by statistical analysis. Manometry assesses anorectal functional properties, which is affected by multiple factors; therefore, sensitivity of manometry may not be as ideal as single-factor evaluation techniques, like intramuscular EMG, which remains the only clinical routine for evaluating neuromuscular disorders in pelvic muscles. However, the examination requires repetitive sampling from multiple sites of the EAS musculature and is therefore a painful experience. Due to its low repeatability, intramuscular EMG is also under scrutiny, and which may explain the controversial results reported thus far [30]. Therefore, in this study, MUP were acquired from multiple recording sites to get a more representative sample of the motor unit pool. Recent advances in high-density surface EMG techniques may provide novel alternatives in evaluating the neuromuscular function of pelvic floor muscles while minimizing invasiveness [27, 31].

This study has several limitations that should be noted. First, to control for confounding factors from chronic diseases and sphincter trauma, participants were limited to healthy women without recognized obstetric sphincter trauma. Inclusion criteria may also limit the severity of neurological EAS injury, as neurological injury is expected to be more severe in patients with direct sphincter tear. Second, elderly women who had cesarean section only were difficult to recruit; therefore, the size of E-CS group was much smaller than the other cohorts. Although no strong evidence of interaction was found in this study, whether the conclusion holds requires further investigation.

This study assesses the effect of delivery modes and age on the overall function of EAS by incorporating anorectal US, manometry, and intramuscular EMG. The study provides a systematic view of EAS alterations associated with delivery mode and advancing age from anatomical, functional, and neurophysiological perspectives. Results show significant difference in MUP features between young and elderly women and between vaginal and cesarean delivery. No interaction between delivery mode and age was observed; further investigations are required to further validate this conclusion.

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Compliance with ethical standards

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Conflicts of interest None.

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