The Effect of Traction Force and Hip Abduction Angle on Pudendal Nerve Compression in Hip Arthroscopy: A Cadaveric Model

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Purpose: To investigate the site of pudendal nerve compression and the relation between traction force and abduction angle regarding pressure levels at setup for hip arthroscopy. **Methods:** A total of 17 hips from 9 fresh-frozen cadavers (6 male and 3 female cadavers) were used. The pudendal nerves were dissected, and 3 FlexiForce force sensors (Tekscan, Boston, MA) were implanted on the pudendal nerve where the inferior rectal nerve, perineal nerve, and dorsal nerve of the clitoris/penis emerge. A custom-made traction table in a supine position was used with a padded perineal post of 9 cm. Recordings were made at 0, 10, 20, 30, and 40 kg of traction at varying hip abduction angles of 0°, 15°, 30°, and 45°. **Results:** The tuber ischiadicum (perineal nerve) and genital region (dorsal nerve of penis/clitoris) had statistically higher pressure values when compared with the pudendal canal (inferior rectal nerve) ($P < .05$). There was a significant increase in forces acting on the pudendal nerve with increasing application of 0 to 40 kg of traction in steps of 10 kg, with the exception of the pudendal canal sensor and reading of the perineal nerve sensor at 45° of hip abduction ($P < .004$ with Bonferroni correction for significant values). On the contrary, hip abduction angle had no statistically significant effect on pudendal nerve compression. (All specific P values with Bonferroni correction were greater than .003.) **Conclusions:** To avoid nerve palsy completely, the etiopathogenesis of compressive neuropathy should be identified. The location for compression and relation between different traction positions and forces are clarified in this study. This information can be used for further research and prevention. **Clinical Relevance:** This study adds objective data on the etiopathogenesis of pudendal nerve compression, which potentially contributes to prevention of pudendal nerve palsy as a common complication of hip arthroscopy.

Hip arthroscopy as a popular and widespread procedure has a complication rate of 1.4% to 7.5%.[1-3] Most of these complications are neurologic, and 99% are transient.[1-3] Even transient lesions may cause delay in rehabilitation, patient dissatisfaction, and medicolegal problems. Nearly half of the neurologic complications are cases of pudendal nerve palsy, which is accepted as being caused by compression of the nerve between the perineal post and bones, causing great distress to the patient with perineal hypoesthesia/dysesthesia or sexual dysfunction.[3-5]

Recommendations for prevention of neurologic injury include minimizing the traction force, limiting the traction time (120 minutes), and using a well-padded perineal post (>9 cm).[4-7] Different positioning and distraction techniques, such as using a hip distractor or arthroscopy without traction, have been described.[8-10] Despite all the preventive measures, compressive neuropathy still exists.

A limited number of objective studies have evaluated the relation between traction and compression neuropathy. It is well known that the risk of compressive neuropathy increases with increasing levels of traction. On the other hand, for prevention of such injury, the relation between traction force and nerve compression in different positions should be known and the exact location of injury should be identified. Despite the difficulty in extrapolating the data to the clinical setting, cadaveric models are the only way to obtain such data in an objective manner.

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This study aimed to investigate the site of pudendal nerve compression and the relation between traction force and abduction angle regarding pressure levels at setup for hip arthroscopy. We hypothesized that pressure on the pudendal nerve was directly related to the traction force used at hip arthroscopy and inversely related to the hip abduction angle at which traction was applied. In addition, we postulated that through its course, the pudendal nerve would be subjected to different amounts of pressure.

Methods

The study was performed on 17 hips of 9 unembalmed (6 male and 3 female) fresh-frozen cadavers. The cadavers were provided by the clinical anatomy laboratory of our institution. Cadaveric hips that had permanent deformity, contracture, or previous dissection at the site of examination were excluded from the study.

Pudendal Nerve Dissection

Pudendal nerve dissections were performed by the team of investigators. Dissections were made bilaterally through a gluteal approach in all 17 cadaveric hips. With the cadavers in a prone position, a 5- to 6-cm incision was made on the tuber ischiadicum through a gluteal approach. After dissection of the subcutaneous tissues, the ischiadic attachment of the sacrotuberous ligament was transected and deflected laterally. The pudendal nerve and its branches were exposed in the pudendal canal at the level of the tuber ischiadicum and proximal to the pubic symphysis.

Sensor Placement

Tekscan FlexiForce A-201 sensors (Tekscan, Boston, MA) were used to record the pressure force applied to the pudendal nerve.[11] A Tekscan FlexiForce Quick Application Board and Elimko E-48 Digital Indicating Control (Elimko, Ankara, Turkey) were used to take the readings (Fig 1A).

Before application, one thin 1.8 × 1.8—cm metal plate was attached below the sensor, which also allowed the sensor to be fixed to the bone through the predrilled holes. To avoid indirect forces caused by the deformation of the surrounding soft tissue affecting the sensor, another plate was used. The plates chosen for this purpose had the same dimensions (1.8 × 1.8 cm) as the sensors. A hard plastic piece measuring 3 mm thick and 9.53 mm in diameter, which was also the diameter of the sensing area, was mounted on the sensing area, and a metal plate measuring 1.8 × 1.8 cm was then fixed onto this plastic piece. This attachment of the metal plate both prevented indirect forces affecting the sensor and converted the dimensions of the sensing area to 1.8 × 1.8 cm (3.24 cm^2) (Fig 1B). This convention also allowed the sensor to work on a solid and linear surface; otherwise, drift and curvature of the sensing area would cause a decrease in the linearity of the measurements.[11] The sensors mounted on the metal plates and the indicator control were calibrated to show 1 N as 1.0 on board by the producer of the digital indicating control (Elimko).

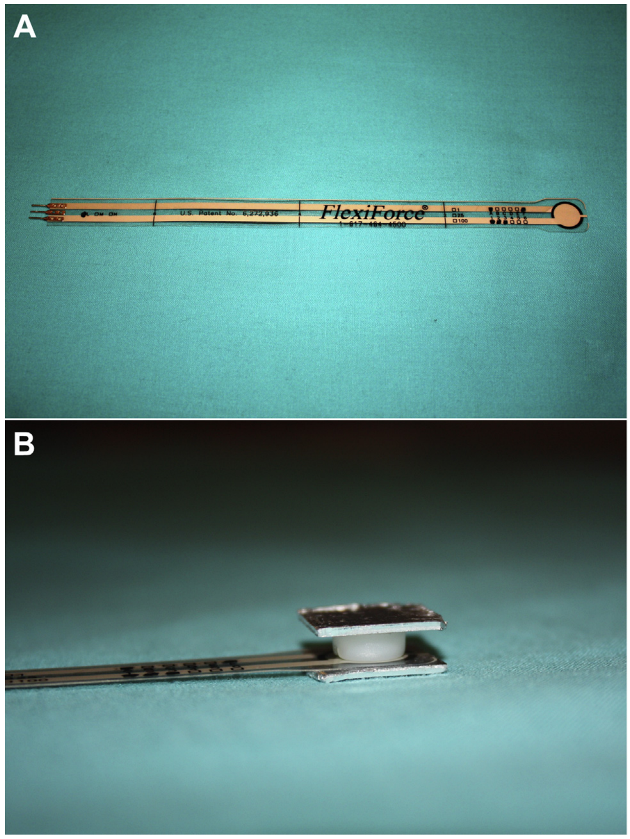

Fig 1. Tekscan FlexiForce A-201 sensor used for force measurement. (A) Single sensor before attachment of plates. (B) Sensor with attached plates and plastic piece.

Three FlexiForce sensors were implanted in each hip at anatomic points, where each sensor obtained the force measurement for a specific pudendal nerve branch[11] (Fig 2). Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis (Fig 3). All the dissected soft tissues were then re-placed in their original positions with sutures to restore an anatomic hip.

Hip Traction

The cadavers were transferred to a traction table in a supine position. A padded perineal post (Bıçakçılar Surgiline 2,000 Orthopedic Traction Set; Bıçakçılar, Istanbul, Turkey) measuring 9 cm in diameter and 20 cm in height was used for perineal support. The perineal post was positioned ipsilateral and as far lateral as possible toward the hip to which traction was to be

Fig 2. FlexiForce sensors implanted on specific pudendal nerve branches.

applied. Standard metal weights were fastened with cables to the ankle of the cadaver, and the weights were suspended freely at the end of table to allow gravitational force to act as the traction force. A 20-kg weight was suspended from the contralateral extremity to avoid movement of the pelvis by traction. A baseline recording was made with countertraction, and the indicator was set to 0 to eliminate countertraction as a factor.

Ten minutes of traction was applied before measurements were made. This time window was set because it is the time window in which the sensors reach their approximately 98% stable values, as mentioned by Ferguson-Pell et al.[11] Four different variables were tested using this method: (1) Recordings were made for both hips of each cadaver. (2) A traction force of 0, 10, 20, 30, and 40 kg was applied for distraction at the hip joint. (3) The vector of each traction force was tested at varying hip abduction angles of 0°, 15°, 30°, and 45° (Fig 4). These abduction angles were chosen to mimic the possible range of motion used during hip arthroscopy, especially when the surgeon is dealing with cam-type impingement. The hip abduction angle was assessed by measurement of the angle between the midline and the axis of the leg with the help of a simple long-arm goniometer.[12] (4) All the recordings were repeated for each of the 3 sensors denoting different possible compression sites on the pudendal nerve for both hips.

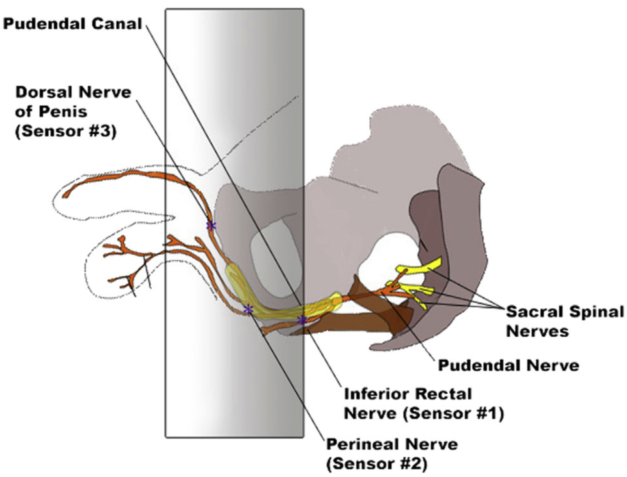

Fig 3. Sagittal view of pelvis, showing pudendal nerve and branches with respect to perineal post used during hip arthroscopy. The anatomic point for each sensor is denoted by an asterisk.

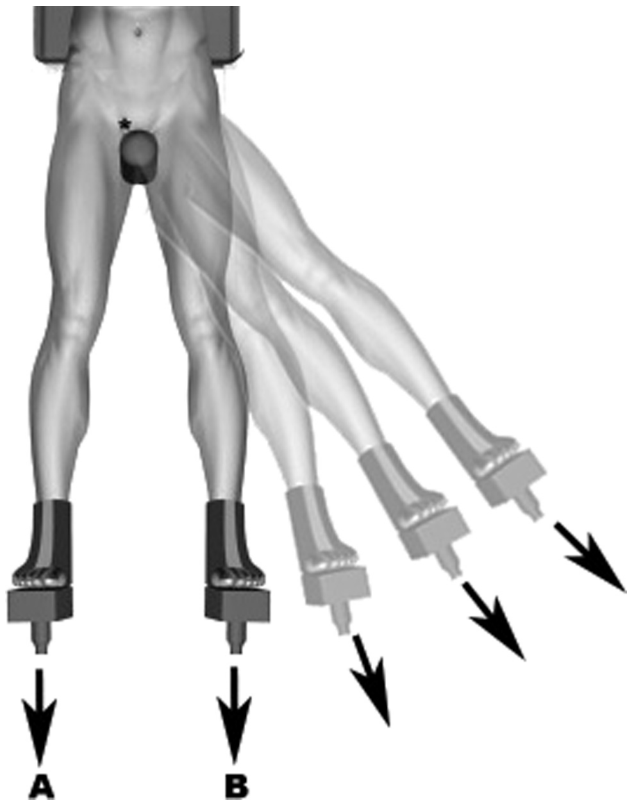

Fig 4. Traction setup. (A) Constant traction vector of 20 kg at contralateral hip. (B) The vector of each traction force was tested at varying hip abduction angles of 0°, 15°, 30°, and 45°. The asterisk indicates the padded perineal post (Bıçakçılar Surgiline 2000 Orthopedic Traction Set).

Statistical Analysis

All the assessments were recorded for statistical analysis by the team of orthopaedic surgeons. The data obtained from the sensors were analyzed using SPSS software for Windows (version 15; SPSS, Chicago, IL). Readings from the left and right hips of each cadaver were compared using the Wilcoxon signed rank test for each abduction angle and traction force. This comparison was made not for the purpose of investigating the differences between the right and left hips but for the purpose of internally validating our methods and using values independent of the side on which they were measured. To investigate the relation between traction force or hip abduction angle (traction vector) separately and the pressure exerted on the pudendal nerve, the Friedman test with Bonferroni correction was used.[13] To investigate which anatomic region of the pudendal nerve was susceptible to pressure, the readings from the 3 sensors for each traction force and hip abduction angle were tested statistically with the Friedman test with Bonferroni correction. When statistical significance was found, post hoc tests were applied to establish which pair was different.

Results

The 9 cadavers studied had a mean age of death of 50.4 years (range, 28 to 60 years), mean weight of 72.03 ± 13.06 kg, mean height of 1.69 ± 0.13 m, and mean body mass index of 26.0 ± 4.19 kg/m^2. One of the cadavers had an existing hip flexion contracture of 30°; thus this hip was not included in measurements. Raw data are available online in Appendix 1 (available at www.arthroscopyjournal.org).

The results collected from the left and right hips of the cadavers exerted no statistical difference ($P \geq .005$). (Each P value for the separate sensors by traction force and angle is provided in Appendix 2, available at www.arthroscopyjournal.org.) Thus the consistency of our methods was internally validated. Moreover, this enabled use of the values obtained from the left and right hips recorded from the same cadaver independent of the side on which the measurement was made (Fig 5).

The relation between the forces acting on the pudendal nerve and the traction force was evaluated for each sensor and abduction angle separately. At the sensors on the perineal nerve (sensor 2), except with 45° of hip abduction, and on the dorsal nerve of the clitoris/penis (sensor 3), significant correlation was seen. (At sensor 2 with 0°, 15°, 30°, and 45° of hip abduction, $P = .002$, $P < .001$, $P = .003$, and $P = .056$, respectively, and at sensor 3 with all abduction angles, $P < .001$, where $P < .004$ is significant with Bonferroni correction.) On the contrary, readings taken from the inferior rectal nerve (sensor 1), except with 45° of hip abduction, showed no relevance between the reading on the nerve tissue and traction force (Fig 6). (At sensor 1 with 0°, 15°, 30°, and 45° of hip abduction, $P = .084$, $P = .190$, $P = .037$, and $P = .004$, respectively, where $P < .004$ is significant with Bonferroni correction.)

No significant correlation between the acting force on the pudendal nerve and the hip abduction angle was seen when every measurement was evaluated for each sensor and traction force separately. (At sensor 1 with 0, 10, 20, 30, and 40 kg of traction, $P = .814$, $P = .651$, $P = .578$, $P = .655$, and $P = .659$, respectively; at sensor 2 with 0, 10, 20, 30, and 40 kg

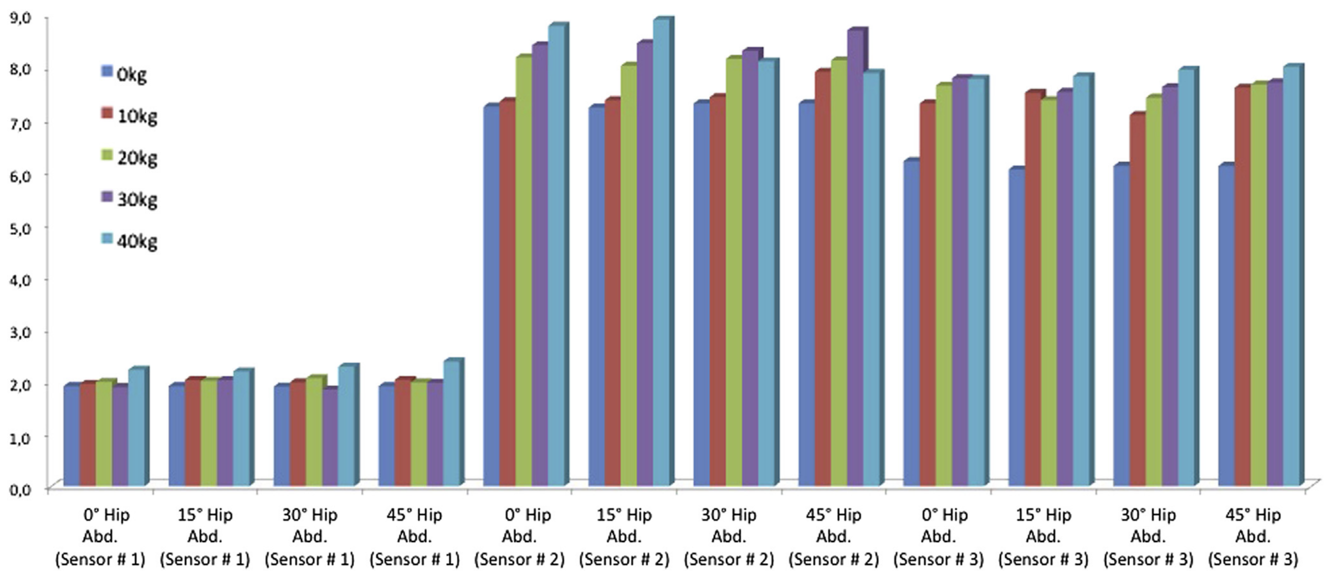

Fig 5. Graph showing mean data (in kilograms) collected from 17 hips. Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the perineal nerve, and sensor 3 was placed on the dorsal nerve of the clitoris/penis. (Abd, abduction.)

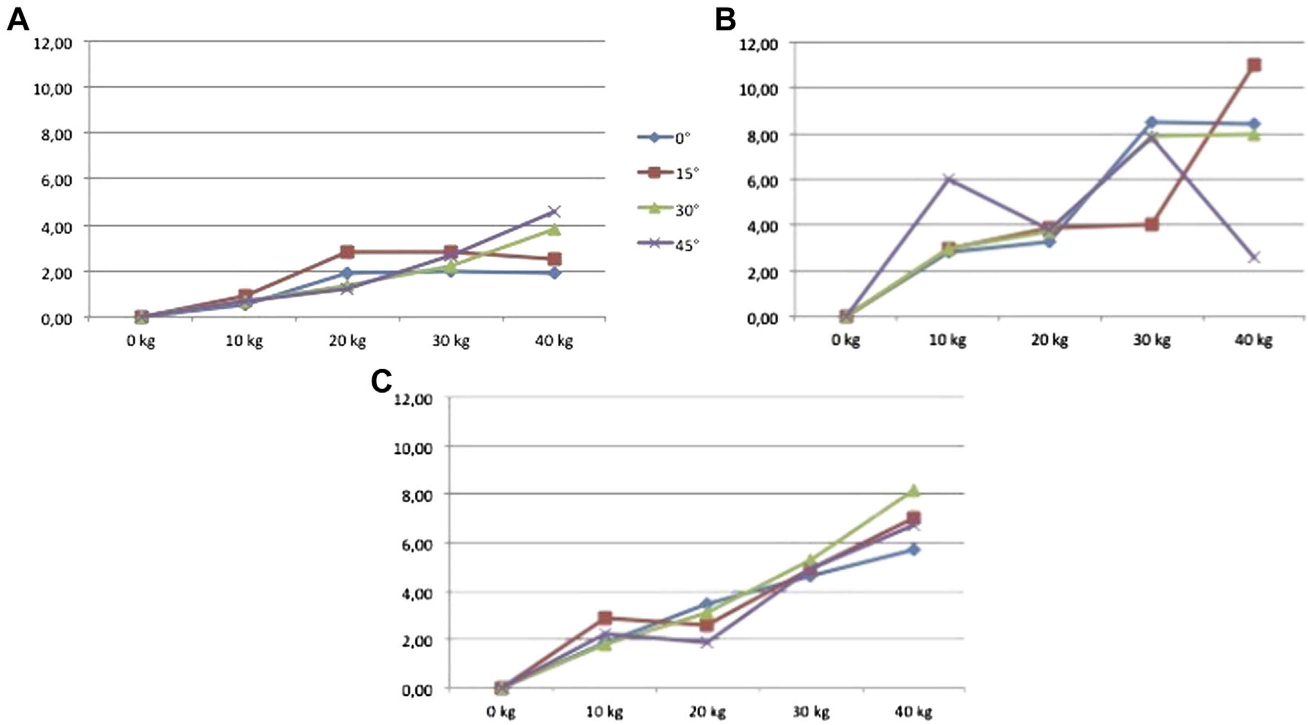

Fig 6. Curves of traction force (in kilograms) versus change in force acting on pudendal nerve for (A) sensor 1, which was placed on the inferior rectal nerve; (B) sensor 2, which was placed on the perineal nerve; and (C) sensor 3, which was placed on the dorsal nerve of the clitoris/penis.

of traction, $P = .258$, $P = .278$, $P = .678$, $P = .299$, and $P = .131$, respectively; and at sensor 3 with 0, 10, 20, 30, and 40 kg of traction, $P = .959$, $P = .508$, $P = .409$, $P = .251$, and $P = .860$, respectively, where $P < .003$ is significant with Bonferroni correction.)

Data collected from the 3 sensors, each mounted to a specific anatomic part of the pudendal nerve, were determined to be statistically different ($P < .001$ for 0, 10, 20, 30, and 40 kg of traction and 0°, 15°, 30°, and 45° of hip abduction in combination, where $P < .002$ is significant with Bonferroni correction). To establish which pair was different, post hoc tests were applied. (Specific P values are listed in Appendix 3, available at www.arthroscopyjournal.org.) Readings both from the tuber ischiadicum and from the genital region (perineal nerve and dorsal nerve of penis/clitoris, respectively) were higher than readings from the sensor in the pudendal canal (inferior rectal nerve) ($P < .05$). However, when the sensor readings in the tuber ischiadicum and genital regions were compared, no statistical difference was found ($P \geq .05$).

Discussion

The results of this study suggest a significant pressure increase on the pudendal nerve, especially on the perineal and dorsal genital branches, with respect to an increase in traction force for hip arthroscopy setup. A 365% increase in the rate of hip arthroscopy was observed between 2004 and 2009.[14] A systemic review of 92 studies and 6,334 hip arthroscopies showed pudendal palsy to be one of the most frequent complications seen in hip arthroscopy (34 of 512 observed complications).[3] The literature has shown that the rate of pudendal palsy as a complication of hip arthroscopy ranges from 0% to 6.4%.[15] Traction-related pudendal palsy is almost always reversible; still, it causes great distress both to patients and to surgeons.[3-5]

It is known that compression of the pudendal nerve, in which the nerve is trapped between the perineal post and bones, causes the palsy.[8] Several articles have given recommendations for the prevention of pudendal palsy. Byrd,[16] on the basis of his clinical experience, noted that 50 lb (22.7 kg) of traction is adequate and this limit should not be exceeded. However, some authors have stated that several of their patients tolerate up to 100 lb (45 kg) of traction without nerve dysfunction.[7,17] Traction times limited to 120 minutes are generally recommended, although some reports in the literature restrain this to 60 minutes.[7,18] A well-padded perineal post with a minimum diameter of 9 cm is the most established suggestion for preventing pudendal palsy.[4,5] Most of the aforementioned recommendations are based on either clinical experience or retrospective data. From a clinical standpoint, it is critical to understand how different traction magnitudes and hip abduction angles affect the pudendal nerve.

The clinical findings of pudendal palsy include perineal pain and sensory deficit affecting the glans penis and scrotum in men and the perineum and labia in women, which may or may not be associated with sexual disorders (impotence, anejaculation, hypoorgasmia).[6] The clinical symptoms actually resemble the branches subjected to compression. However, compression can occur at different sites along the pudendal nerve's course, and information about the localization of compression may be used for a specially designed pad. In our study, readings from the Alcock canal were statistically different from those of the sensors at the tuber ischiadicum and pubic symphysis. This finding shows that compression on the pudendal nerve develops primarily at the level of the tuber ischiadicum, at the point of the perineal nerve, as well as at the level of the pubic symphysis, where the dorsal sensory nerve of the penis/clitoris emerges.

It is well known that increased traction will cause an increased amount of nerve compression.[19] However, to our knowledge, the relation between traction and pressure has remained unevaluated. The amount of traction and position of the hip that will leave the pudendal nerve susceptible to palsy remain unknown. Although the knowledge that the rising forces of traction accumulate more pressure on the pudendal nerve and increase the risk of nerve palsy is intuitive, evidence is required. The results of this study suggest a significant pressure increase on the pudendal nerve, especially on the perineal and dorsal genital branches, with respect to an increase in traction force. On the contrary, the results showed no correlation between the hip abduction angle and the pressure accumulated on the pudendal nerve. These initial findings can help future research to focus on the position and limit of the traction force to be used.

Further clinical and pathophysiological research should be conducted to establish a safe and effective way to achieve hip distraction and traction during hip arthroscopy to eliminate pudendal palsy. Considering that this study is the first attempt to investigate the site of compression and the direct relation of the traction force and the hip abduction angle with pudendal nerve pressure and palsy, this method can be a guide for future studies.

Clinically thinking, we believe this study adds objective data on the etiopathogenesis of pudendal nerve compression and can potentially contribute to the prevention of pudendal nerve palsy as a common complication of hip arthroscopy. Specially designed padding or even different traction techniques that enable hip distraction with less traction can be tested with this cadaveric model.

Limitations

To our knowledge, there is only 1 other published cadaveric study about hip arthroscopy and traction; it was performed by Dienst et al.[20] and stated that joint distention with air could avoid the use of high traction forces. Although it is difficult to transfer limited cadaveric data to the clinical setting, cadaveric studies can improve our understanding about pathophysiology. In addition, because of concern regarding nerve tissue dissection and traction forces beyond the recommended limits in the literature, our hypotheses could only be tested in cadavers. Fresh-frozen cadaveric tissue may cause some limitations: Although the tissue came from humans, the tissue consistency and the buffering effect of cadaveric tissue may be altered. Moreover, elongation at the pudendal nerve cannot be taken into consideration with a cadaveric model. It is known that palsy can be induced by nerve tissue elongation.[21,22] Likewise, the effects of traction time can be investigated only by an in vivo model. Both physiology and the clinical literature clearly indicate that time is an important factor regarding nerve palsy.[6,21,23] A statistical limitation of this study is that conducting a power analysis for the results was not considered because this work is a cadaveric study with a limited number of subjects. However, there are similar cadaveric works published on this topic with comparable numbers of cadavers.[20,24]

Conclusions

To avoid nerve palsy completely, the etiopathogenesis of compressive neuropathy should be identified. The location for compression and relation between different traction positions and forces are clarified in this study. This information can be used for further research and prevention.

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Appendix 1

Cadaver 1

Appendix Table 1. Descriptive Data of Cadaver 1

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
26	Male	62	65	1.70	22.49	1.5

Appendix Table 2. Force Recordings From Right Hip of Cadaver 1

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	1.08	1.95	1.69	1.79	2.22
	15°	1.09	1.91	1.69	1.78	2.18
	30°	1.12	1.90	1.67	1.78	2.01
	45°	1.02	1.90	1.67	1.81	2.03
2	0°	7.00	8.53	8.61	8.70	9.26
	15°	7.49	8.42	8.62	8.69	9.15
	30°	7.40	8.40	8.59	8.68	9.14
	45°	7.22	8.20	8.64	8.69	9.23
3	0°	6.20	6.53	7.23	7.55	7.58
	15°	5.96	6.32	7.20	7.40	7.56
	30°	6.00	6.30	7.22	7.28	7.38
	45°	5.88	6.21	7.12	7.20	7.44

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 3. Force Recordings From Left Hip of Cadaver 1

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	4.45	4.57	4.19	4.13	4.69
	15°	4.41	4.44	4.06	4.10	4.85
	30°	4.17	4.28	4.04	4.03	4.69
	45°	4.04	3.89	3.71	3.35	4.67
2	0°	8.45	8.21	8.26	8.41	8.78
	15°	8.33	8.15	8.23	8.45	8.64
	30°	8.26	8.16	8.15	8.03	7.77
	45°	8.19	8.18	8.12	7.34	7.88
3	0°	8.35	8.39	8.45	8.58	9.75
	15°	8.37	8.31	8.42	8.58	9.65
	30°	8.31	8.29	8.40	8.55	9.53
	45°	8.30	8.24	8.35	8.53	9.53

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Cadaver 2

Appendix Table 4. Descriptive Data of Cadaver 2

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
22	Male	54	80	1.64	29.74	2.5

Appendix Table 5. Force Recordings From Right Hip of Cadaver 2

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	3.02	3.76	3.51	3.49	3.61
	15°	2.96	3.57	3.46	3.42	3.61
	30°	2.96	3.59	3.07	3.39	3.59
	45°	3.05	3.56	3.12	3.35	3.56
2	0°	7.63	7.34	8.18	9.12	9.38
	15°	7.63	7.34	8.02	9.09	9.56
	30°	7.61	6.73	7.98	9.04	9.32
	45°	7.57	7.41	7.95	9.09	9.10
3	0°	9.81	9.62	9.75	9.15	9.82
	15°	9.75	9.62	9.79	9.11	9.89
	30°	9.67	9.64	9.63	9.01	9.80
	45°	9.56	9.00	9.75	8.86	9.76

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 6. Force Recordings From Left Hip of Cadaver 2

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	1.50	3.42	3.62	3.51	2.91
	15°	1.60	3.39	3.32	3.52	3.07
	30°	1.60	3.35	3.24	3.52	3.10
	45°	2.00	3.55	3.33	3.58	3.79
2	0°	7.46	7.10	7.49	7.22	7.13
	15°	7.16	7.04	7.44	7.24	7.25
	30°	7.15	7.13	7.41	7.24	7.04
	45°	7.37	7.16	7.37	7.26	7.13
3	0°	7.05	7.09	7.13	7.44	7.39
	15°	7.03	7.09	7.21	7.52	7.29
	30°	7.08	7.06	7.17	7.61	7.37
	45°	7.05	7.11	7.15	7.70	7.40

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Cadaver 3

Appendix Table 7. Descriptive Data of Cadaver 3

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
24	Male	43	65	1.58	26.03	2

Appendix Table 8. Force Recordings From Right Hip of Cadaver 3

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	2.13	1.84	2.23	2.22	2.29
	15°	1.91	2.02	2.36	2.33	2.34
	30°	1.90	1.89	2.43	2.12	2.28
	45°	1.94	2.10	2.23	2.34	2.40
2	0°	2.26	2.16	2.38	2.80	2.45
	15°	2.32	2.24	2.41	2.66	2.52
	30°	2.16	2.19	2.52	2.92	2.56
	45°	2.62	2.28	2.68	3.15	2.88
3	0°	7.32	7.77	7.67	7.78	7.77
	15°	7.34	7.63	7.60	7.63	7.82
	30°	7.34	7.08	7.70	7.67	7.94
	45°	7.35	7.60	7.66	7.62	8.00

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 9. Force Recordings From Left Hip of Cadaver 3

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	1.12	1.76	1.31	1.35	1.17
	15°	1.12	1.78	1.31	1.40	1.17
	30°	1.11	1.67	1.31	1.37	1.16
	45°	1.10	1.67	1.31	1.37	0.95
2	0°	7.94	9.36	9.34	9.87	9.82
	15°	7.91	9.27	9.84	9.54	9.70
	30°	7.96	9.10	9.73	9.32	9.66
	45°	8.00	9.41	9.57	9.18	9.60
3	0°	3.50	4.69	4.63	4.86	4.34
	15°	3.28	4.64	4.41	4.87	4.35
	30°	3.11	4.47	3.93	4.84	4.28
	45°	2.80	4.32	3.81	4.77	4.25

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Cadaver 4

Appendix Table 10. Descriptive Data of Cadaver 4

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
29	Female	28	80	1.73	26.72	4

Appendix Table 11. Force Recordings From Right Hip of Cadaver 4

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	1.91	1.94	1.80	1.89	2.01
	15°	1.94	2.03	1.82	2.02	2.19
	30°	1.91	1.98	1.77	1.81	2.33
	45°	1.91	1.95	1.86	1.97	2.38
2	0°	7.06	7.01	6.58	7.27	7.22
	15°	7.12	7.21	6.57	7.25	7.24
	30°	7.14	7.22	6.88	7.67	7.43
	45°	7.27	7.24	6.71	7.88	7.49
3	0°	1.72	1.63	1.60	2.00	1.85
	15°	1.76	1.64	1.60	2.19	2.10
	30°	1.73	1.80	1.80	2.27	2.21
	45°	1.85	1.79	1.96	2.08	2.17

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 12. Force Recordings From Left Hip of Cadaver 4

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	2.01	2.06	1.99	1.80	1.77
	15°	2.14	2.07	2.01	1.84	1.74
	30°	2.40	2.05	2.11	1.83	1.85
	45°	2.39	2.07	2.13	1.79	1.95
2	0°	6.70	7.10	7.00	7.70	8.80
	15°	6.70	7.00	7.20	7.10	8.90
	30°	7.30	7.30	8.50	8.30	8.10
	45°	7.30	7.90	8.30	8.90	7.40
3	0°	3.15	3.66	3.09	3.78	3.72
	15°	3.08	3.78	3.11	3.98	3.89
	30°	3.12	3.55	3.21	4.02	3.98
	45°	3.19	3.13	3.26	3.97	4.01

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Cadaver 5

Appendix Table 13. Descriptive Data of Cadaver 5

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
33	Male	48	69	1.64	25.65	2.5

Appendix Table 14. Force Recordings From Right Hip of Cadaver 5

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	2.23	2.21	2.18	2.99	2.36
	15°	2.28	2.17	2.21	2.86	2.50
	30°	2.31	2.20	2.22	2.83	2.48
	45°	2.29	2.23	2.23	3.05	2.54
2	0°	7.24	9.15	9.25	9.23	11.00
	15°	7.22	9.09	9.23	9.20	10.68
	30°	7.21	9.21	9.20	9.08	11.02
	45°	7.23	9.28	9.15	9.21	10.85
3	0°	4.13	4.13	4.49	4.77	4.99
	15°	4.20	4.18	4.51	4.79	4.90
	30°	4.27	4.19	4.58	4.70	5.09
	45°	4.25	4.20	4.48	4.74	4.91

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 15. Force Recordings From Left Hip of Cadaver 5

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	2.87	2.54	3.13	3.07	3.27
	15°	2.82	2.24	3.12	2.86	3.04
	30°	2.84	2.51	3.18	2.94	2.95
	45°	2.82	2.39	3.07	2.84	3.13
2	0°	7.46	7.18	7.60	7.52	7.24
	15°	7.52	7.36	7.53	7.49	6.89
	30°	7.35	7.42	7.44	7.52	6.73
	45°	7.38	7.28	7.39	7.44	6.65
3	0°	5.57	6.50	6.57	7.14	7.14
	15°	5.64	6.45	6.46	7.08	6.88
	30°	5.80	6.41	6.52	6.74	6.86
	45°	5.87	6.40	6.01	6.57	6.54

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Cadaver 6

Appendix Table 16. Descriptive Data of Cadaver 6

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
27	Male	47	87	1.78	27.45	3

Appendix Table 17. Force Recordings From Right Hip of Cadaver 6

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	0.61	0.85	1.08	0.67	0.78
	15°	0.61	0.79	0.89	0.67	0.79
	30°	0.58	0.63	0.76	0.67	0.80
	45°	0.57	0.64	0.74	0.60	0.80
2	0°	2.37	3.27	3.89	3.50	3.21
	15°	2.00	3.05	3.76	3.27	3.17
	30°	1.91	2.65	3.66	3.15	2.88
	45°	1.83	2.51	2.89	2.87	2.78
3	0°	6.00	8.31	8.30	9.45	9.23
	15°	6.04	8.40	8.31	9.34	9.24
	30°	6.11	8.33	8.37	9.35	8.97
	45°	6.11	8.34	8.32	9.08	8.80

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 18. Force Recordings From Left Hip of Cadaver 6

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	1.41	1.25	1.09	1.10	1.05
	15°	1.44	1.22	1.18	1.09	1.09
	30°	1.45	1.71	1.13	1.05	1.09
	45°	1.49	1.81	1.17	0.99	1.00
2	0°	2.89	2.92	2.74	2.86	2.67
	15°	2.81	2.86	2.79	2.91	2.59
	30°	2.73	2.85	2.87	2.90	2.63
	45°	2.71	2.81	2.93	2.75	2.70
3	0°	2.62	7.30	7.64	7.82	8.29
	15°	2.65	7.50	7.36	7.44	8.24
	30°	2.59	7.58	7.41	7.60	8.41
	45°	2.60	7.64	7.73	7.97	8.50

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Cadaver 7

Appendix Table 19. Descriptive Data of Cadaver 7

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
20	Male	58	75	1.67	26.89	3.5

Appendix Table 20. Force Recordings From Left Hip of Cadaver 7*

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	2.06	1.97	2.08	2.12	2.04
	15°	2.09	2.06	2.06	2.11	2.02
	30°	2.08	2.01	2.06	2.15	2.05
	45°	2.15	2.03	1.98	2.09	2.06
2	0°	3.16	3.44	3.49	4.01	4.61
	15°	3.33	3.37	3.37	3.90	4.43
	30°	3.24	3.54	3.32	4.03	4.41
	45°	3.34	3.54	3.49	4.12	4.38
3	0°	2.10	2.08	2.15	2.04	2.03
	15°	2.15	2.15	2.28	2.12	2.10
	30°	2.16	2.20	2.31	2.17	2.38
	45°	2.17	2.19	2.30	2.26	2.42

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

*The right hip of cadaver 7 was excluded because of an existing hip flexion contracture of 30°.

Cadaver 8

Appendix Table 21. Descriptive Data of Cadaver 8

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
17	Female	54	45	1.60	17.57	2.5

Appendix Table 22. Force Recordings From Right Hip of Cadaver 8

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	1.96	2.45	2.25	2.66	2.78
	15°	1.97	2.47	2.55	2.60	2.72
	30°	1.94	2.48	2.53	2.65	2.74
	45°	1.90	2.42	2.66	2.67	2.69
2	0°	10.22	10.41	10.86	10.15	10.60
	15°	10.07	10.37	10.78	9.98	10.56
	30°	9.92	10.37	10.80	9.81	10.35
	45°	10.06	10.66	10.66	9.81	9.81
3	0°	9.10	9.03	9.56	8.93	9.67
	15°	8.97	9.05	9.56	9.11	9.12
	30°	8.99	9.09	9.98	9.36	9.43
	45°	8.92	9.08	9.86	9.24	9.67

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 23. Force Recordings From Left Hip of Cadaver 8

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	1.51	1.62	1.80	1.81	2.62
	15°	1.52	1.62	1.80	1.83	2.76
	30°	1.52	1.62	1.77	1.84	2.77
	45°	1.52	1.61	1.77	1.91	2.81
2	0°	10.46	10.92	10.07	10.71	10.20
	15°	10.36	10.95	10.05	10.72	10.04
	30°	10.22	11.01	10.03	10.70	9.96
	45°	10.27	10.95	10.03	10.61	10.22
3	0°	7.14	8.20	10.49	10.37	10.43
	15°	6.83	8.82	10.45	10.14	10.33
	30°	7.12	8.94	10.29	10.27	10.22
	45°	7.17	8.50	10.25	10.28	10.11

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Cadaver 9

Appendix Table 24. Descriptive Data of Cadaver 9

Tag No.	Gender	Age of Death, yr	Weight, kg	Height, m	Body Mass Index, kg/m^2	Perineal Thickness, cm
34	Female	60	85	1.63	31.99	3

Appendix Table 25. Force Recordings From Right Hip of Cadaver 9

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	0.12	0.09	0.05	0.13	0.44
	15°	0.12	0.12	0.05	0.12	0.43
	30°	0.11	0.13	0.06	0.12	0.51
	45°	0.11	0.13	0.06	0.13	1.08
2	0°	7.11	8.58	8.64	9.01	8.73
	15°	7.01	8.61	9.14	9.02	9.01
	30°	7.01	8.72	9.00	9.02	9.27
	45°	6.92	8.64	9.20	8.94	9.14
3	0°	9.20	9.39	9.18	8.82	9.45
	15°	9.13	9.25	9.21	8.63	9.63
	30°	9.03	9.21	8.98	8.77	9.54
	45°	9.01	9.23	8.96	8.76	9.39

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix Table 26. Force Recordings From Left Hip of Cadaver 9

Sensor	Hip Abduction Angle	Traction Force, kg				
		0	10	20	30	40
1	0°	0.98	0.98	1.57	1.32	1.17
	15°	0.99	0.93	1.55	1.41	1.13
	30°	1.03	0.83	1.17	1.33	1.25
	45°	0.99	0.95	1.11	1.36	1.14
2	0°	8.00	9.18	8.64	9.82	9.86
	15°	8.03	9.17	8.83	9.54	9.80
	30°	8.06	9.13	8.69	9.34	9.83
	45°	8.09	9.09	8.73	9.53	9.84
3	0°	9.20	9.39	9.18	8.82	9.45
	15°	9.13	9.55	9.21	8.63	9.63
	30°	9.03	9.51	8.98	8.77	9.45
	45°	7.17	8.50	10.25	10.28	10.11

NOTE. Forces acting on the pudendal nerve were measured with 0, 10, 20, 30, and 40 kg of traction applied at varying hip abduction angles of 0°, 15°, 30°, and 45°. (Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.)

Appendix 2

Appendix Table 27. Comparison of Left and Right Hip Measurements With Wilcoxon Signed Rank Test

Sensor	Traction Force, kg	Hip Abduction Angle			
		0°	15°	30°	45°
1	0	.484	.327	.327	.327
	10	.069	.063	.069	.069
	20	.069	.123	.123	.866
	30	.208	.263	.069	.208
	40	.484	.726	.889	.575
2	0	.161	.161	.123	.123
	10	.674	.161	.779	.484
	20	.866	.889	>.99	.779
	30	.674	.401	.401	.575
	40	>.99	.889	.889	.401
3	0	.499	.499	.499	.499
	10	.866	>.99	>.99	.866
	20	.735	.735	.735	.735
	30	.735	.735	.799	.866
	40	.735	.735	.674	.735

NOTE. $P < .005$ is significant with Bonferroni correction.

Appendix 3

Appendix Table 28. Post Hoc Comparison of Sensor Pair Readings With 0 kg of Traction at Varying Hip Abduction Angles

Sensor Pair	Hip Abduction Angle			
	0°	15°	30°	45°
1 and 2	<.001*	<.001*	<.001*	<.001*
1 and 3	.002*	.001*	.001*	.001*
2 and 3	.510	.910	.910	.910

NOTE. Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.
*Statistically significant ($P < .05$).

Appendix Table 29. Post Hoc Comparison of Sensor Pair Readings With 10 kg of Traction at Varying Hip Abduction Angles

Sensor Pair	Hip Abduction Angle			
	0°	15°	30°	45°
1 and 2	<.001*	<.001*	<.001*	<.001*
1 and 3	<.001*	.001*	<.001*	<.001*
2 and 3	>.99	>.99	>.99	>.99

NOTE. Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.
*Statistically significant ($P < .05$).

Appendix Table 30. Post Hoc Comparison of Sensor Pair Readings With 20 kg of Traction at Varying Hip Abduction Angles

	Hip Abduction Angle			
Sensor Pair	0°	15°	30°	45°
1 and 2	<.001*	<.001*	<.001*	<.001*
1 and 3	<.001*	<.001*	<.001*	<.001*
2 and 3	>.99	>.99	>.99	>.99

NOTE. Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.

*Statistically significant ($P < .05$).

Appendix Table 31. Post Hoc Comparison of Sensor Pair Readings With 30 kg of Traction at Varying Hip Abduction Angles

	Hip Abduction Angle			
Sensor Pair	0°	15°	30°	45°
1 and 2	<.001*	<.001*	<.001*	<.001*
1 and 3	.001*	<.001*	<.001*	<.001*
2 and 3	.910	>.99	.690	.690

NOTE. Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.

*Statistically significant ($P < .05$).

Appendix Table 32. Post Hoc Comparison of Sensor Pair Readings With 40 kg of Traction at Varying Hip Abduction Angles

	Hip Abduction Angle			
Sensor Pair	0°	15°	30°	45°
1 and 2	<.001*	<.001*	<.001*	<.001*
1 and 3	.001*	<.001*	<.001*	<.001*
2 and 3	>.99	>.99	>.99	>.99

NOTE. Sensor 1 was placed on the inferior rectal nerve, sensor 2 was placed on the tuber ischiadicum on the perineal nerve, and sensor 3 was installed proximal to the pubic symphysis on the dorsal nerve of the clitoris/penis.

*Statistically significant ($P < .05$).