Turk Neurosurg, 2022

Original Investigation

Received: 24.02.2022
Accepted: 19.07.2022

DOI: 10.5137/1019-5149.JTN.38397-22.3

Published Online: 19.09.2022

Innervation Patterns of the Psoas Major and Iliacus Muscles in Fetal Cadavers

Kenan OZTURK, Ahmet DURSUN, Yadigar KASTAMONI, Soner ALBAY

Suleyman Demirel University, Faculty of Medicine, Department of Anatomy, Isparta, Turkey

Corresponding author: Kenan OZTURK ✉ kenanozt@hotmail.com

ABSTRACT

AIM: To investigate in detail the innervation patterns of the psoas major and iliacus muscles in fetal cadavers.

MATERIAL and METHODS: The innervation patterns of 94 psoas major and 94 iliacus muscles belonging to 47 fetuses (28 males, 19 females) aged between the 18^{th}-40^{th} gestational weeks in the laboratory of the Department of Anatomy, Faculty of Medicine were examined. The nerve branches innervating the psoas major and iliacus muscles and the origin levels of these branches were determined. The branches innervating the psoas major and iliacus muscles were classified as L1, L1-L2 level, L2, L2-L3 level, L3, L3-L4 level, L4 and femoral nerve according to the levels at which they originate from the spinal nerves.

RESULTS: It was determined that the psoas major muscle was innervated by the ventral branches of the L1-L4 spinal nerves and the femoral nerve, while the iliacus muscle was innervated only by the femoral nerve. The mean number of branches innervating each psoas major and iliacus muscle was 4.69 ± 2.02 and 3.07 ± 1.14, respectively. It was observed that the branches innervating the psoas major muscle originated at least at the level between the L1-2 spinal nerves and at most at the level between the L2-3 spinal nerves.

CONCLUSION: The spinal nerves innervating the psoas major muscle are at risk of injury during lateral transpsoas surgery, lateral discectomy, and spinal fusion surgery. Therefore, it may be useful for surgeons to know the innervation patterns of the psoas major muscle in surgical interventions in this region. Furthermore, it will be beneficial for surgeons to know the innervation of the iliacus muscle in various surgical interventions on the iliac fossa.

KEYWORDS: Spinal nerve, Lumbar plexus, Femoral nerve, Iliopsoas, Iliac fossa

ABBREVIATIONS: PMM: Psoas major muscle, **IM:** Iliacus muscle, **FN:** Femoral nerve

INTRODUCTION

The psoas major (PMM) and iliacus (IM) are two muscles that attach together to the lesser trochanter of the femur as flexors of the hip joint. These muscles are often considered a functional unit (iliopsoas). Different information is available in anatomy textbooks about the innervation of the PMM. Some sources (18) state that the PMM is innervated by L1, L2, and sometimes L3, while other sources (13) report that it is innervated by the anterior branches of the L2-L4 spinal nerves. It is indicated that the IM is innervated by the anterior branches of the L2, L3 spinal nerves, and the femoral nerve (FN) (13,18). However, studies show that the innervation of these two muscles is different from that specified in textbooks (4,11).

Since the development of axonal structure and myelination is still continuing in fetuses, fetuses have slower conduction velocity and a more sensitive peripheral nervous system. Since fetuses have weaker muscles, the lumbar plexus is more prone to traumas. Human fetuses can be traumatized either in the womb or during birth (9,15,21,23). Pressures applied to

Kenan OZTURK : 0000-0002-5552-8684
Ahmet DURSUN : 0000-0003-4568-8761
Yadigar KASTAMONI : 0000-0002-3504-5853
Soner ALBAY : 0000-0001-8438-8628

the hip and lumbar region of the fetus, especially at birth, may cause neurological damage (23).

Lumbar plexus lesions are rare and difficult to treat (9). Surgical approaches are complex, and since it is difficult to reach anatomically, interventions in this region may cause negative outcomes. Therefore, the detailed knowledge of the PMM and IM innervation patterns may be beneficial for surgeons in various abdominal and pelvic surgeries in newborns and adults (5,6).

Retroperitoneal endoscopic surgery is performed in case of various spinal disorders in adults. There is a potential risk of injury to the lumbar plexus or nerve roots when the PMM is separated during retroperitoneal endoscopic surgery and in various surgical interventions such as lateral transpsoas surgeries (1,3,7,8,10). The knowledge of the PMM and IM innervation patterns may reduce the incidence of persistent hip flexion weakness during surgical interventions such as lateral transpsoas surgery (11). However, little is known about the relationship between the PMM and the lumbar plexus (11,14).

There are very few studies in the literature on the innervation of the PMM and IM in adult cadavers (11,17). However, we could not find any study conducted on fetal cadavers. Therefore, we aimed to investigate in detail the innervation patterns of the PMM and IM in fetal cadavers since they are available in sufficient numbers in our laboratory to overcome this limitation in the literature.

MATERIAL and METHODS

This study was approved by the Clinical Research Ethics Committee of the Faculty of Medicine (Date: 11.02.2022; No: 42).

In our study, the innervation patterns of 94 PMM and 94 IM muscles belonging to 47 fetuses (28 males, 19 females) in the Department of Anatomy, Faculty of Medicine, were examined. Fetuses aged between the 18^{th}-40^{th} gestational weeks and without any external anomalies and pathologies were procured from the Maternity and Children's Hospital with the permission of their families between the years 1996-2014. All fetal cadavers were fixed by the arterial injection of 10% (v/v) formaldehyde solution into water and stored in a pool of 10 L of 10% (v/v) formaldehyde solution.

Structures such as fascia, connective tissue, etc. around the PMM and IM were removed in each fetal cadaver. The ilioinguinal, iliohypogastric, genitofemoral, lateral femoral cutaneous, and femoral nerves were identified by making the muscles visible. The parts where the PMM attaches to the lumbar vertebrae were cut, and the nerves of the lumbar plexus terminating in this muscle were identified. Fetuses were investigated under a "Euromex Edublue 1805-S binocular digital stereo microscope (Euromex microscopen BV, Arnhem, Holland)". The number of T12-L5 spinal nerves and branches of the FN innervating the PMM and IM were determined. Branches innervating the PMM and IM were classified as L1, L1-L2 level, L2, L2-L3 level, L3, L3-L4 level, L4 and FN according to the levels at which they originate from the spinal nerves.

RESULTS

It was determined that each PMM muscle was innervated by branches from the ventral rami of the L1-L4 spinal nerves and the FN. No branches originating from the T12 and L5 spinal nerves were observed to innervate the PMM. The mean number of branches innervating each PMM muscle was 4.69 ± 2.02 (in the range of 1-12). The number of branches innervating the PMM according to their origin levels from the spinal nerves, their distribution ratios (Table I) and the mean number of branches according to the side were determined (Figure 1). The branches innervating the PMM originated at least at the level between the L1-2 spinal nerves and at most at the level between the L2-3 spinal nerves (Table I, Figures 1, 2A).

It was observed that all 94 IMs in this study were innervated only by the FN, and the mean number of branches innervating the IM was determined by side (Figures 1, 2B). The mean number of branches innervating each IM was 3.07 ± 1.14 (in the range of 1-5).

The distribution of branches innervating the PMM and IM according to their number and level of spinal nerve origin was determined (Table II). It was observed that most of the branches innervating PMM originate from L2, L2-3, L3 and L3-4 levels (most frequently L2-3). The number of branches originating from the L2-3 level and innervating the PMM varied between 1-6. However, 73.4% of these PMMs were innervated by branches varying in number from 1-3, originating from the L2-3 level. It was observed that 2 (29.8%) branches were most frequently separated from the L2-3 level to innervate the PMM. In addition, in order to innervate the IM, it was found that 3 branches were often separated from the femoral nerve.

The distribution of the mean number of branches innervating the PMM and IM by spinal nerve origin levels and sex was revealed (Table III). When the data were evaluated according to

Table I: Distribution of the Total Number of Branches Innervating All Psoas Major Muscles According to Their Origin Levels From Spinal Nerves

	Total number of branches	L1	L1-L2	L2	L2-L3	L3	L3-L4	L4	FN
PMM n(%)	N=441 branch (100)	15 (3.4)	5 (1.13)	64 (14.51)	186 (42.1)	47 (10.65)	86 (19.5)	8 (1.81)	30 (6.8)

***PMM:** Psoas major muscle, **N:** Total number of branches innervating the psoas major in all fetuses, **FN:** Femoral nerve.*

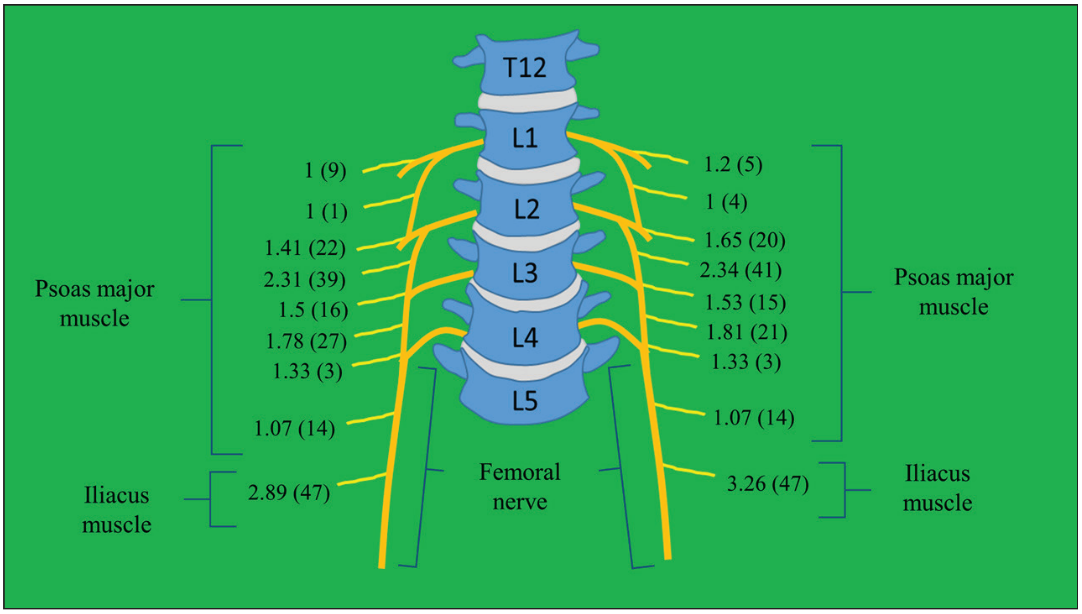

Figure 1: The mean number of branches innervating all psoas major and iliacus muscles according to their origin levels from spinal nerves and side (in how many fetuses the branches are observed at each level is indicated in parentheses).

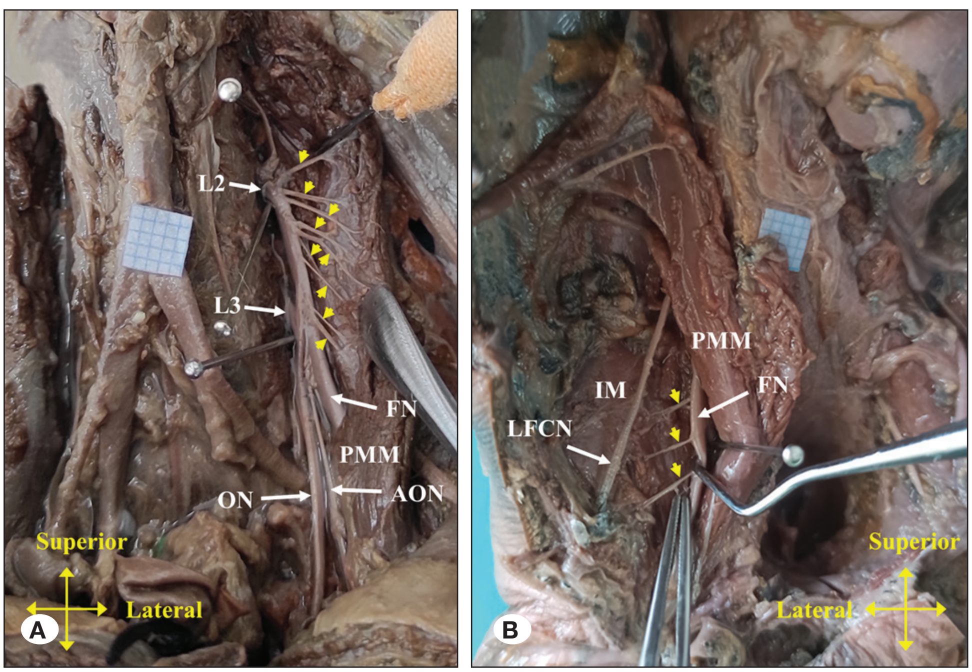

Figure 2: Innervations of the psoas major in a 29-week-old female fetus **(A)** and iliacus in a 27-week-old male fetus **(B)**. **L2:** L2 spinal nerve origin level, **L3:** L3 spinal nerve origin level, **arrowheads:** branches innervating the psoas major and iliacus muscles, **FN:** femoral nerve, **PMM:** psoas major muscle, **ON:** obturator nerve, **AON:** accessory obturator nerve, **IM:** iliacus muscle, **LFCN:** lateral femoral cutaneous nerve.

sex, it was seen that the results were quite close to each other. Finally, the frequency of the PMMs was calculated according to the total number of branches innervating a single PMM (Table IV). Accordingly, it was observed that a single PMM was most frequently innervated by 4 (in 23 PMMs) branches. This was followed by the PMMs innervated by 5 (in 18 PMMs) branches and 3 (in 16 PMMs) branches, respectively.

DISCUSSION

Being aware of the innervation variations of the PMM and IM is important in anatomical studies and in preventing complications in surgical procedures (16). Although there are few studies on the PMM and IM innervations in adult cadavers (11,17), we did not find any study on the innervation of these muscles in fetal cadavers in the literature. Since the peripheral nervous system does not have a strong support tissue in the fetal period and the development of myelination continues, it is very difficult to examine the innervation variations of these muscles anatomically (23).

It has been reported that the dorsal and ventral roots of spinal nerves and plexuses are formed in an embryo at approximately 4 weeks (19), and the ventral roots enter the muscle at the 14th stage (days 31-35), according to the Carnegie staging (2). Since

Table II: Distribution of Branches Innervating Psoas Major and Iliacus According to Their Number and Level of Spinal Nerve Origin

Number of branches	Branches innervating the PMM (n=94 PMM) n (%)								Branches innervating the IM (n=94 IM) n (%)
	L1	**L1-L2**	**L2**	**L2-L3**	**L3**	**L3-L4**	**L4**	**FN**	**FN**
1	13 (13.8)	5 (5.3)	25 (26.6)	21 (22.3)	21 (22.3)	19 (20.2)	4 (4.3)	26 (27.7)	8 (8.5)
2	1 (1.1)	-	14 (14.9)	28 (29.8)	4 (4.3)	22 (23.4)	2 (2.1)	2 (2.1)	22 (23.4)
3	-	-	1 (1.1)	20 (21.3)	6 (6.4)	6 (6.4)	-	-	31 (33)
4	-	-	2 (2.1)	8 (8.5)	-	1 (1.1)	-	-	21 (22.3)
5	-	-		1 (1.1)	-	-	-	-	12 (12.8)
6	-	-		2 (2.1)	-	-	-	-	-
Absent	80 (85.1)	89 (94.7)	52 (55.3)	14 (14.9)	63 (67)	46 (48.9)	88 (93.6)	66 (70,2)	-
Total	94 (100)	94 (100)	94 (100)	94 (100)	94 (100)	94 (100)	94 (100)	94 (100)	94 (100)

PMM: *Psoas major muscle,* ***IM:*** *Iliacus muscle,* ***FN:*** *Femoral nerve.*

Table III: Distribution of the Mean Number of Branches Innervating the Psoas Major and Iliacus According to Their Origin Levels from the Spinal Nerves and Sex

		PMM								IM
		L1	**L1-L2**	**L2**	**L2-L3**	**L3**	**L3-L4**	**L4**	**FN**	**FN**
Male	**Mean**	1.13	1	1.58	2.37	1.35	1.81	1.25	1.08	3.05
	N	8	5	24	51	17	32	4	12	56
	Std deviation	0.35	0	0.88	1.19	0.70	0.85	0.50	0.28	1.22
Female	**Mean**	1		1.44	2.24	1.71	1.75	1.5	1.06	3.11
	N	6	-	18	29	14	16	2	16	38
	Std deviation	0		0.61	1.09	0.91	0.77	0.70	0.25	1.03

N: *Number of psoas major and iliacus,* ***PMM:*** *Psoas major muscle,* ***IM:*** *Iliacus muscle,* ***FN:*** *Femoral nerve*

Table IV: Frequency of Psoas Majors According to the Number of Innervating Branches

Number of branches innervating a single psoas major	Number of psoas major	%
1	1	1.1
2	10	10.6
3	16	17.0
4	23	24.5
5	18	19.1
6	9	9.6
7	9	9.6
8	4	4.3
9	2	2.1
11	1	1.1
12	1	1.1
Total	94	100.0

the fetuses we used in this study were aged between the 18th-40th gestational weeks, the entry of the nerves innervating the PMM and IM into these muscles was completed. Therefore, we believe that the results of our study will contribute to research examining the PMM and IM innervation and surgical interventions on this region in newborn and adult patients.

The information in anatomy textbooks (13,18) on the innervation of the PMM differs. In the detailed dissection performed in our study, we observed that the innervation of this muscle was different from that reported in anatomy textbooks. Contrary to the common view indicating that the origin of the PMM innervation is “mainly L1 and L2, and L3 also contributes to it to some extent” (11), our study revealed that the PMM was innervated by the ventral rami of the L1-L4 spinal nerves and FN. In their study on adult cadavers, Mahan et al. reported that the PMM was innervated by the ventral rami of the L1-L4 spinal nerves (11). Although our results were similar to those obtained by Mahan et al., we also observed that the PMM was innervated by the FN in our study. Mahan et al. reported that the branches innervating the PMM mostly originated from the L2-L3 spinal nerves, similar to our results (11). In their study on adult cadavers, Van Campenhout et al. stated that the

PMM was mainly innervated by the L2-L3 spinal nerves and sometimes by the FN, L1, or L4 spinal nerves. However, they did not report at what rate and from which spinal nerves the branches innervating the PMM originated. They also indicated that a PMM received 2 to 7 branches (3.7 on average) (22). Although the results of our study are similar to those of Mahan et al. and Van Campenhout et al., there are some minor differences (11,22). We think this is due to the different populations and numbers of the studied samples.

While the PMM is dissected during lateral transpsoas surgery, the branches innervating the PMM may be damaged. Therefore, according to the results of our study, surgeons may need to be more careful under the level of the L2-3 intervertebral disc, where the branches innervating the PMM are dense. However, despite all the attention of surgeons, denervation injuries of the PMM may occur during dissection, and these denervation injuries may lead to hip flexion weakness (11). Therefore, it is necessary to avoid the extensive dissection of the PMM in the lateral transpsoas approach to prevent denervation injuries.

Denervation injuries are characterized by a less return of muscle strength and slower healing compared to trauma injuries. A partially denervated muscle is reinnervated by the collateral sprouting of adjacent motor units. However, such a healing process takes months. Therefore, hip flexion weakness lasting more than 3 months was stated to indicate denervation rather than muscle trauma or neuropraxic injury (11).

Most previous studies have focused only on the branches of the lumbar plexus within the PMM (7,8,10). However, they did not evaluate the exit level of the branches that innervate the PMM itself or the risk of denervation of this muscle during surgical intervention. Nevertheless, Mahan et al. focused on the branches inside the PMM and innervating this muscle. Additionally, they reported that hip flexion weakness could be seen after lateral transpsoas surgery due to the PMM denervation (11). Moreover, Moller et al. reported hip flexion weakness in 36 percent of patients after lateral transpsoas surgery (12). Another study using a lateral approach to the spine (lateral lumbar interbody fusion) reported that 27.5% of the patients experienced hip flexion weakness and 100% recovered completely after 6 months (20).

It takes months for hip flexion weakness to heal. This healing process may be related to the number of branches coming to the PMM because with an increase in the number of branches innervating the PMM, the faster re-innervation of the muscle fibers innervated by the injured nerves can be achieved by collateral sprouting. The low number of branches innervating the PMM may indicate that these branches are at a lower risk during surgical intervention. However, due to the scarcity of adjacent branches, it may take longer for the muscle fibers innervated by the injured branch to be re-stimulated by collateral sprouting. In our study, the rate of the PMMs innervated by at most 3 branches was 28.7% (Table IV). The fact that this rate is similar to the rate of hip flexion weakness in the literature may arise the question of whether there is a relationship between hip flexion weakness and the number of branches innervating the PMM However, we think there is a need for more studies on this subject. Additionally, in light of this information, the results of our study may be useful in explaining to patients the recovery process of patients who develop hip flexion weakness after lateral transpsoas surgeries.

While anatomy textbooks state that the IM is innervated by the ventral rami of the L2, L3 spinal nerves, and the FN (17), Delaney et al. reported that the branches innervating the IM originated from the T12 and L1-L4 spinal nerves (4). In our study, the IM was innervated only by the FN, and the L2-L4 spinal nerves formed the FN. The results of our study differ from those stated in the textbooks and reviews mentioned above. The reason for this difference may be the fact that other sources do not specify whether the branch innervating the IM is evaluated according to the nerve from which it originates or according to the spinal nerve from which fibers originate. Furthermore, we did not find any information on the mean number of branches innervating the IM in the literature, and we think that our study is a pioneering study in this regard.

Our study examined only the origin points of the spinal nerve branches innervating the muscles. It did not determine from which spinal nerves the branches contained fibers. Furthermore, since our study is not a population study including samples from various populations, it does not provide information on the innervation patterns of the above-mentioned muscles according to populations. Therefore, it should be considered that the results may differ between populations.

CONCLUSION

In this study, it was determined that PMM is innervated by the ventral branches of L1-L4 spinal nerves and FN. It was observed that the IM was innervated only by FN. Since the spinal nerves innervating the PMM are located between the medial edge of this muscle and the lateral edge of the vertebral column, they are at risk of denervation injury during lateral transpsoas surgery, lateral discectomy, and spinal fusion surgery. According to the results of our study, surgeons may need to be more careful under the L2-3 intervertebral disc level, where the branches innervating the PMM are dense. Denervation injuries in this area can lead to hip flexion weakness. Therefore, extensive dissection of the PMM should be avoided during the lateral transpsoas approach. We also think that there may be a link between the number of branches innervating the PMM and the healing process of hip flexion weakness. However, more work is needed on this subject. Based on this information, the results of our study may be useful in explaining the recovery process of patients who develop hip flexion weakness after lateral transpsoas surgeries. Therefore, it will be useful for surgeons to know the innervation patterns of PMM in surgical interventions such as the lateral transpsoas approach and the innervation patterns of IM in various surgical interventions to the iliac fossa.

ACKNOWLEDGMENTS

The authors sincerely thank those who donated their bodies to science so that anatomical research could be performed.

Results from such research can potentially increase mankind's overall knowledge that can then improve patient care. Therefore, these donors and their families deserve our highest gratitude.

AUTHORSHIP CONTRIBUTION

Study conception and design: KO, SA

Data collection: KO, AD, YK

Analysis and interpretation of results: KO, AD

Draft manuscript preparation: KO

Critical revision of the article: AD, YK, SA

All authors (KO, AD, YK, SA) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Barber SM, Boghani Z, Steele W, Blacklock JB, Trask T, Holman P: Variation in psoas muscle location relative to the safe working zone for l4/5 lateral transpsoas interbody fusion: A morphometric analysis. World Neurosurg 107:396–399, 2017
2. Bossy J: Development of the dorsal branches of the spinal nerves during the true embryonic period. Bull Assoc Anat (Nancy) 64:199-206, 1980
3. Davis TT, Bae HW, Mok JM, Rasouli A, Delamarter RB: Lumbar plexus anatomy within the psoas muscle: Implications for the transpsoas lateral approach to the L4-L5 disc. J Bone Jt Surg 93:1482-1487, 2011
4. Delaney H, Bencardino J, Rosenberg ZS: Magnetic resonance neurography of the pelvis and lumbosacral plexus. Neuroimaging Clin N Am 24:127-150, 2014
5. Dib M, Bedu A, Garel C, Mazda K, Philippe-Chomette P, Rajguru M, Hassan M, Aujard Y: Ilio-psoas abscess in neonates: Treatment by ultrasound-guided percutaneous drainage. Pediatr Radiol 30:677-680, 2000
6. Grau-Cruz EE, Nourbakhsh A: Posterior approach for debridement of the psoas abscess. J Vis Exp 157:e60796, 2020
7. Guérin P, Obeid I, Bourghli A, Masquefa T, Luc S, Gille O, Pointillart V, Vital JM: The lumbosacral plexus: Anatomic considerations for minimally invasive retroperitoneal transpsoas approach. Surg Radiol Anat 34:151-157, 2012
8. Guérin P, Obeid I, Gille O, Bourghli A, Luc S, Pointillart V, Cursolle JC, Vital JM: Safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: A morphometric study. Surg Radiol Anat 33:665-671, 2011
9. Hope EE, Bodensteiner JB, Thong N: Neonatal lumbar plexus injury. Arch Neurol 42:94-95, 1985
10. Kepler CK, Bogner EA, Herzog RJ, Huang RC: Anatomy of the psoas muscle and lumbar plexus with respect to the surgical approach for lateral transpsoas interbody fusion. Eur Spine J 20:550-556, 2011
11. Mahan MA, Sanders LE, Guan J, Dailey AT, Taylor W, Morton DA: Anatomy of psoas muscle innervation: Cadaveric study. Clin Anat 30:479-486, 2017
12. Moller DJ, Slimack NP, Acosta FL, Koski TR, Fessler RG, Liu JC: Minimally invasive lateral lumbar interbody fusion and transpsoas approach-related morbidity. Neurosurg Focus 31:E4, 2011
13. Moore KL, Dalley AF: Clinically Oriented Anatomy, 5th ed. Baltimore: Lippincott Williams and Wilkins, 2006:334
14. Moro T, Kikuchi S, Konno S, Yaginuma H: An anatomic study of the lumbar plexus with respect to retroperitoneal endoscopic surgery. Spine (Phila Pa 1976) 28:423-427, 2003
15. Ram S, Patel J, Kanani S: Human cadaveric study of lumbar plexus and its clinical implication. Natl J Clin Anat 6:24-34, 2017
16. Rao TR, Vanishree, Kanyan PS, Rao S: Bilateral variation of iliacus muscle and splitting of femoral nerve. Neuroanatomy 7:72-75, 2008
17. Singh R, Rajkumar, Chandra N, Gupta K, Ansari MS: Microanatomy of the nerve to iliacus muscle and its clinical significance. Int J Morphol 37:1150-1163, 2019
18. Standring S: Gray's Anatomy: The Anatomical Basis of Clinical Practice, 40th. ed. Edinburgh: Churchill Livingstone/Elsevier, 2008:564
19. Streeter GL: The development of the cranial and spinal nerves in the occipital region of the human embryo. Am J Anat 4:83-116, 1905
20. Tohmeh AG, Rodgers WB, Peterson MD: Dynamically evoked, discrete-threshold electromyography in the extreme lateral interbody fusion approach. J Neurosurg Spine 14:31-37, 2011
21. Turgut F, Turgut M, Menteş E: Lumbosacral plexus compression by fetus: An unusual cause of radiculopathy during teenage pregnancy. Eur J Obstet Gynecol Reprod Biol 73:203-204, 1997
22. Van Campenhout A, Hubens G, Fagard K, Molenaers G: Localization of motor nerve branches of the human psoas muscle. Muscle and Nerve 42:202–207, 2010
23. Yasar S, Kaya S, Temiz C, Tehli O, Kural C, Izci Y: Morphological structure and variations of lumbar plexus in human fetuses. Clin Anat 27:383-388, 2014