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Anatomical study on radiofrequency ablation for the treatment of lumbar facet joint syndrome

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Abstract

Study Design: Anatomical study.

Background: While radiofrequency ablation (RFA) is a well-established and effective treatment for lumbar facet joint syndrome (FJS), some studies have reported that pain relief in certain patients is limited, with symptoms potentially recurring within 1-2 years following medial branch RFA. A deeper understanding of the course and distribution of the medial branches of the dorsal rami from their origin to the fibro-osseous canal entrance could enhance the success rate of RFA for denervation. This study investigated the anatomical characteristics of the medial branches of the dorsal rami of L1-L4 and explored their potential clinical significance.

Methods: An anatomical examination was conducted on ten human specimens to document the characteristics of the medial branches of the dorsal rami of L1-L4.

Results: The angles between the medial branches of the dorsal rami and the MAL at the fibro-osseous canal entrance were as follows: 65±3°, 66±3°, 68±3° and 67±4°, respectively. The distances from the caudal aspect of the mamillary process to the medial branches at the fibro-osseous canal entrance were measured as 4.66 ± 1.02 mm, 4.80 ± 1.08 mm, 5.15 ± 1.23 mm, and 5.07 ± 0.99 mm, respectively.

Conclusion: To optimize RF denervation, the electrode should form an angle of approximately 60-70° with the line connecting the mamillary process to the accessory process. The distal tip of the RF electrode should be positioned 3-6 mm below the caudal mamillary process at the fibro-osseous canal entrance, which may improve parallel tip alignment and selectivity for the targeted nerves.

BACKGROUND

Radiofrequency ablation (RFA) is a commonly used and effective technique for managing lumbar facet joint syndrome (FJS) [1]. However, studies have shown that only 32%-56.5% of patients report more than 50% pain relief following RFA targeting the medial branch of lumbar dorsal rami, and pain recurrence can occur within 1–2 years[2, 3]. Recurrence may be attributed to anatomical variations in the medial branches, suboptimal placement of the radiofrequency (RF) needle tips, nerve fiber regeneration, and patient selection factors. Some reports indicate that positioning the RF electrode parallel to the medial branch of the lumbar dorsal ramus enhances pain relief and prolongs the duration of relief[4–6]. However, specific guidelines on how to achieve optimal electrode placement remain unclear, highlighting the need for a detailed anatomical understanding of the medial branch of the lumbar dorsal ramus to increase RFA efficacy in denervation.

Originally, Shealy et al.[7] described the medial branch of the lumbar dorsal rami as passing dorsally across the lateral aspect of the superior articular processes, recommending RF needle placement lateral to the articular process and perpendicular to the coronal plane. However, this anatomical description was later found to be inaccurate. Subsequent studies clarified that the medial branch of the dorsal rami

of L1-L4 exits the intervertebral foramen and courses around the neck of the superior articular process to reach the back's posterior compartment, while the medial branch of L5 traverses a groove between the sacral ala and the root of the S1 superior articular process[7, 8]. Tran et al.[9] further identified anatomical relations between the medial branch and both bony and soft tissue landmarks but did not detail the anatomical course of the medial branch of L1-L4 from its origin to the fibro-osseous canal.

This study investigated the course and distribution of the medial branch of the dorsal rami of L1-L4 from origin to the fibro-osseous canal entrance. We aim to clarify these anatomical features and examine their clinical relevance for improving RFA outcomes in lumbar facet joint denervation.

METHODS

This study analyzed the medial branches of the dorsal rami from 80 specimens of 10 embalmed human cadavers (6 male and 4 female; mean age 67 years). None of the cadavers had a history of spinal surgery or apparent deformities. The study was approved by the Ethics Committee of Southern Medical University. All the specimens from the remains receiving station of Southern Medical University which were used in the experiment have the consent form of body donation.

The skin, latissimus dorsi, longissimus, and iliocostal muscles were removed from the T11/12 intervertebral disc segment towards the caudal end of the specimen. This exposed the lateral, intermediate, and medial branches of the dorsal rami of L1-L4. The adjacent fat tissue surrounding the medial branches was meticulously excised under a surgical microscope (Carl Zeiss Inc., Jena, Germany) until the branches of the medial ramus were no longer visible.

The angles formed by the medial branches of the dorsal rami of L1-L4 and the mamillo-accessory ligament (MAL) at the entrance of the fibro-osseous canal were measured, along with the distance from the caudal aspect of the mamillary process to the medial branch of the dorsal rami of L1-L4. Additionally, the diameter of the medial branch at the fibro-osseous canal entrance was also recorded using a digital caliper, accurate to 0.01 mm.

Data analysis was performed using SPSS version 20.0 software. Results are presented as "$\bar{x} \pm s$". The angles formed by the medial branches of the dorsal rami of L1-L4 and the MAL at the fibro-osseous canal entrance were assessed using the Kruskal-Wallis test. The angles between paired medial branches (e.g., left and right branches of the dorsal rami of L1) and the MAL at the fibro-osseous canal entrance were compared using the Wilcoxon signed-rank test. The distance between the caudal aspect of the mamillary process and the medial branches of the dorsal rami of L1-L4 at the fibro-osseous canal entrance was analyzed with one-way analysis of variance (ANOVA). The paired t-test was used to assess the distance between the caudal mamillary process and the left or right medial branch of the dorsal rami at the fibro-osseous canal entrance. A p-value of less than 0.05 was considered statistically significant.

RESULTS

In this study, 80 medial branches of the dorsal rami from L1-L4 were examined. These branches originated from the dorsal rami of L1-L4 and ran along the medial side of the lateral and intermediate branches (Fig. 1). From their origin to the entrance of the fibro-osseous canal, the medial branches followed the neck of the superior articular process toward the lateral caudal side before passing through the fibro-osseous canal (Fig. 2). After traversing the canal, each medial branch divided into 2–5 smaller branches that innervate structures such as the facet joints, supraspinous ligament, and multifidus muscle (Fig. 3). Additionally, we observed that the lumbar facet joints were innervated not only by the medial branches of the dorsal rami from the same segment but also by those from the superior segment (Fig. 4).

Table 1 reports the angles between the medial branches of the dorsal rami of L1-L4 and the MAL at the entrance to the fibro-osseous canal. These angles were measured as 65 ± 3°, 66 ± 3°, 68 ± 3°, and 67 ± 4°, respectively, with no significant differences across segments ($H = 6.749$, $P = 0.080$). The angle between the left medial branches of the dorsal rami and the MAL was similar to that of the corresponding right medial branches ($P > 0.05$).

Table 1
Measurements of the angle formed by the medial branch of the dorsal rami of L1-L4 and the MAL at the entrance of the fibro-osseous canal "$\bar{x} \pm s$ (minimum-maximum)"

	MB	Angle (°) (minimum-maximum)
Left	MB1	65 ± 3 (60–70)
	MB2	65 ± 3 (61–70)
	MB3	68 ± 3 (65–75)
	MB4	68 ± 4 (62–74)
Right	MB1	65 ± 3 (60–69)
	MB2	67 ± 3 (62–72)
	MB3	67 ± 3 (64–71)
	MB4	67 ± 5 (62–74)

MB, medial branch of the dorsal rami; Angle, angle formed by the medial branch of the dorsal rami of L1-L4 and the MAL at the entrance of the fibro-osseous canal

The distance between the caudal aspect of the mammillary process and the medial branch at the fibro-osseous canal entrance, as well as the diameter of the medial branches, are also detailed in Table 2. The diameters of the medial branches were 0.64 ± 0.19 mm, 0.66 ± 0.17 mm, 0.68 ± 0.19 mm, and 0.64 ± 0.17 mm, respectively. The distances from the caudal mammillary process to the medial branches were 4.66 ± 1.02 mm, 4.80 ± 1.08 mm, 5.15 ± 1.23 mm, and 5.07 ± 0.99 mm, respectively. There was no significant difference in the distance between the caudal aspect of the mammillary process and the medial branch of the dorsal rami of L1-L4 at the entrance of the fibro-osseous canal (F = 0.877, P = 0.457). Similarly, the

distance between the caudal mammillary process and the medial branch of the dorsal rami of the left L1-L4 did not differ from that of the corresponding right L1-L4 at the fibro-osseous canal entrance (P > 0.05). Additionally, no statistically significant differences were observed between male and female embalmed human cadavers regarding these measurements (P > 0.05).

Table 2
Measurements of the distribution of the medial branch of the dorsal rami of L1-L4 "$\bar{x} \pm s$ (minimum-maximum)"

MB	Diameter (mm) (minimum-maximum)	Distance (mm) (minimum-maximum)
MB1	0.64 ± 0.19 (0.54–0.82)	4.66 ± 1.02 (3.30–6.20)
MB2	0.66 ± 0.17 (0.53–0.85)	4.80 ± 1.08 (3.60–6.60)
MB3	0.68 ± 0.19 (0.56–0.86)	5.15 ± 1.23 (3.20–6.90)
MB4	0.64 ± 0.17 (0.51–0.79)	5.07 ± 0.99 (3.60–6.90)

MB, medial branch of the dorsal rami; Diameter, diameter of the medial branch of the dorsal rami of L1-L4 at the entrance of the fibro-osseous canal; Distance, distance between the caudal of the mamillary process and the medial branch of the dorsal rami of L1-L4 at the entrance of the fibro-osseous canal

DISCUSSION

Numerous studies have indicated that conservative treatment and pharmacotherapy are the primary management strategies for facet joints (FJs) in clinical practice[10–13]. However, for patients who fail conservative treatments and are prone to recurrence, long-term medication becomes a significant burden[14, 15]. Lilius et al.[16] observed a strong correlation between poor responses to intra-articular and periarticular blockades and steroid injections, along with mismatched signs and symptoms. Consequently, many experts suggest that the optimal management of FJs should include interventional treatments, such as radiofrequency ablation (RFA)[1]. In a prospective study assessing RFA outcomes, Dreyfuss et al.[17] reported that 87% of patients experienced at least 60% pain relief after 12 months, with 60% achieving at least 90% relief. However, local bleeding complications associated with this technique remain unacceptably high. Furthermore, improper needle placement during RFA can lead to incomplete coagulation of the medial branches of the lumbar dorsal rami, allowing for rapid nerve

recovery and resulting in a shorter duration of pain relief[18, 19]. Thus, understanding the anatomical features of these medial branches is crucial for successful RFA treatment of FJs.

Anatomy of the Medial Branch of the Dorsal Rami of L1–L4

Previous studies have detailed the course of the medial branches of the lumbar dorsal rami and their innervation of the lumbar facet joints. Bogduk et al.[20, 21] first described the dorsal rami of lumbar nerves, noting that the L1–L4 rami typically branch into three divisions: the medial, intermediate, and lateral branches, which innervate the multifidus, longissimus, and iliocostal muscles, respectively. Demondion et al.[8] further documented that the medial branches of the L1–L4 dorsal rami pass across the tops of their respective transverse processes, descend along the junction of the transverse and superior articular processes, and cross the mamillo-accessory ligament before branching.

Despite these observations, the anatomical characteristics of the medial branch and its dominance pattern in lumbar facet joint innervation remain poorly understood. Liu et al.[22] found that the medial branches of the L1–L4 segments give off one to two small branches to innervate joints of the adjacent lower segment, while 23.75% of branches also provide recurrent branches to the upper segment. This study primarily focused on the medial branches before they crossed the MAL. Our findings align with Saito's description that, after crossing the fibro-osseous canal, the medial branches of the L1–L4 dorsal rami divide into 3–5 smaller branches[23]. Notably, the lumbar facet joints receive innervation not only from the medial branches of the same segment but also from those of the superior segment, forming the anatomical basis for treating FJs (Fig. 4)[7, 20].

Anatomical studies addressing the relationship between the medial branch, mamillary process, accessory process, and surrounding soft tissues are limited. Tran et al.[9] explored the origin and distribution of the medial branches of the lumbar dorsal rami, describing their course before and after crossing the MAL and their anatomical relationship with surrounding bony landmarks. In our study, we also assessed the angles formed by the medial branches of the L1–L4 dorsal rami and the MAL at the entrance to the fibro-osseous canal, as well as the distance between the caudal end of the mamillary process and the medial branches at the canal entrance. Our results showed no significant difference in the angles formed by the medial branches and the MAL on either side of the body ($P > 0.05$), indicating that the courses of ipsilateral and adjacent medial branches of the dorsal rami of L1–L4 are nearly parallel. Additionally, the distance between the caudal mamillary process and the medial branches at the fibro-osseous canal entrance was predominantly (83.8%) between 3–6 mm. This information is critical for surgeons performing RFA on FJs, as it helps to accurately locate the medial branches of the dorsal rami of L1–L4 at the fibro-osseous canal entrance.

Clinical Relevance

Recent attention has highlighted the advantages of medial branch RFA in treating FJ pain, prompting further research into the anatomical characteristics of the medial branches involved, rather than focusing solely on the nerve innervation of lumbar facet joints. Previous studies established that the lumbar facet joints are predominantly innervated by the medial branch of the lumbar dorsal ramus[24]. Nociceptors around these joints can be activated by factors such as inflammation and degenerative conditions[7]. Pain signals are transmitted via the medial branch to the lumbar dorsal ramus, then onward to the sensory centers. Consequently, radiofrequency denervation of the medial branch has become a key therapeutic approach for treating FJ pain. This procedure utilizes radiofrequency energy delivered through a small-diameter needle to create a controlled burn that severs the nerve supply to the lumbar facet joints[25].

However, the accuracy of electrode placement significantly influences the success and effectiveness of lumbar dorsal ramus RFA. Recent literature advocates for a lateral-to-medial approach, known as the "parallel" technique, for denervating the medial branch[4–6]. Building on this, Tran et al.[9] proposed an enhanced technique involving placement of the radiofrequency electrode in the parasagittal plane with increased cranial-to-caudal angulation. This modification improves the alignment of the electrode tip with the target medial branch, potentially enhancing denervation effectiveness. Our study supports this approach and identifies three critical factors for optimizing RF electrode placement to increase the area of effective denervation.

The first key finding emphasizes the importance of determining the correct cranial-to-caudal angulation for needle placement, which depends on understanding the medial branch's anatomical course. The medial branch extends from the lumbar dorsal ramus to the mamillo-accessory notch, with a relatively short distance between these points. The branches of the L1-L4 dorsal rami typically follow a straight path, as shown in Fig. 3. The angle between the L1-L4 medial branch and the MAL at the fibro-osseous canal entrance is 60°–70°. Thus, the RF electrode should be positioned at a similar angle, approximately 60°–70° relative to the connection between the mammillary and accessory processes. Additionally, the electrode tip should lie just below the anterior portion of the superior articular process, near the level of the superior vertebral endplate. This positioning can be verified using lateral X-ray imaging, regardless of whether the traditional or parasagittal approach is used.

The medial branch of the dorsal rami of L1-L4 originates near the lateral and intermediate branches of the lumbar dorsal ramus. If a lesion extends to the anterior portion of the superior articular process, just above the superior vertebral endplate, it may inadvertently affect surrounding nerve tissues at the origin of the medial branch. This increases the risk of thermal injury. Additionally, due to the medial branch's lack of specificity, this approach is not optimal. Therefore, placing the electrode tip in the "withdrawal position" as described by Lau et al.[7], at the midpoint (50%) of the superior articular process, enhances selective targeting of the medial branch while minimizing risk to the lateral and intermediate branches of the lumbar dorsal ramus.

The MAL is positioned in the posterior quarter of the lateral neck of the superior articular process, which prevents thermal coagulation of the medial branch. Consequently, lesioning in this region is ineffective. To maximize electrode contact with the medial branch, increasing the denervation effect, the electrode should be placed 3-6mm below the caudal end of the mammillary process at the entrance of the fibro-osseous canal. This positioning avoids interference from the MAL, allowing for more effective thermal coagulation of the medial branch.

Limitations

However, this study primarily used preserved gross specimens, which introduces potential errors due to nerve fibers being displaced during dissection. Additionally, the need for extensive nerve exposure in each specimen complicates large-scale studies with detailed anatomical analysis. Moreover, as this is an anatomical study lacking clinical data, further research is needed to assess its clinical significance, feasibility, and effectiveness.

CONCLUSIONS

In conclusion, understanding the spatial relationship between the medial branch of the dorsal rami of L1-L4 and key anatomical landmarks is essential for optimizing image-guided lumbar denervation. The current study's detailed analysis of the medial branch's course, from its origin to the fibro-osseous canal, suggests that the RF electrode should form an angle of approximately 60–70 degrees with the connection between the mammillary and accessory processes. The electrode's tail end should be placed 3–6 mm below the caudal edge of the mammillary process, optimizing alignment and selectivity for the targeted nerves.

Abbreviations

RF radiofrequency

RFA radiofrequency ablation

FJS facet joint syndrome

MAL mamillo-accessory ligament

FJs facet joints

Declarations

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Authors XGW and LHB contributed equally to this work and should be considered co-first authors. The authors express their gratitude and admiration to the volunteers who donated their bodies.

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DATA AVAILIABILITY

Data is contained within the article. Individual data is unavailable due to privacy or ethical restrictions.

Contributions

G.X. and H.L., Conceptualization and methodology; J.L. and Z.M., data acquisition; G.W., formal analysis; S.R. and J. G., writing—original draft preparation; G.X., writing—review and editing; G.X. and J.O., funding acquisition; G.X. and H.L., validation; All authors have read and agreed to the published version of the manuscript.

Ethics approval and consent to participate

This study was approved by the the Ethics Committee of Southern Medical University. All procedures performed in studies were in accordance with the Helsinki declaration.

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Figures

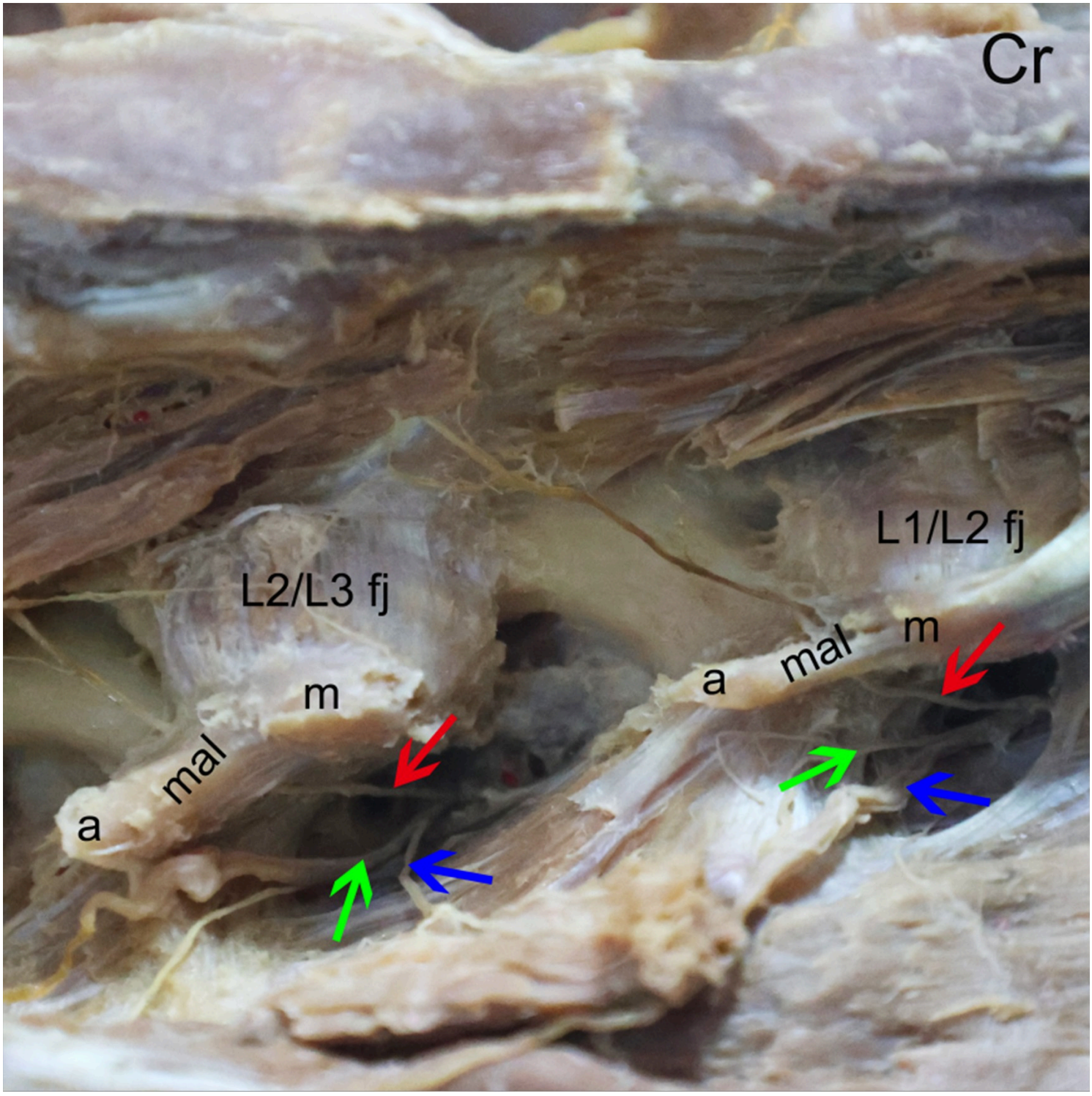


Figure 1

Branches of lumbar dorsal rami. Cr indicates cranial; fj, facet joint; mal, the mamillo-accessory ligament; m, the mamillary process; a, accessory process; Blue arrows, lateral branch; Green arrows, intermediate branch; Red arrows, medial branch

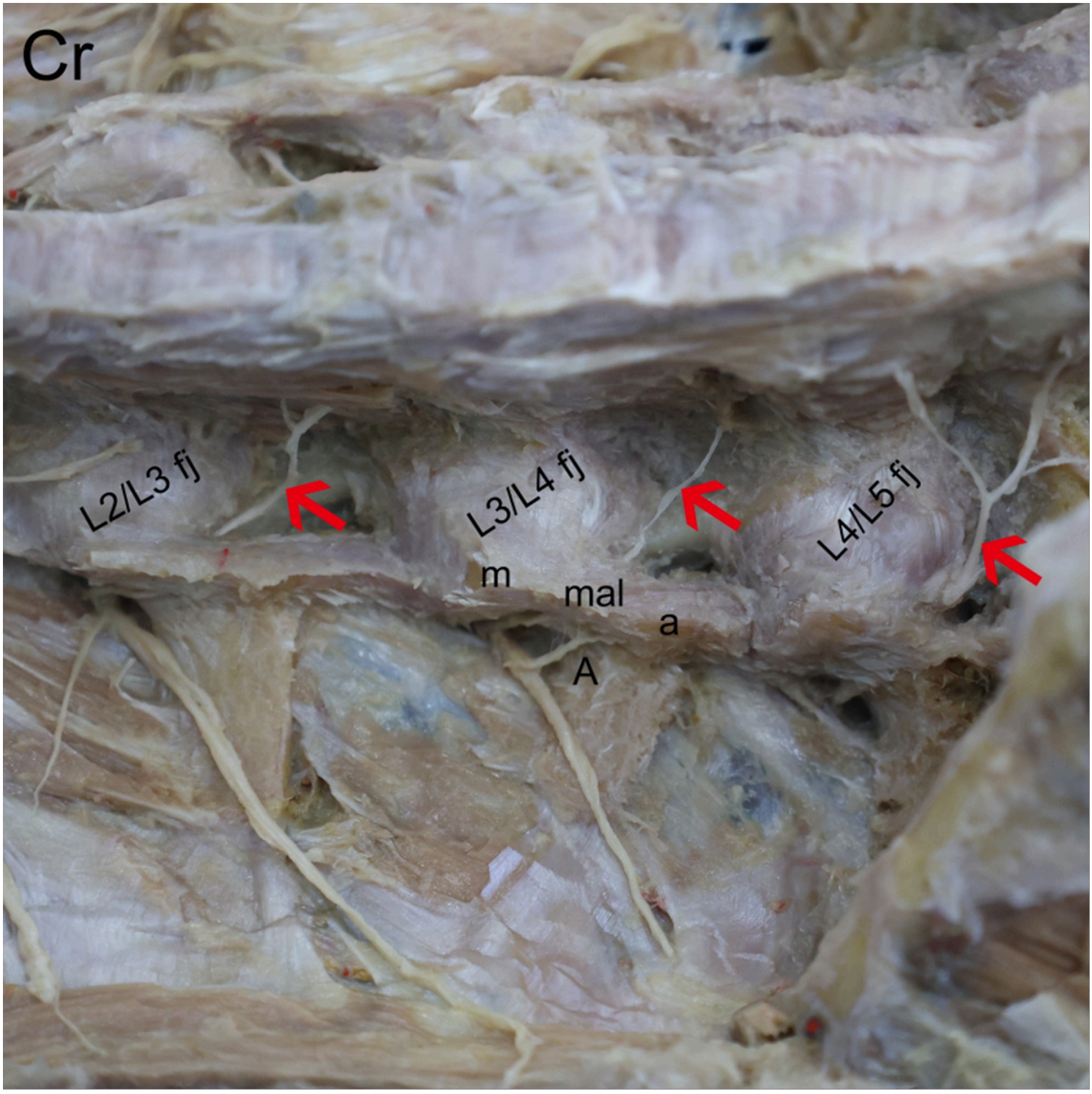


Figure 2

Posterior view of the lumbar spine, demonstrating the fibro-osseous canal. Cr indicates cranial; fj, facet joint; mal, the mamillo-accessory ligament; m, mamillary process; a, accessory process; A, transverse process; Red arrows, medial branch

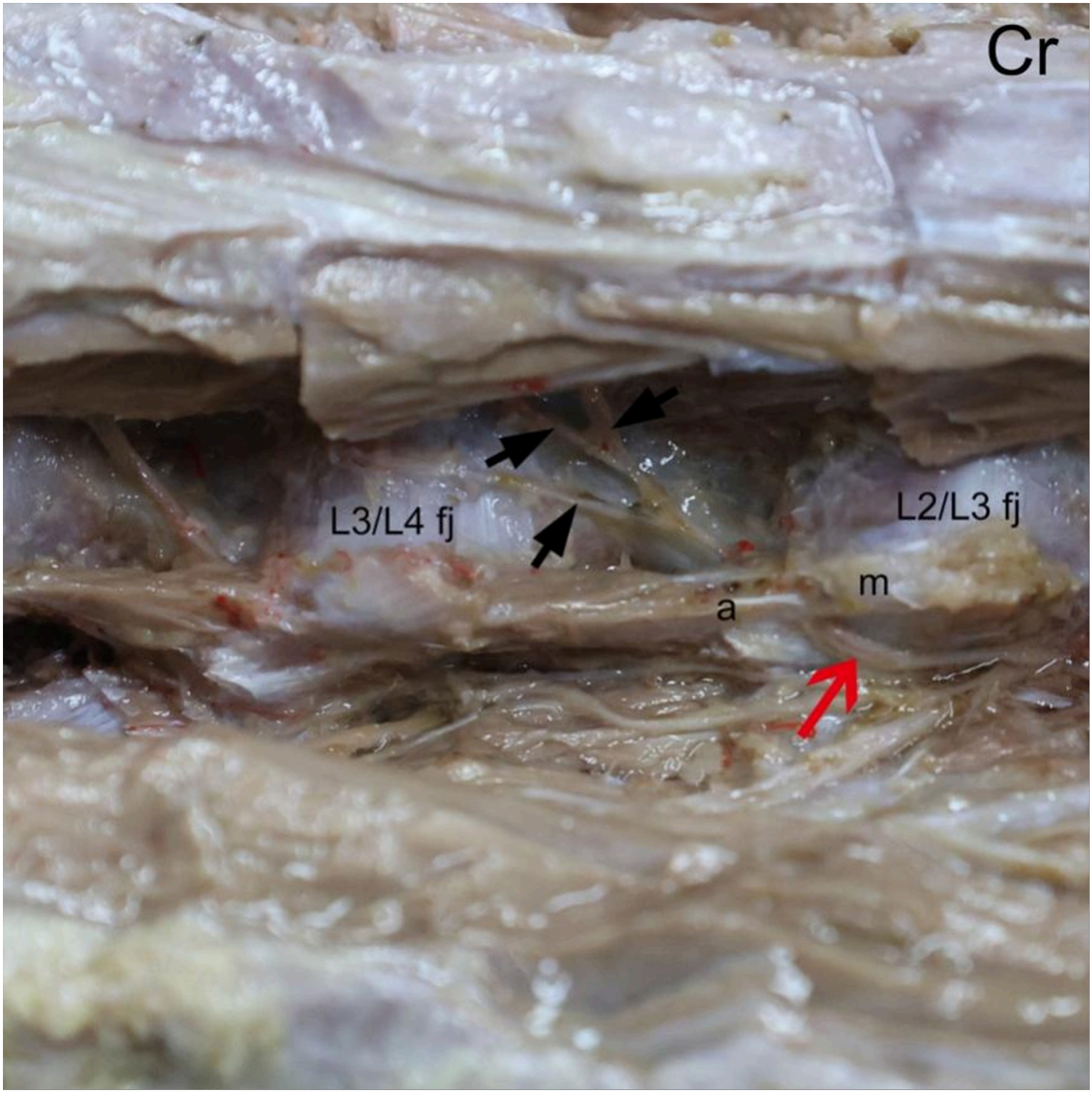


Figure 3

Branches of the medial branches of the dorsal rami of L3. Cr indicates cranial; fj, facet joint; m, mamillary process; a, accessory process; Red arrows, medial branch; Black arrows, branches of the medial branches of the dorsal rami of L3

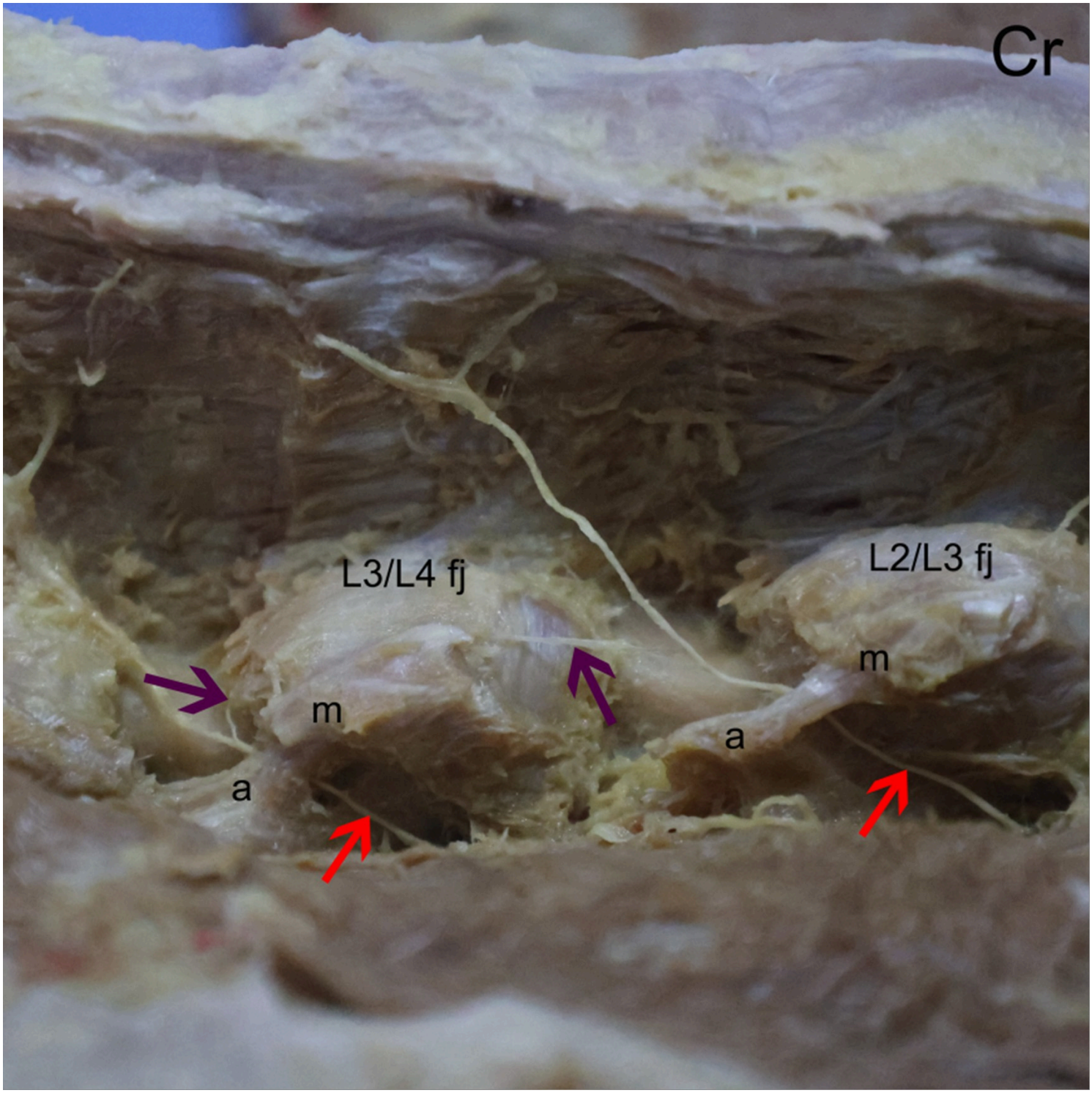


Figure 4

Nerve innervation of the L3/L4 facet joint. Cr indicates cranial; fj, facet joint; m, mamillary process; a, accessory process; Red arrows, medial branch; Purple arrows, articular branches of the L3/L4 facet joint