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Immediate alteration of the lumbar intervertebral foramen during the so-called osteopathic locking technique: a preliminary analysis on healthy subjects

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ABSTRACT

Background: Degenerative processes in the lumbar spine can lead to a decrease of the disc height and an alteration of the foramen with potential compression of the nerve root.

Several osteopathic manipulative techniques are designed to improve the intervertebral joints and the foraminal area.

Objective: This study was intended to explore the effect of so-called osteopathic manipulative locking technique (OMLT) on the lumbar foramen.

Methods: Ten asymptomatic volunteers underwent CT scan examination in neutral position and during OMLT targeting the L4-L5 level on the left side. Two subjects were excluded from the sample due to lumbosacral transitional anomaly. Anatomical modeling was obtained by segmenting imaging CT data. 3D kinematics and intervertebral foramen dimensions (height, width and area) were computed for both positioning.

Results: The findings indicate that OLMT applied on the L4-L5 level consisted in small combined angular motions including extension, contralateral LB and contralateral AR. These motion components result in a significant alteration of the foramen height on the targeted side. In contrast, other foramen variables remained unchanged on both sides.

Conclusion: Better understanding of how osteopathic manipulative technique may affect the intervertebral motion and the foraminal area could improve the knowledge in osteopathic approaches. Further investigations are needed to confirm these primary outcomes and to determine the potential clinical effects of such an application.

Keywords: Osteopathic manipulative technique, foramen, lumbar spine, nerve impairment, intervertebral disc, axial rotation, lumbar kinematics, locking technique

INTRODUCTION

Lumbar intervertebral disc (IVD) is one of the main anatomical structures of the spine that undergoes degenerative processes which may lead to disc height decrease, alteration of lumbar range of movement and foramen impairment with potential nerve root compression [1]. Association between nonspecific low back pain and disc degeneration is clearly suggested in systematic reviews [2–4]. Further postural changes of the lumbar spine (i.e. lumbar lordosis) have shown to be obviously linked to low back pain and/or disc disorders [5]. Lumbar spine positioning has demonstrated various effects on the IVD and foraminal dimensions that may induce closing or opening of the posterior intervertebral areas [6,7]. Furthermore, nerve root impairment within the lumbar foramen may play a key role in the occurrence of low-back pain and sciatica [8].

Non-surgical treatment approaches of the lumbar spine comprise manual applications that seek to assess and improve intervertebral mobility [9–11]. Such methods are usually based on expected joint kinematics during manual tasks although investigations are limited on this issue. Another purpose of intervertebral physical application is to alter or improve intervertebral disc physiology and/or foraminal area for reducing symptoms in patients with disc degeneration [11–13]. However, specificity of manual technique has so far not been a topic of much in the way of targeted research, although some clinicians have proposed several non-thrust osteopathic manipulative techniques to improve the intervertebral disc function [14,15]. In fact, these approaches do not clarify scientifically their advantages and remain biomechanical models for describing a specific manual application.

Only very few studies, have explored lumbar segmental motions during manual or instrumental loading [16–18] confirming intervertebral responses to sagittal mobilization and according to the feature of the application. However, other types of mobilization have not yet been considered regarding axial rotation or side bending motion components.

On the other hand, some experimental studies demonstrated that combined motions usually occurred during axial rotation, inter alia, due to the facet gapping [19]. This condition produces 3D motion of the vertebra [20] and specific biomechanical features of the disc [21,22]. These biomechanical behaviors represent the basis of the so-called osteopathic manipulative locking technique (OMLT) which is designed to involve the intervertebral joint movements [14]. The OMLT model is based on the assumption that facet joint contact occurring primarily during axial rotation produces coupled motions driven by the facet joint geometry. These exhibited motions are related to an anteroposterior orientation of the motion axis located at approximately the facet joint in contact (contralateral facet to the rotation direction) [20]. According to Dethier's hypothesis [14], angular displacement around such a motion axis may lead to alteration of the intervertebral distance laterally and the foramen space. Nevertheless, this issue has not yet been addressed by scientific investigations.

The purpose of the present study is to explore the morphometric characteristics of the intervertebral foramen (IVF) during OMLT applied on the L4-L5 lumbar level compare to neutral position in asymptomatic volunteers. The results could provide interesting details regarding the impact of osteopathic manipulative technique on the lumbar intervertebral foramen and its potential clinical use in the condition of nerve root irritation or compression.

MATERIALS AND METHODS

Participants

Ten asymptomatic volunteers were recruited by convenience sample to participate in the present study. Inclusion criteria were the absence of low back pain, and subjects with a medical history of low back disorders, sign of radiculopathy, trauma were excluded from the study. Participants underwent CT scan examination (SOMATOM Siemens 16, Germany, slice thickness 1.5 mm with low-dose protocol 350, 120 kV, 150 mAs) to acquire imaging data of their lower lumbar spine in neutral (NP) and OMLT position (see below). The latter was sustained by the practitioner during the second CT examination (figure 1).

The study protocol has been checked and approved by the Ethical Committee of the Academic Hospital (CE2006/16 ref BL/CDC/CE/412796). All participants had signed an informed consent document.

Data processing

Anatomical modeling was obtained by segmenting imaging CT data using dedicated software (Amira 3,0®, Germany). The latter enabled virtual palpation to identify anatomical landmarks to determine (1) the anatomical local coordinate system (Fig. 2), hence the position and orientation of the L4 and L5, and (2) the L4-L5 IVF dimensions for both positioning. This method has demonstrated good to excellent consistency of measurement for assessing three-dimensional kinematics of the cervical spine [23,24]. However, in the present investigation, reliability of measurements was assessed for IVF variables (see below).

Kinematics was computed using the decomposition of helical axis rotation into helical angles around the axes of the anatomical reference system [25] to provide lateral bending (LB), axial rotation (AR) and flexion extension

(FE) angular displacements. Intervertebral foramen height (FH) and width (FW) were obtained from Euclidian distance between palpated landmarks on 3D models as depicted in figure 3. Foramen height was estimated using the longest pedicle-to-pedicle distance, and FW was defined as the distance, between the anterior aspect of the superior facet of the inferior vertebra and the posterolateral border of the superior vertebra (inferior plate). All measurements were completed three times by one single operator.

The foramen area (FA) was estimated by assuming that the IVF has almost an elliptic shape, as follows: $FA = \pi * FH/2 * FW/2$

To establish the reliability of the data, the same operator performed 3 measurements of FH and FW at the L4-L5 level in neutral position (on both sides) for 6 subjects on 3 separate occasions. Intra-rater reliability of measurements and agreement was assessed using intra-class correlation coefficient and 95% confidence intervals for FH, FW and FA. In addition, standard error of measurement ($SEM = \text{standard deviation} * \sqrt{(1\text{-}ICC)}$) and smallest detectable difference at 95% confidence levels ($SDD_{95}=1.96\ (SEM * \sqrt{2})$) were also examined. These data are presented in table 1.

Intervention

The OMLT is a non-thrust manipulative technique that consists in applying a manual sequence of axial rotation, extension and lateral bending motion focused on a specific lumbar spine level. A practitioner with 20-years of experience carried out the maneuver on the L4-L5 level for each subject lying in prone position. First, the practitioner locates the L4 spinous process and places his thenar eminence (cephalic hand) firmly against its right lateral side (figure 1 and 4). His fingers are spread, the elbow in extension and the entire arm is oriented in approximately 30° to 40° with respect to the horizontal plane. The caudal hand grips the left iliac crest anteriorly at the level of the ASIS to induce motion of the pelvis and the L5 segment. By fixing the L4 spinous process with the cephalic hand, the practitioner mobilizes the pelvic and L5 in rotation then extension and lateral bending with the caudal hand (figure 4). In short, this maneuver aims to create L4-L5 right rotation with coupled extension and lateral bending in order to increase the foraminal space on the left side. The participants should not be aware of any discomfort or pain. This model is based on a previous unpublished report [14] and scientific studies on the lumbar spine biomechanics (see introduction section). The figure 4 shows the starting and ending position during the maneuver.

Statistical analysis

Data were analyzed using SPSS statistics software version 20.0 (SPSS Inc, Chicago, IL). Descriptive data was calculated for each position on both sides. A normal distribution of quantitative data was assessed by means of the Shapiro-Wilk test ($p>0.05$). All data sets were normally distributed and therefore were analyzed with parametric tests. The paired Students t-test was performed to identify the significance of foramen changes between NP and OMLT for each side. The statistical significance level was acknowledged as $p < 0.05$.

RESULTS

After the first CT scan examination in neutral prone position, two subjects were excluded from the sample due to an unknown lumbosacral transitional anomaly in both cases. Thus, 8 volunteers (age between 24 and 58 years), 1 female (26 years) and 7 males, completed the study. Demographic data are presented in table 2. Regarding the technique applied, no side effect was reported by the participants during the task.

Kinematics data

During OMLT targeting the L4-L5 left side, L4 displayed 1.0 ± 1.1° of right LB, 0.4 ± 1.2° of right AR and 0.6 ± 2.5° extension with respect to L5, which corresponds to a helical angle of 2.8 ± 1.1°. In contrast, L5 exhibited 0.9 ± 1.6° of left LB, 0.3 ± 0.9° of left AR and 1.7 ± 1.9° flexion with respect to S1 (helical angle = 2.9 ± 1.1°). A maximal magnitude of 5° was observed for the sagittal motion component at both levels.

Intervertebral foramen data

First, there was no significant difference in measurements between right and left IVF in NP (FH: $t=0.492$, $p=0.638$; FW: $t=-0.137$, $p=0.895$; FA: $t=0.035$, $p=0.973$).

Central tendency and dispersion of foramen data are presented in table 2 according to lumbar NP and OMLP positioning. Changes in outcome measures including paired samples T-test analysis, mean difference with 95% confidence intervals and effect size (Cohen's d) are presented in table 3. A significant difference was depicted in FH on the targeted side during OMLT. In contrast, no significant changes were observed for FW and FA on both sides ($p>0.05$). OMLT showed larger effect size and higher frequency of data which depicted smallest detectable difference for the ipsilateral FH.

Supplementary material B displays a 3D anatomical model (L4-L5) with movement simulation http://....

DISCUSSION

This study examined the immediate effects of OMLT on the morphometric characteristics of the lumbar foramen in asymptomatic volunteers. The current protocol design and data processing were similar to those previously established for assessing pre-manipulative positioning with regards to the cervical spine [26]. Based on our small sample, the findings indicate that osteopathic manipulative locking technique applied on the L4-L5 level resulted in small combined angular motions including extension, contralateral LB and contralateral AR. For instance, OMLT targeting L4-L5 on the left side demonstrates extension, right LB and right AR. These motion components resulted in an alteration of the foramen height on the targeted side (i.e. the left foramen). Most of these FH changes were greater than the smallest detectable difference. Consequently, L4-L5 foramen height was increased on the side of the assumed facet coaptation. In contrast, other foramen variables remained unchanged during the technique applied on both sides.

It is well documented that axial rotation of the lumbar spine is associated with coupled flexion-extension and lateral bending motion [27–29]. Although inconsistency in patterns of coupled motions has been mentioned [30]. During OMLT, magnitudes of intervertebral motion were very small and remained within the physiological values [27,31,32]. Slightly higher values were obtained among patients with mild/moderate facet degeneration during loading in vivo conditions [33,34]. On the other hand, it was highlighted that discrepancies in intervertebral motion data may be related to different loading and experimental conditions [29]. Accordingly, extension posture or motion is likely to reduce other motion components (i.e. axial rotation) by increasing facet loading [20,35]. This aspect may also explain the occurrence of small motion magnitudes found during OMLT.

Regarding the kinematic behaviors observed, authors found similar motion pattern combining extension, contralateral axial rotation and lateral bending using a comparable manipulative task on the animal model [36]. Correspondingly, comparable motion pattern was found during dynamic axial rotation in standing position [31]. On the basis of previous studies such motion behavior should probably be related to the facet joint coaptation [20,37], the alteration of motion axis orientation [20] and the disc constraint [21], which gives consistency to the proposed model. Thus, OMLT may elicited specific motion pattern on the targeted level relative to the subjacent vertebral segment.

Few studies investigating lumbar segmental motion during posteroanterior mobilization found higher magnitude of intervertebral sagittal motion [16,17], but the latter did not concern combined motion procedure. To the best of our knowledge, no in vivo studies have been thoroughly conducted to date to examine segmental three-dimensional kinematics of the lumbar spine during OMLT. Surprisingly, regarding our data, motion components between the target L4-L5 level and the subjacent L5-S1 level showed contrasting results. In fact, L4 displayed extension, right AR and right LB while L5 exhibited an opposite pattern of motion in flexion, left AR and left LB. Similar observation was also reported by Lee et al. [18] describing an extension movement of L4 whereas L5 tended to flex during lumbar posteroanterior mobilization. So far, this feature is difficult to interpret due to individual variations and requires confirmation in future research.

Regarding the characteristics of the lumbar IVF, the present outcomes were comparable to those previously reported [6,38,39] including the absence of right versus left IVF difference [40]. Various investigations have described IVF changes related to motion direction [6,7,41], disc vertical dimension [38] but also to degenerative processes [42,43]. On the other hand, foraminal dimension changes may be related to the spinal flexibility that may vary from individual to individual [6].

Impairment of foraminal spaces may compromise neural but also vascular structures that may contribute to the development of symptoms [44]. Indeed, neurovascular structures within the intervertebral foramen are vulnerable to compression [45]. Therefore, manual foramen opening techniques have been designed to improve clinical outcomes in patients with cervical or lumbar radiculopathy [13,46]. Nonetheless, biomechanical investigations and related effects on the foramen dimensions are lacking regarding these approaches. In this study, an average increase of 6% in foraminal height was demonstrated on the contralateral side with respect to the axial rotation and lateral bending direction. Regarding the cut-off level, related to SDD value, a larger proportion of subjects (88%) were likely to show an improvement in FH. This morphometric alteration corroborates with the previous in-vitro findings of Fujiwara et al. [6], though it should be noted that these authors used larger magnitude of motion to obtain their outcomes. Moreover, notwithstanding the extension component observed during OMLT, no decrease of FH was found as reported by Panjabi et al. [43]. Consequently, OMLT supporting an improvement in foraminal height is consistent with the model initially proposed by Dethier [14] but the assumption that this technique could be appropriate to reduce mechanical compression on the nerve root and its surrounding vascular structures has to be established yet. Likewise, the deformation features of the intervertebral disc have not been examined either, which could be of interest in the context of foraminal involvement.

On the other hand, FW and FA changes were not significant and remained under the SDD values during OMLT. It must be noted that various methods are used for examining these types of measurements including inferior and superior width, bony boundary area of intervertebral foramina [40,42,47]. According to these authors, these morphological parameters are likely to better reflect the anatomical characteristics of the foramen and related structures which is worth to be considered in further study.

Limitations

The present study has some limitations. First, our results were based on a very small sample size and therefore should be treated with caution. Thus, it would be necessary to reproduce this investigation on a larger sample to provide adequate statistical power.

Second, the load applied by the practitioner was not standardized and may have various effect on the spinal motion patterns and foramen changes. However, this reflects better the current application in daily practice.

Also, the broad range of age (29-50 years) may represent a large discrepancy of physiological degenerative processes between the subjects that may affect the segmental motion features, nevertheless medical imaging revealed only early stages of degeneration within our sample. Consequently, a larger sample should also provide information regarding the effect of spinal level and spinal degeneration on subsequent changes of intervertebral foramen during manual tasks.

In addition, the present technique has not been compared to other manual tasks or physiological posture, and it is obvious that further studies must be completed on that topic, although it was not the primary purpose of this preliminary investigation.

CONCLUSION

Better understanding of how osteopathic manipulative techniques affect the intervertebral motion and foraminal space could improve the knowledge in osteopathic procedures and their related biomechanical effects. Such development may have an impact on the therapeutic decision making although further clinical investigations on much larger samples are clearly needed to confirm these preliminary outcomes and to assess the potential clinical effects of such an approach.

Appendix

Supplementary data: Three-dimensional musculoskeletal model and visualization of anatomical motion during osteopathic manipulative locking technique targeted on the left foramen.

REFERENCES

[1] Battié MC, Joshi AB, Gibbons LE. Degenerative Disc Disease: What is in a Name? Spine 2019;44:1523–9. https://doi.org/10.1097/BRS.0000000000003103.

[2] Brinjikji W, Diehn FE, Jarvik JG, Carr CM, Kallmes DF, Murad MH, et al. MRI Findings of Disc Degeneration are More Prevalent in Adults with Low Back Pain than in Asymptomatic Controls: A Systematic Review and Meta-Analysis. Am J Neuroradiol 2015;36:2394–9. https://doi.org/10.3174/ajnr.A4498.

[3] Mok FPS, Samartzis D, Karppinen J, Fong DYT, Luk KDK, Cheung KMC. Modic changes of the lumbar spine: prevalence, risk factors, and association with disc degeneration and low back pain in a large-scale population-based cohort. Spine J Off J North Am Spine Soc 2016;16:32–41. https://doi.org/10.1016/j.spinee.2015.09.060.

[4] Raastad J, Reiman M, Coeytaux R, Ledbetter L, Goode AP. The association between lumbar spine radiographic features and low back pain: a systematic review and meta-analysis. Semin Arthritis Rheum 2015;44:571–85. https://doi.org/10.1016/j.semarthrit.2014.10.006.

[5] Chun S-W, Lim C-Y, Kim K, Hwang J, Chung SG. The relationships between low back pain and lumbar lordosis: a systematic review and meta-analysis. Spine J Off J North Am Spine Soc 2017;17:1180–91. https://doi.org/10.1016/j.spinee.2017.04.034.

[6] Fujiwara A, An HS, Lim T-H, Haughton VM. Morphologic Changes in the Lumbar Intervertebral Foramen Due to Flexion-Extension, Lateral Bending, and Axial Rotation: An In Vitro Anatomic and Biomechanical Study. Spine 2001;26:876–82. https://doi.org/10.1097/00007632-200104150-00010.

[7] Chung SS, Lee CS, Kim SH, Chung MW, Ahn JM. Effect of low back posture on the morphology of the spinal canal. Skeletal Radiol 2000;29:217–23. https://doi.org/10.1007/s002560050596.

[8] Silav G, Arslan M, Comert A, Acar HI, Kahilogullari G, Dolgun H, et al. Relationship of dorsal root ganglion to intervertebral foramen in lumbar region: an anatomical study and review of literature. J Neurosurg Sci 2016;60:339–44.

[9] Will JS, Bury DC, Miller JA. Mechanical Low Back Pain. Am Fam Physician 2018;98:421–8.

[10] Powers CM, Kulig K, Harrison J, Bergman G. Segmental mobility of the lumbar spine during a posterior to anterior mobilization: assessment using dynamic MRI. Clin Biomech 2003;18:80–3. https://doi.org/10.1016/S0268-0033(02)00174-2.

[11] Mitchell UH, Helgeson K, Mintken P. Physiological effects of physical therapy interventions on lumbar intervertebral discs: A systematic review. Physiother Theory Pract 2017;33:695–705. https://doi.org/10.1080/09593985.2017.1345026.

[12] Choi J, Hwangbo G, Park J, Lee S. The Effects of Manual Therapy Using Joint Mobilization and Flexion-distraction Techniques on Chronic Low Back Pain and Disc Heights. J Phys Ther Sci 2014;26:1259–62. https://doi.org/10.1589/jpts.26.1259.

[13] Ferreira GE, Stieven FF, Araújo FX, Wiebusch M, Rosa CG, Plentz RDM, et al. Neurodynamic treatment for patients with nerve-related leg pain: Protocol for a randomized controlled trial. J Bodyw Mov Ther 2016;20:870–8. https://doi.org/10.1016/j.jbmt.2016.02.012.

[14] Dethier C. Objectivation du Locking Manuel par imagerie 3D. Complement. Altern. Med. Sciatica, Ghent, Belgium: 2008.

[15] Stoddard A. Manual of osteopathic technique. London: Hutchinson; 1978.

[16] Kulig K, Landel R, Powers CM. Assessment of lumbar spine kinematics using dynamic MRI: a proposed mechanism of sagittal plane motion induced by manual posterior-to-anterior mobilization. J Orthop Sports Phys Ther 2004;34:57–64. https://doi.org/10.2519/jospt.2004.34.2.57.

[17] Kulig K, Powers CM, Landel RF, Chen H, Fredericson M, Guillet M, et al. Segmental lumbar mobility in individuals with low back pain: in vivo assessment during manual and self-imposed motion using dynamic MRI. BMC Musculoskelet Disord 2007;8:8. https://doi.org/10.1186/1471-2474-8-8.

[18] Lee R, Evans J. An in vivo study of the intervertebral movements produced by posteroanterior mobilization. Clin Biomech Bristol Avon 1997;12:400–8. https://doi.org/10.1016/s0268-0033(97)00019-3.

[19] Fazey PJ, Song S, Price RI, Singer KP. Nucleus pulposus deformation in response to rotation at L1-2 and L4-5. Clin Biomech Bristol Avon 2013;28:586–9. https://doi.org/10.1016/j.clinbiomech.2013.03.009.

[20] Haberl H, Cripton PA, Orr T-E, Beutler T, Frei H, Lanksch WR, et al. Kinematic response of lumbar functional spinal units to axial torsion with and without superimposed compression and flexion/extension. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 2004;13:560–6. https://doi.org/10.1007/s00586-004-0720-6.

[21] Li L, Shen T, Li Y-K. A Finite Element Analysis of Stress Distribution and Disk Displacement in Response to Lumbar Rotation Manipulation in the Sitting and Side-Lying Positions. J Manipulative Physiol Ther 2017;40:580–6. https://doi.org/10.1016/j.jmpt.2017.07.006.

[22] Takasaki H. Comparable effect of simulated side bending and side gliding positions on the direction and magnitude of lumbar disc hydration shift: *in vivo* MRI mechanistic study. J Man Manip Ther 2015;23:101–8. https://doi.org/10.1179/2042618613Y.0000000059.

[23] Dugailly P-M, Feipel V, Jan S, Lubansu A, Rooze M, Sobczak S. Validation protocol for assessing the upper cervical spine kinematics and helical axis: An in vivo preliminary analysis for axial rotation, modeling, and motion representation. J Craniovertebral Junction Spine 2013;4:10. https://doi.org/10.4103/0974-8237.121617.

[24] Salem W, Lenders C, Mathieu J, Hermanus N, Klein P. In vivo three-dimensional kinematics of the cervical spine during maximal axial rotation. Man Ther 2013;18:339–44. https://doi.org/10.1016/j.math.2012.12.002.

[25] Cappozzo A, Catani F, Della Croce U, Leardini A. Position and orientation in space of bones during movement: anatomical frame definition and determination. Clin Biomech 1995;10:171–8. https://doi.org/10.1016/0268-0033(95)91394-T.

[26] Dugailly P-M, Beyer B, Salem W, Feipel V. Morphometric changes of the cervical intervertebral foramen: A comparative analysis of pre-manipulative positioning and physiological axial rotation. Musculoskelet Sci Pract 2018;34:97–102. https://doi.org/10.1016/j.msksp.2018.01.007.

[27] Fujii R, Sakaura H, Mukai Y, Hosono N, Ishii T, Iwasaki M, et al. Kinematics of the lumbar spine in trunk rotation: in vivo three-dimensional analysis using magnetic resonance imaging. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 2007;16:1867–74. https://doi.org/10.1007/s00586-007-0373-3.

[28] Panjabi MM, Oxland TR, Yamamoto I, Crisco JJ. Mechanical behavior of the human lumbar and lumbosacral spine as shown by three-dimensional load-displacement curves. J Bone Joint Surg Am 1994;76:413–24. https://doi.org/10.2106/00004623-199403000-00012.

[29] Li G, Wang S, Passias P, Xia Q, Li G, Wood K. Segmental in vivo vertebral motion during functional human lumbar spine activities. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 2009;18:1013–21. https://doi.org/10.1007/s00586-009-0936-6.

[30] Legaspi O, Edmond SL. Does the evidence support the existence of lumbar spine coupled motion? A critical review of the literature. J Orthop Sports Phys Ther 2007;37:169–78. https://doi.org/10.2519/jospt.2007.2300.

[31] Shin J-H, Wang S, Yao Q, Wood KB, Li G. Investigation of coupled bending of the lumbar spine during dynamic axial rotation of the body. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 2013;22:2671–7. https://doi.org/10.1007/s00586-013-2777-6.

[32] Ochia RS, Inoue N, Renner SM, Lorenz EP, Lim T-H, Andersson GBJ, et al. Three-dimensional in vivo measurement of lumbar spine segmental motion. Spine 2006;31:2073–8. https://doi.org/10.1097/01.brs.0000231435.55842.9e.

[33] Li W, Wang S, Xia Q, Passias P, Kozanek M, Wood K, et al. Lumbar Facet Joint Motion in Patients with Degenerative Disc Disease at Affected and Adjacent Levels: An In Vivo Biomechanical Study. Spine 2011;36:E629–37. https://doi.org/10.1097/BRS.0b013e3181faaef7.

[34] Yin J, Liu Z, Li C, Luo S, Lai Q, Wang S, et al. Effect of facet-joint degeneration on the in vivo motion of the lower lumbar spine. J Orthop Surg 2020;15:340. https://doi.org/10.1186/s13018-020-01826-z.

[35] Panjabi M, Yamamoto I, Oxland T, Crisco J. How does posture affect coupling in the lumbar spine? Spine 1989;14:1002–11. https://doi.org/10.1097/00007632-198909000-00015.

[36] Funabashi M, Kawchuk GN, Vette AH, Goldsmith P, Prasad N. Tissue loading created during spinal manipulation in comparison to loading created by passive spinal movements. Sci Rep 2016;6:38107. https://doi.org/10.1038/srep38107.

[37] Shirazi-Adl A, Ahmed AM, Shrivastava SC. Mechanical response of a lumbar motion segment in axial torque alone and combined with compression. Spine 1986;11:914–27. https://doi.org/10.1097/00007632-198611000-00012.

[38] Yusof MI, Hassan MN, Abdullah MS. The Relationship amongst Intervertebral Disc Vertical Diameter, Lateral Foramen Diameter and Nerve Root Impingement in Lumbar Vertebra. Malays Orthop J 2018;12:21–5. https://doi.org/10.5704/MOJ.1803.004.

[39] Jenis LG, An HS. Spine update. Lumbar foraminal stenosis. Spine 2000;25:389–94. https://doi.org/10.1097/00007632-200002010-00022.

[40] Cramer GD, Cantu JA, Dorsett RD, Greenstein JS, McGregor M, Howe JE, et al. Dimensions of the lumbar intervertebral foramina as determined from the sagittal plane magnetic resonance imaging scans of 95 normal subjects. J Manipulative Physiol Ther 2003;26:160–70. https://doi.org/10.1016/S0161-4754(02)54109-9.

[41] Mayoux-Benhamou MA, Revel M, Aaron C, Chomette G, Amor B. A morphometric study of the lumbar foramen. Influence of flexion-extension movements and of isolated disc collapse. Surg Radiol Anat SRA 1989;11:97–102. https://doi.org/10.1007/BF02096463.

[42] Cinotti G, De Santis P, Nofroni I, Postacchini F. Stenosis of Lumbar Intervertebral Foramen: Anatomic Study on Predisposing Factors. Spine 2002;27:223–9. https://doi.org/10.1097/00007632-200202010-00002.

[43] Panjabi MM, Takata K, Goel VK. Kinematics of lumbar intervertebral foramen. Spine 1983;8:348–57. https://doi.org/10.1097/00007632-198305000-00002.

[44] Choi YK. Lumbar foraminal neuropathy: an update on non-surgical management. Korean J Pain 2019;32:147–59. https://doi.org/10.3344/kjp.2019.32.3.147.

[45] Gilchrist RV, Slipman CW, Bhagia SM. Anatomy of the intervertebral foramen. Pain Physician 2002;5:372–8.

[46] Afzal R, Ghous M, Shakil Ur Rehman S, Masood T. Comparison between Manual Traction, Manual Opening technique and Combination in Patients with cervical radiculopathy: Randomized Control Trial. JPMA J Pak Med Assoc 2019;69:1237–41.

[47] Yan S, Zhang Y, Wang K, Han Y, Zhu K, He F, et al. Three-Dimensional Morphological Characteristics of Lower Lumbar Intervertebral Foramen with Age. BioMed Res Int 2018;2018:1–8. https://doi.org/10.1155/2018/8157061.

Table 1. Reliability of measurements. Intraclass correlation coefficient (ICC), standard error of measurements (SEM) and smallest detectable difference at 95% confidence levels (SDD_{95}).

	ICC (95% CI)	SEM	SDD_{95}
FH	0.989 (0.970–0.996)	0.22	0.61
FW	0.982 (0.953–0.994)	0.25	0.70
FA	0.984 (0.958–0.995)	4.09	11.32

Foramen height (FH, width (FD) and area (FA).

Table 2. Demographic data (mean ± SD)

Age (y)	32.0 ± 11.0
Body height (cm)	180.4 ± 7.7
Body mass (kg)	78.2 ± 10.4
BMI (kg/m2)	23.7 ± 3.1

Table 3. Central tendency and dispersion of data.

		Left (target side)					Right				
		Mean	SD	SE	95% CI		Mean	SD	SE	95% CI	
FH (mm)	NP	16.7	2.2	0.8	15.2	18.2	16.5	1.7	0.6	15.3	17.7
	OMLT	17.6	2.1	0.8	16.1	19.1	16.9	1.8	0.7	15.6	18.2
FW (mm)	NP	9.0	2.8	1.0	7.0	11.0	9.1	1.8	0.6	7.9	10.3
	OMLT	9.0	2.2	0.8	7.5	10.5	9.5	2.1	0.7	8.1	10.9
FA (mm^2)	NP	117.9	37.7	13.3	91.7	144.1	117.6	23.5	8.3	101.3	133.9
	OMLT	123.8	33.3	11.8	100.7	146.9	127.1	35.0	12.4	102.8	151.4

Foramen height (FH, width (FD), area (FA), neutral position (NP), osteopathic manipulative locking technique (OMLT).

Table 4. Comparison of foraminal data between neutral position and osteopathic manipulative locking technique.

		MD (95%CI)	Effect size	SDD_{95} frequency	t-test	
				n (%)	*t*	p
FH	Left (target side)	0.9 (0.4 − 1.5)	1.378	7 (88%)	3.898	0.006
	Right	0.4 (-0.2 − 1.1)	0.556	2 (25%)	1.571	0.16
FW	Left (target side)	0.0 (-0.9 − 0.8)	-0.042	3 (38%)	-0.12	0.908
	Right	0.4 (-0.5 − 1.2)	0.343	3 (38%)	0.97	0.364
FA	Left (target side)	6.0 (-8.4 − 20.3)	0.348	5 (63%)	0.985	0.357
	Right	9.6 (-2.9 − 22.0)	0.642	5 (63%)	1.815	0.112

Foramen height (FH, width (FD), area (FA), mean difference (MA) and smallest detectable difference (SDD).

Figure 1

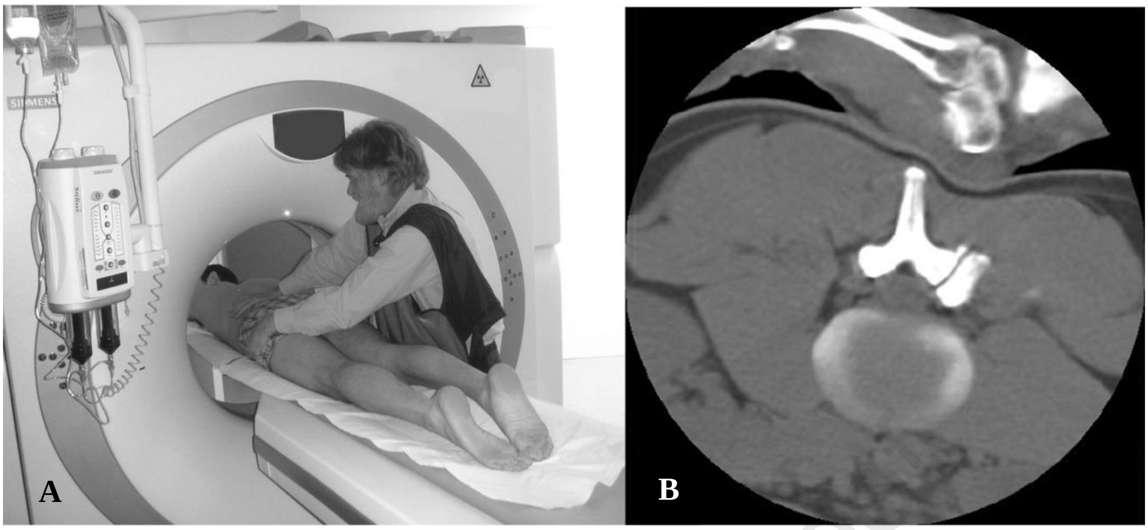

Figure 1: A. Participant and practitioner positioning within the CT scan system prior to the osteopathic manipulative locking technique (see details in text); B. CT imaging of the practitioner's hand against the lateral part of the spinous process.

Figure 2

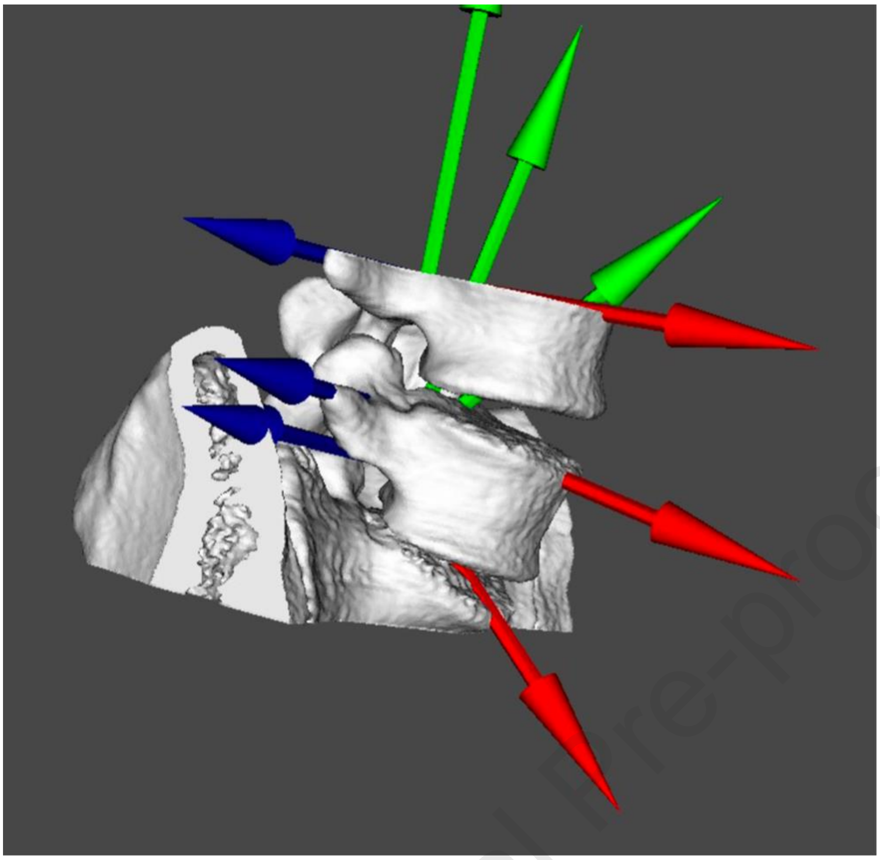

Figure 2: 3D modeling of the lower lumbar spine in neutral position (right anterior oblique view). Reference frame of each bone (L4, L5 and sacrum) is defined according to anatomical landmarks (i.e. transverse and spinous processes).

Figure 3

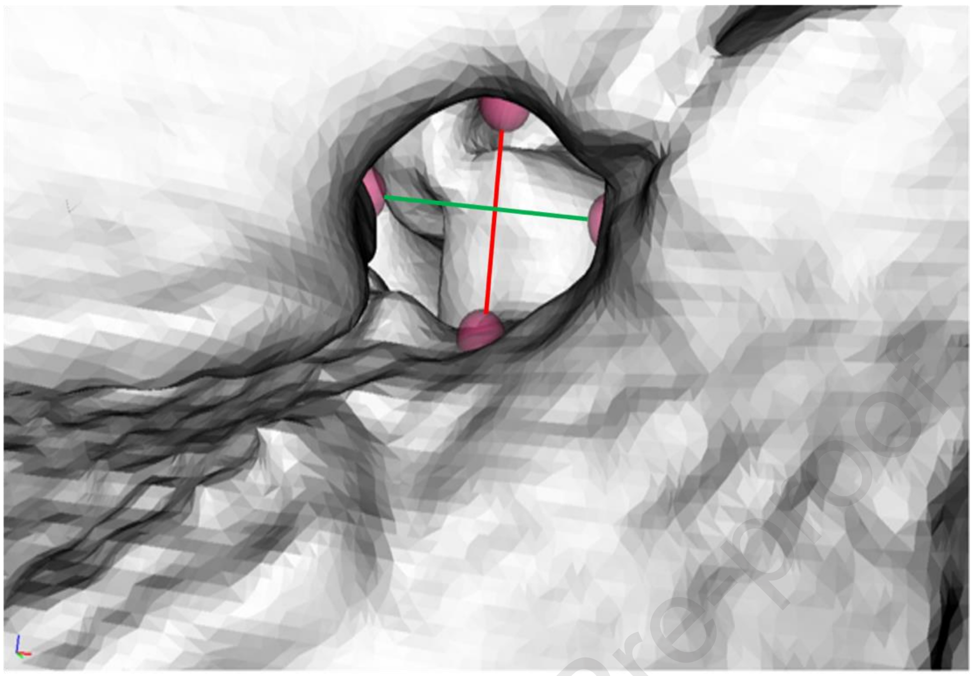

Figure 3: Anatomical reconstruction of the L4-L5 intervertebral foramen. Height (FH, red line) and width (FW, green line) estimation by computing Euclidian distances between anatomical landmark centroid (red spheres) at the bony surface (see text for details).

Figure 4

Figure 4: Osteopathic manipulative locking technique. Starting position, lateral view (A) and final position, upper view (B).

Figure 5

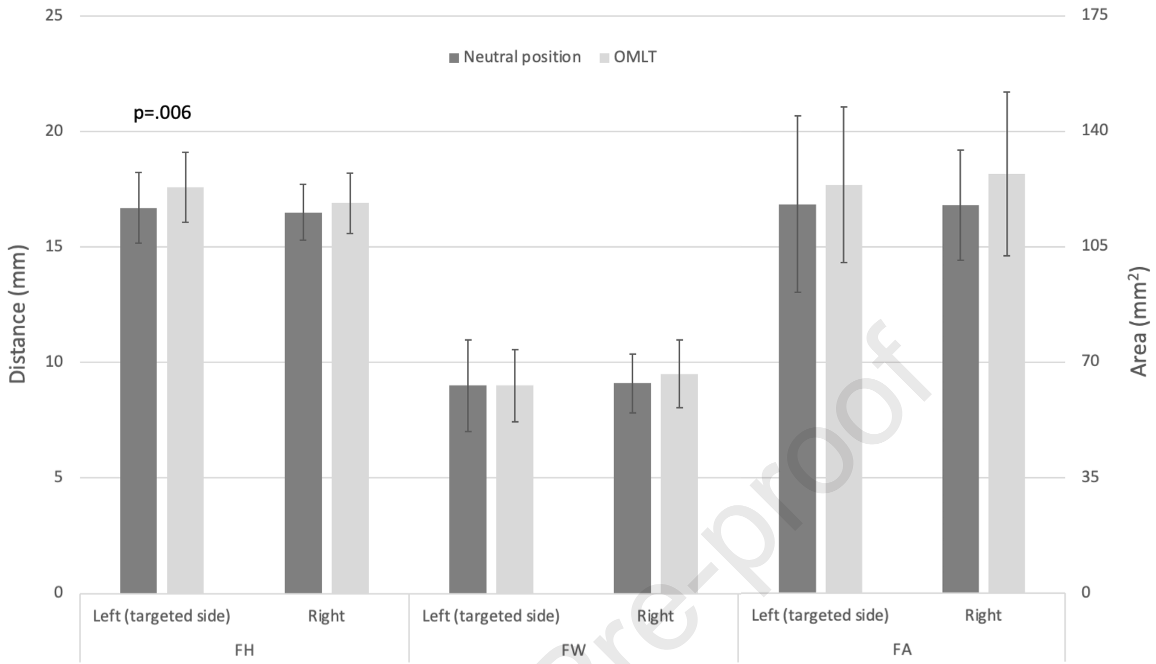

Figure 5: Average data (including error bar: 2SE) in neutral and osteopathic manipulative locking technique (OMLT) position. FH, FW and FA: foramen height, width and area. Only significant difference is defined by the p-value.

IMPLICATIONS FOR PRACTICE

- The present outcomes show consistent data regarding the classical model of osteopathic manipulative locking technique designed to improve intervertebral disc and foraminal area.
- Osteopathic manipulative locking technique allows three-dimensional movements of the targeted lumbar segment that remain below the physiological ranges of motion.
- Foramen height is increased at the lumbar level and the target side during the application of osteopathic manipulative locking technique.

CONFLICT OF INTEREST

(1) Conflict of Interest: Authors declare they have no conflict of interest

(2) Funding Sources: None

(3) ethical approval details (if applicable) under these headings. ref : CE2006/16 - BL/CDC/CE/412796

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