Integrative Medicine Research 10 (2021) 100679

Contents lists available at ScienceDirect

Integrative Medicine Research

journal homepage: www.imr-journal.com

Original Article

Using magnetic resonance imaging to measure the depth of acupotomy points in the lumbar spine: A retrospective study

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ARTICLE INFO

Article history:
Received 19 June 2020
Received in revised form 2 October 2020
Accepted 2 October 2020
Available online 14 October 2020

Keywords:
Acupotomy
Needling depth
MRI
Lumbar spine
Complementary medicine

ABSTRACT

Background: The acupotomy is an acupuncture device recently used to stimulate lumbar vertebrae such as transverse processes (TPs) and facet joints (FJs). However, there are many organs, nerves, and blood vessels, which can lead to side effects if the needle misses the treatment target. Therefore, information regarding appropriate insertion depths, which is currently lacking, could facilitate its safe use. We retrospectively investigated the depth from the skin to the TP and FJ of the lumbar vertebrae, using magnetic resonance imaging (MRI).
Methods: This retrospective chart review was conducted at a single medical centre in Korea. From 55,129 patient records, 158 subjects were selected. Perpendicular depth from the skin to the left and right TPs and FJs was measured using T1-weighted sagittal plane MRI. Depth differences between the left and right sides were evaluated using the paired *t*-test and analysis of covariance (body mass index [BMI] as a covariate). The influence of BMI on depth at each location was evaluated by simple linear regression analysis.
Results: The mean age was 43.2 years and mean BMI was 23.6 kg/m^2. The depth from skin to the TPs or FJs was unaffected by age, sex, or side. Mean depths (cm) were as follows: (TPs) L1 = 4.5, L2 = 4.9, L3 = 5.3, L4 = 5.7, L5 = 5.9; (FJs) L12 = 3.8, L23 = 4.0, L34 = 4.4, L45 = 4.6, L5S1 = 4.6. Depth was highly correlated with BMI at each location.
Conclusion: The depth of TPs and FJs adjusted for BMI can safely and effectively be used for treatment via various invasive interventions, including acupotomy treatment, in the lumbar region.

1. Introduction

Acupuncture is a frequently used treatment modality for musculoskeletal pain in traditional east Asian medicine.[1,2] Several studies have described the effectiveness and cost-effectiveness of acupuncture in musculoskeletal disorders.[3–5] The acupotomy, a type of acupuncture needle, is an acupuncture device with a flat knife at the tip of the needle.[6,7] Since it has a fine blade at the tip, which cuts the adhesive tissue,[7,8] acupotomy is also called a miniscalpel-needle and needle knife.[9] Recently published overview studies have reported that acupotomy is mainly used for musculoskeletal pain such as cervical spondylosis, frozen shoulder, osteoarthritis of the knee, lumbar spinal stenosis, the third lumbar vertebrae transverse process syndrome, and trigger finger.[10] According to a network meta-analysis, the acupotomy was the most effective treatment modality for increasing the pressure pain threshold, compared to manual acupuncture or electro-acupuncture, in myofascial pain syndrome.[11]

The lumbar vertebrae is a major target treatment region for acupotomy therapy.[12–17] From clinicians' point of view, the TPs and FJs are direct treatment targets for facet joint pain, lumbar spinal stenosis, and the 3rd transverse process syndrome. Further, the TPs and FJs are utilized as landmark structures when other muscles, such as the quadratus lumborum, iliopsoas, and multifidi, are stimulated. Previous studies on acupotomy therapy in

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https://doi.org/10.1016/j.imr.2020.100679

lumbar region have shown that when practitioners insert acupotomy in the location of lumbar vertebrae, anatomical structures such as the transverse process (TPs), the facet (zygapophyseal) joint (FJs), and yellow ligament were more frequently adopted rather than standard acupuncture points defined in the “WHO (World Health Organization) standard acupuncture point locations in the Western Pacific” guidelines,[13–15,18] In particular, the third lumbar vertebra TP is one of the major treatment target regions for acupotomy treatment.[16,19] When the acupotomy is inserted directly into the lumbar structures, the depth of insertion is likely to be different from that of the standard acupuncture points in the lumbar region.[20,21] In addition, the risk of damaging internal organs increases because the acupotomy has a knife attached to the needle tip.[22] According to a 2018 Chinese literature review, a total of 17 studies reported 64 nerve injuries associated with acupotomy.[23] Large-scale safety studies are underway to determine the types and incidence of adverse events (AEs) that can occur with the use of acupotomy.[24,25]

For this reason, a C-arm imaging device is sometimes used to improve the safety of the acupotomy treatment on the lumbar vertebrae, although in typical clinical practice settings, the treatment is more often conducted without a medical imaging device.[14] In addition, because the skin-to-TP distance varies according to BMI and sex, it is difficult to predict the proper depth of insertion without using a medical imaging device.[26] When a medical imaging device is not available, practitioners are required to estimate the appropriate depth. Therefore, occasionally the needle is not inserted close enough to the target, or is inserted much deeper than the target structure. Particularly in treatments targeting the TP of the upper lumbar vertebrae, there is a risk of puncturing the kidney when crossing the TP.[27,28] In the treatment of FJs and yellow ligaments, AEs such as post-dural puncture headache,[29] lumbar epidural hematoma,[30] trauma,[31] and transverse myelopathy[32] may occur. For these reasons, information regarding proper insertion depth for the target site is important for the acupotomy treatment procedure. Although the general depth of acupuncture insertion has been studied previously in the lumbar region,[20,21] no studies concerning the appropriate depth of acupotomy insertion are available. The purpose of this study was to investigate the depth of insertion for the TPs and FJs, which are the anatomical landmarks most commonly used in acupotomy therapy of the lumbar vertebrae. Although the yellow ligament is widely used for epidural injection therapy, several research studies have already described the depth of this ligament.[33–35] Therefore, we did not investigate this question in our study.

There were four previous studies on the depths of FJs and TPs, however, limitations of these studies included a limited number of subjects, a limited number of vertebral measurements, and no consideration given to potential differences by sex.[36–39] Except one study, ultrasonography was used in all studies, and the depths of only some of the FJs and TPs were studied.

In this study, we measured the depth from skin to the TPs and FJs along the entire lumbar vertebrae. To overcome the limitations of previous studies, we measured as many patients as possible using MRI. In addition, we analysed the differences in depth according to sex, BMI, left/right side, and age. We also recorded the distribution of depth according to BMI at each point location and derived a regression equation so that the results of this study could help clinicians determine the appropriate depth of insertion of the acupotomy and various needles in the lumbar region. The aforementioned process could help apply invasive treatments (acupuncture, acupotomy, etc.) in situations where it is difficult to use inspection devices, such as C-arm, by guiding the anatomical location of the facet joint and transverse process.

This study was planned and implemented according to STROBE guideline[40] **(Supplemental digital content 1)**.

2. Methods

2.1. Inclusion criteria

1) Patients aged 18–90 years, regardless of sex, who visited the Cheong Yeon Korean Medicine Hospital between September 9, 2013 and November 27, 2017
2) Availability of patient information such as sex, age, and history of surgery in the medical records
3) History of MRI of the lumbar spine
4) BMI information available in the medical records.

2.2. Exclusion criteria

1) Patients with congenital spinal deformities, such as lumbarization, sacralization, or congenital fusion of lumbar vertebral bodies[41,42] 2) Patients with grade 2 or greater spondylolisthesis or retrospondylolisthesis 3) Patients with scoliosis whose Cobb's angle was greater than 20° [43] 4) Patients who underwent surgery for posterior lumbar interbody fusion (PLIF), anterior lumbar interbody fusion (ALIF), or artificial disc replacement 5) Compression fracture of grade 2 or higher [44] 6) Patients with transverse process fracture 7) Quality of MR image was inadequate for accurate measurements 8) Distortion of the skin layer was more than 5% of the total depth due to tightening of clothes, etc.

2.3. Depth measurement

MRI was acquired using a Siemens Magnetom Essenza 1.5 T (Siemens, Berlin, Germany) scanner in the Cheong Yeon Korean Medicine Hospital. A ZeTTA PACS Viewer (Taeyoung Soft, Anyang-si, Gyeonggi-do, Korea) was used for depth measurements. To evaluate the reliability of the PACS Viewer measurements, the length of a ruler was measured in the PACS viewer and it was confirmed that the actual length and the value measured by the program were identical. In addition, MRI was used to confirm its accuracy with phantom imaging tests once a year.

Depth from skin to the TPs and FJs was measured in the sagittal plane view. This was because transverse plane images of the lumbar vertebrae were taken parallel to the direction of the intervertebral discs, which means the transverse plane images were not exactly 90 degrees to the coronal plane. This approach causes distances to become distorted, preventing precise measurements from being taken.[45] For this reason, the transverse plane was not utilised for depth measurement. We also selected T1-weighted images (repetition time: 514 ms, echo time: 12 ms, field of view: 300 × 300 mm, slice thickness: 4 mm, slice gap between sagittal images: 4.6 mm, matrix: 768 × 768, in-plane image resolution: 0.39 mm) with clearly detectable skin boundaries. Two independent assessors measured both the left- and right-side depth for each subject. To obtain accurate measurements, although not previously described, if the difference between the depths measured by the two assessors was more than 5%, it was measured again.

The shape of the acupotomy (Fig. 1a) and acupotomy treatment on the FJs and TPs of the lumbar vertebrae (Fig. 1b) are shown in Fig. 1. The depth of the TPs was defined as the vertical depth from the skin to the back of the TP (Fig. 2). The depth of the FJs was defined as the vertical depth from the skin to the FJ (Fig. 3). The exact location and peak points (highest point) of the FJs and TPs were found by using the scout image.

2.4. Statistical analysis

We used R 3.3.0. (R Core Team, Vienna, Austria) and R packages for descriptive statistics and visualisation. For the baseline charac-

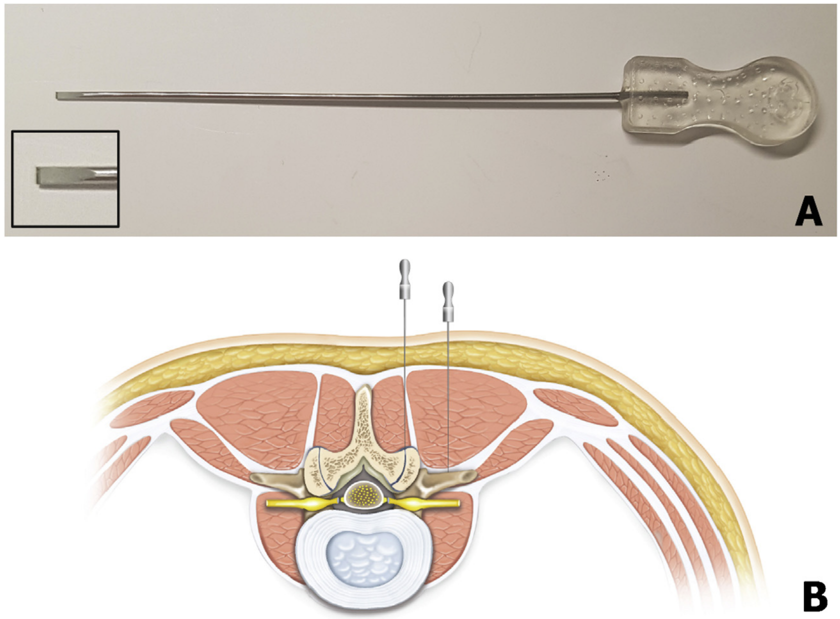

Fig. 1. a, A flat knife-shaped acupotomy (needle length 80 mm, knife edge width 1.0 mm); b, Acupotomy treatment on the facet joint and the transverse process joint of the lumbar spine.

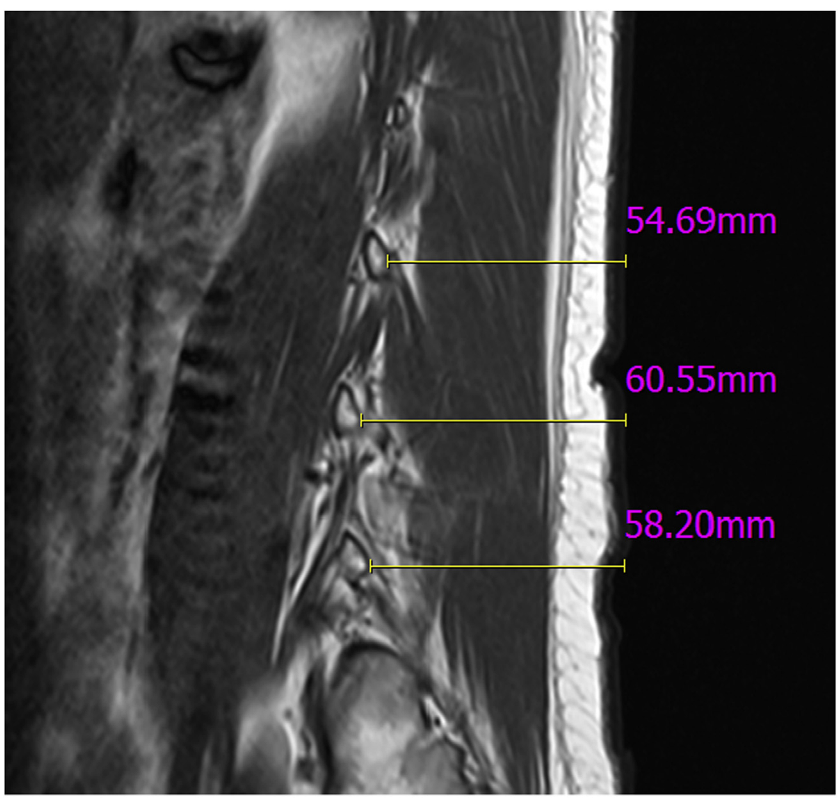

Fig. 2. The depth of the posterior parts of the transverse processes of L3, L4, and L5 from the skin.

teristics, continuous variables are expressed as means and standard deviations (SD). Categorical variables are expressed as frequencies and percentages. The depth of each location is expressed as minimum values, 25th percentiles, median values, 75th percentiles, and maximum values, as well as mean values ± SD. Depth differences between the left and right side were compared using paired t-tests. Depth differences according to sex were compared using analysis of covariance (ANCOVA) tests with BMI as a covariate. Depth differences according to age were examined by Pearson's correlation analysis.

The influence of BMI on depth at each location was evaluated by simple linear regression analysis. Equations for each location were acquired by linear regression analysis. Data from patients with BMI values of more than 30 or less than 18.5 were excluded. Values of $p < 0.05$ were considered statistically significant. The adjusted R^2 values were also calculated. The normality of distribution of

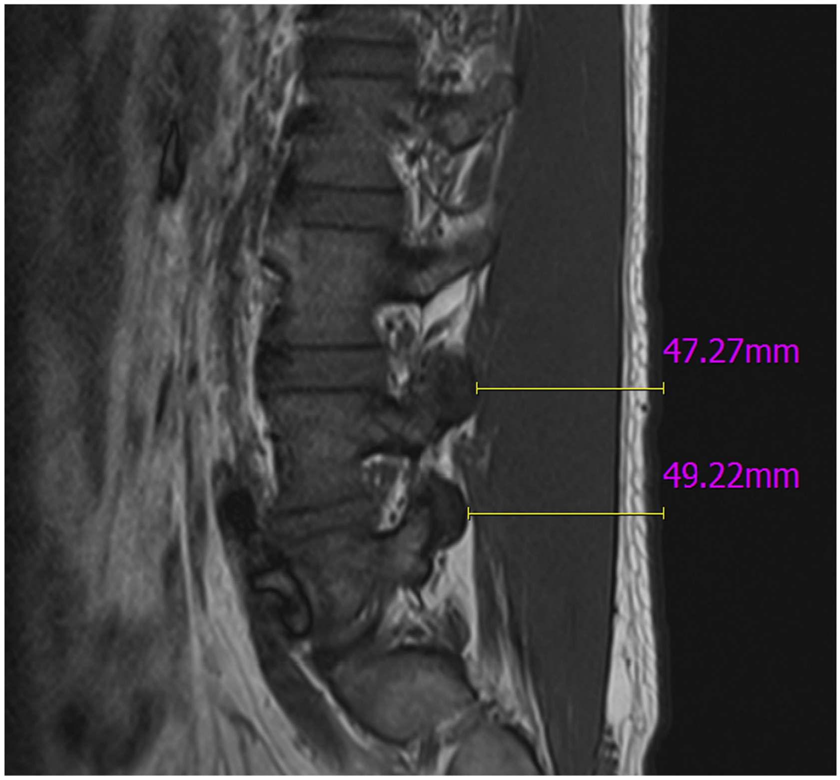

Fig. 3. The depth of the facet joints in L3-L4 and in L4-L5 from the skin.

Table 1
Demographic characteristics of participants.

	All	Male	Female	p-value
Number	158	64 (40.5%)	94 (59.5%)	
Age (year)	43.2 ± 14.4	39.1 ± 13.3	46.0 ± 14.4	0.003
Weight (kg)	65.0 ± 12.7	74.0 ± 10.5	58.9 ± 10.2	<0.001
Height (cm)	165.4 ± 7.8	173.2 ± 4.9	160.1 ± 4.2	<0.001
BMI (kg/m^2)	23.6 ± 3.5	24.6 ± 2.8	22.9 ± 3.7	0.001
Underweight	5 (3.2%)	2 (3.1%)	3 (3.2%)	
Normal	66 (41.8%)	17 (26.6%)	49 (52.1%)	
Overweight	37 (23.4%)	20 (31.3%)	17 (18.1%)	
Obese class I	45 (28.5%)	23 (35.9%)	22 (23.4%)	
Obese class II	5 (3.2%)	2 (3.1%)	3 (3.2%)	
Disease				0.860*
ICD M code	90 (56.9%)	37 (57.8%)	53 (56.4%)	
ICD S code	64 (40.5%)	26 (40.6%)	38 (40.4%)	
ICD I code	2 (1.3%)	0 (0%)	2 (2.1%)	
ICD G code	2 (1.3%)	1 (1.6%)	1 (1.1%)	

BMI, Body Mass Index; ICD, International Classification of Disease.
BMI classification for Asians [46]: Underweight (BMI < 18.5); Normal (BMI: 18.5 22.99); Overweight (BMI: 23.0 24.99; Obese class I (BMI: 25.0 29.99); Obese class II (BMI: ≥30).
M code, Diseases of the musculoskeletal system and connective tissue; S code, Injury; I code, Diseases of the circulatory system; G code, Diseases of the nervous system.
Categorical data are expressed with frequencies and ratios (%). Continuous data are expressed with means and standard deviations. *, Fisher's exact test was adopted.

the residuals was evaluated using Kolmogorov-Smirnov analysis, where p-values > 0.05 indicated normality. Autocorrelation was evaluated using the Durbin-Watson index; values between 1.8 and 2.2 indicated the absence of autocorrelation. The homoscedasticity of the residuals was evaluated by graphs qualitatively. The regression equations for depth according to BMI at each location were developed and are presented below. When basic assumptions of linear regression were not satisfied, outliers were excluded for which the absolute values of the standardised residuals were greater than 3.

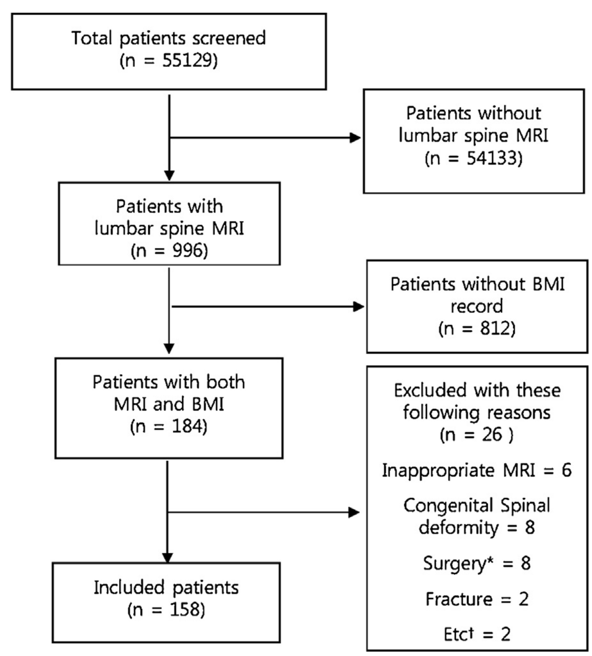

Fig. 4. Data Extraction Flow Sheet. *Surgery, Artificial disc replacement, spinal fusion; †Etc., Distortion of the fat layer caused by clothes.

3. Results

A total of 55,129 patient records were screened. Out of a total of 996 patients with lumbar MRI images, 158 images were finally included in our study (Fig. 4). Of 158 patients, 94 were female and 64 were male, and the mean age was 43.2 years. BMI was classified into five subgroups using the BMI criteria for Asians from the regional office of the Western Pacific region of WHO.[46] As a result,

Table 2
Depth differences between sex and left/right side (N, All subjects = 158, Male = 64, Female = 94).

	Mean and ragne of all subject[c] (mm)	Left side (mm)	Right side (mm)	Difference (mm)	p-value[a]	Male (mm)	Female (mm)	p-value[b]
TP L1	45.12 ± 8.51 (30.84 78.76)	44.85 ± 8.46	45.38 ± 8.78	−0.53 ± 2.76	.018[d]	46.30 ± 8.30	44.31 ± 8.60	.167
TP L2	48.73 ± 8.44 (31.44 80.13)	48.43 ± 8.46	49.03 ± 8.62	−0.61 ± 2.65	.005[d]	49.85 ± 8.18	47.97 ± 8.57	.195
TP L3	53.13 ± 8.69 (34.33 83.41)	52.86 ± 8.85	53.41 ± 8.76	−0.55 ± 2.80	.015[d]	54.53 ± 8.57	52.19 ± 8.69	.460
TP L4	57.43 ± 9.62 (38.75 88.44)	57.34 ± 9.76	57.52 ± 9.73	−0.18 ± 3.21	.478	59.14 ± 9.59	56.26 ± 9.50	.861
TP L5	58.56 ± 9.67 (40.18 93.44)	58.45 ± 9.80	58.67 ± 9.83	−0.23 ± 3.37	.400	59.33 ± 9.58	58.04 ± 9.75	.139
FJ L1-L2	37.88 ± 8.82 (23.14 69.46)	37.87 ± 8.69	37.89 ± 9.10	−0.02 ± 2.31	.914	38.82 ± 8.61	37.24 ± 8.95	.081
FJ L2-L3	40.24 ± 8.98 (24.32 71.65)	40.40 ± 8.93	40.08 ± 9.23	0.32 ± 2.70	.144	41.53 ± 8.65	39.36 ± 9.13	.331
FJ L3-L4	43.85 ± 9.80 (26.26 78.75)	43.81 ± 9.92	43.89 ± 9.84	−0.08 ± 2.39	.683	45.77 ± 9.54	42.55 ± 9.82	.954
FJ L4-L5	46.06 ± 9.77 (28.93 75.64)	45.91 ± 9.83	46.20 ± 9.96	−0.29 ± 3.21	.251	47.77 ± 9.80	44.89 ± 9.63	.858
FJ L5-S1	45.60 ± 8.99 (27.92 72.27)	45.51 ± 8.98	45.69 ± 9.17	−0.18 ± 2.55	.371	46.56 ± 8.80	44.94 ± 9.10	.291

Unit, mm; BMI, Body Mass Index; CI, Confidence intervals; FJ, Facet Joint; SD, Standard Deviation; SE, Standard Error; TP, Transverse Process.

[a] Depths are presented as mean ± SD. Difference was calculated as left side depth minus right side depth. Paired t-tests were used. Although depths are significantly different in some point locations, these are not clinically meaningful difference as the difference is less than 1 mm.

[b] Depths are presented as mean ± SD. There were no depth differences between males and females in all point location after adjusting for BMI. Analysis of Covariance (ANCOVA) test was used to compare depth differences between the sexes. Body mass index (BMI) was used as a covariate.

[c] Average depth value for the left and right side were used. Depth of all subject are presented with mean ± standard deviation and range (minimum value, maximum value).

[d] significant difference.

Table 3
Results of simple linear regression analysis in each vertebral location.

	B	SE	t	significance	Adj.R2	F	p-value
TP L1 (Constant)	1.662	3.815	0.436	0.664	0.468	130.103	<0.001
TP L1 BMI	1.839	0.161	11.406	<0.001	Depth (mm) = 1.839 x BMI (kg/m^2) + 1.662		
TP L2 (Constant)	8.358	3.795	2.202	0.029	0.432	112.250	<0.001
TP L2 BMI	1.702	0.161	10.595	<0.001	Depth (mm) = 1.702 x BMI (kg/m^2) + 8.358		
TP L3 (Constant)	14.707	3.827	3.843	<0.001	0.403	98.718	<0.001
TP L3 BMI	1.611	0.162	9.936	<0.001	Depth (mm) = 1.611 x BMI (kg/m^2) + 14.707		
TP L4 (Constant)	17.095	4.436	3.854	<0.001	0.356	80.993	<0.001
TP L4 BMI	1.689	0.188	9.000	<0.001	Depth (mm) = 1.689 x BMI (kg/m^2) + 17.095		
TP L5 (Constant)	19.252	5.027	3.830	<0.001	0.290	61.156	<0.001
TP L5 BMI	1.661	0.212	7.820	<0.001	Depth (mm) = 1.661 x BMI (kg/m^2) + 19.252		
FJ L1-L2 (Constant)	−1.794	3.930	−0.457	0.649	0.406	100.009	<0.001
FJ L1-L2 BMI	1.667	0.167	10.000	<0.001	Depth (mm) = 1.667 x BMI (kg/m^2) - 1.794		
FJ L2-L3 (Constant)	4.469	3.650	1.225	0.223	0.388	91.643	<0.001
FJ L2-L3 BMI	1.484	0.155	9.573	<0.001	Depth (mm) = 1.484 x BMI (kg/m^2) + 4.469		
FJ L3-L4 (Constant)	12.446	4.108	3.030	0.003	0.271	53.888	<0.001
FJ L3-L4 BMI	1.284	0.175	7.341	<0.001	Depth (mm) = 1.284 x BMI (kg/m^2) + 12.446		
FJ L4-L5 (Constant)	5.748	4.933	1.165	0.246	0.308	66.411	<0.001
FJ L4-L5 BMI	1.699	0.208	8.149	<0.001	Depth (mm) = 1.699 x BMI (kg/m^2) + 5.748		
FJ L5-S1 (Constant)	15.237	4.431	3.439	0.001	0.235	45.555	<0.001
FJ L5-S1 BMI	1.266	0.188	6.749	<0.001	Depth (mm) = 1.266 x BMI (kg/m^2) + 15.237		

Linear regression only provides trends of the data. This result should not be directly applied to decide the insertion depth in acupotomy. The average depth value of left and right side was used. Data from patients whose BMI was more than 30 or less than 18.5 was excluded. When basic assumptions of linear regression were not satisfied, outliers were excluded for which the absolute value of the standardised residual was more than 3. The number of outliers was 0 to 5 at all vertebral locations. The equation for each location was acquired by linear regression analysis.
Adj.R2, adjusted R-square; B, unstandardised coefficient; SE, standard error; BMI, body mass index; F, F statistic; FJ, facet joint; TP, transverse process.

there were 5 people in the underweight group (BMI: <18.5), 66 people in the normal weight group (BMI: 18.5–22.9), 37 people in the overweight group (BMI: 23.0–24.9), 45 people in the obese class I (BMI: 25.0–29.9) group, and 5 people in the obese class II (BMI: ≥30) group (Table 1).

With respect to the difference in depth between the left and right sides, the 1 st, 2nd, and 3rd TPs were significantly deeper on the right side. However, the actual clinical significance was not meaningful considering that the difference was less than 1 mm. There was no significant difference in the other locations (Table 2).

The weight, height, and BMI values of the male subjects were significantly higher compared to the females ($p < 0.001$). If we compare depth between male and female subjects without considering BMI as a covariate, the depth values were greater for males than females at all point locations. However, there were no significant differences between men and women at any points when the ANCOVA test was performed with an adjustment for BMI (Table 2). In addition, when correlation between age and depth was examined, none was observed (data not shown).

The acupotomy insertion depth decreased according to the BMI reduction at all points (Table 3). Single regression analysis was performed for depth by each point according to BMI. The regression equation that could estimate the depth of insertion at each point and B, SE, and other values are shown in Table 3. The mean, standard deviation, minimum, and maximum values of the insertion depth according to BMI are presented in Fig. 5 and Supplemental digital content 2. We have not presented the 95% confidence interval to prevent any misunderstanding by the readers and physicians. Line graphs are expressed with dodge position for visual separation. However, decision making for the maximum value should be as conservative as possible. There might be outliers in real-world clinical practice, and the regression analysis only provides trends of data. Therefore, the insertion depth should not solely depend on our table and regression analysis.

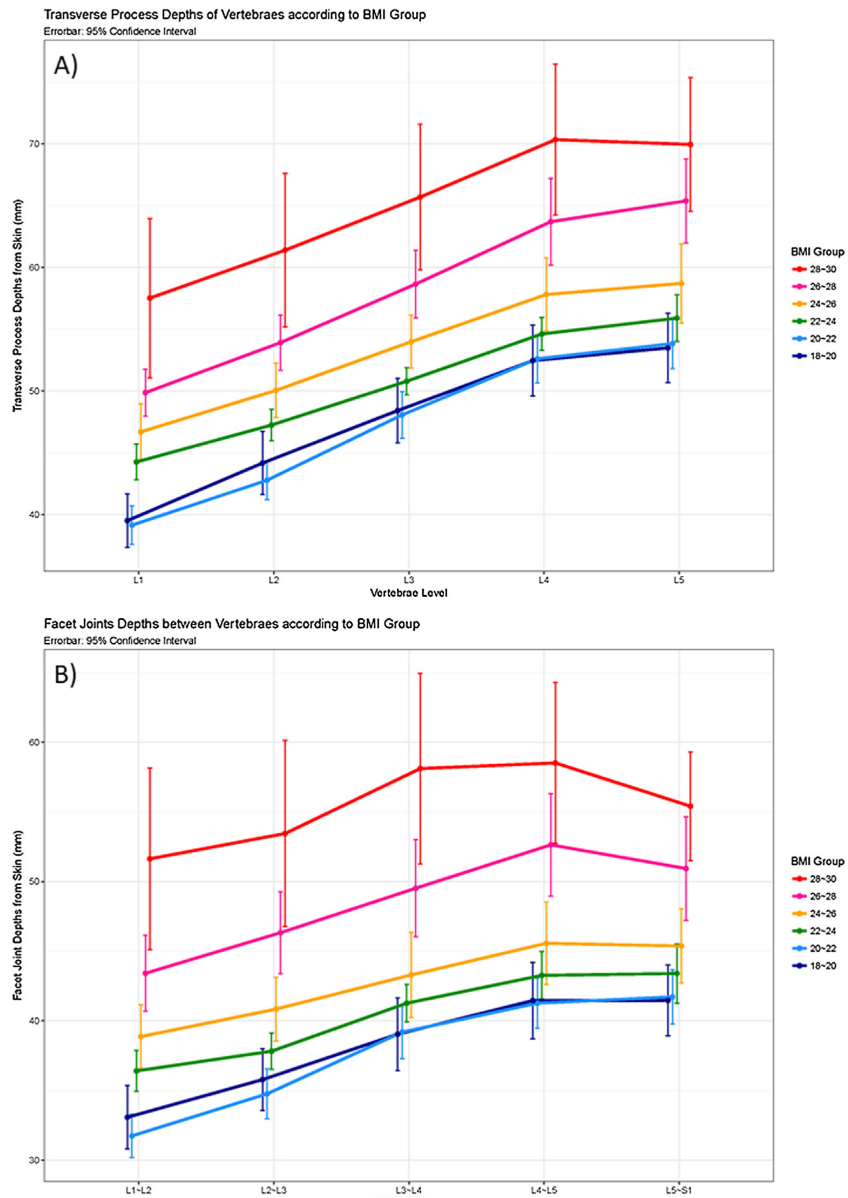

Fig. 5. a, Transverse process depth of lumbar vertebrae according to BMI group.
BMI: body mass index; b, Facet joints depth between lumbar vertebrae according to BMI group. BMI: body mass index.

4. Discussion

4.1. Summary of findings

To our knowledge, this study represents the first attempt to analyse the depth of the TPs and FJs for all lumbar vertebral segments. The purpose of our study was to provide practical information for determining the insertion depth in invasive interventions (acupuncture, acupotomy, and needling therapies) for the TPs and FJs of the lumbar vertebrae. In addition to injection therapy, such as lumbar medial nerve branch blocks, acupotomy therapy also requires image guidance for accurate treatment.[38,47] However, depending on the medical environment, medical imaging devices such as C-arm and ultrasound may not be available. If there is no accurate depth information about the needling depth acquired by medical imaging devices, the needle may pass over the target and damage nearby organs.[36] To help clinicians determine the safe depth of needling, we have provided guidelines that include the maximum depth, minimum depth, and quartile of the TPs and FJs according to BMI in Table 5 and Supplemental digital content 2 By using appropriate insertion depths in the lumbar vertebrae, clinicians can improve the effectiveness and reduce the adverse events of acupotomy treatment.

4.2. Cautions and debates

The following points should be considered when interpreting the results of this study. Physicians should be aware of outliers. The standard value in our study is not generalizable for outliers who have a significantly different depth. Liner regression only provides trends of data. Therefore, our results do not imply that the insertion depth should be mechanically increased according to BMI. Without considering individual patient characteristics, it might cause medical accidents.

Four previous studies examined the depth of the TPs and FJs[36–39] (Supplemental digital content 3). The total number of subjects in the previous studies ranged from 20 to 64, all of which were relatively small to derive sound conclusions. In three of the studies,[36–38] depths were measured by ultrasound. In the fourth study,[39] the depths were measured twice, using both ultrasonography and MRI, and the depths were compared between the two modalities. It should be noted that the depths of the ultrasound measurements in the four previous studies were shallower than the depths reported in our study. A possible explanation is that a pillow was placed on the abdomen in the prone position in order to flex the lumbar vertebrae. Further, it is possible that lumbar lordosis was compensated by lying on the side and flexing the waist. The pressure of the ultrasound acoustic probe might also have resulted in this difference.[39]

The first study, performed in 2004 by Greher et al.,[38] measured the depth of TPs of the 3rd, 4th, and 5th lumbar vertebrae in 20 patients. The depths of the TPs of the 3rd, 4th, and 5th lumbar vertebrae were shallower than those of our study. However, it was thought that Greher et al. measured the depth in the prone position with the hips supported by pillows to compensate for lumbar lordosis. In 2007, Moon et al.[39] measured the depth of the TPs in 20 patients using both ultrasound and MRI, and the results were also shallower than in our study. Although the subjects were also Koreans and MRI was used, there was a significant difference in depths compared to those in our study. The sample size in Moon et al. was relatively small (only 20 patients) and the method of measurement was not described in detail. Further, it is possible that the angle was distorted, and the distorted depth was measured because the transverse plane of the MRI was used. In 2010, Ilfeld et al.[36] measured the depth of one TP in the iliac crest line using ultrasonography in 50 patients. Although a direct comparison is difficult to establish because the position of the TP was not specified, as the spinous process of L4 is mainly located on the intercrestal line, we compared the depth of L4 in our study with the depth of the TP in the previous study.[48] Again, the depth of the previous study was shallower than that in our study. This might be because the depth of the TP was measured after flexing the lumbar vertebrae as much as possible by having the patients lie on their sides. In 2014, Gharaei et al.[37] measured the depth of the TPs and FJs of the 3rd, 4th, and 5th lumbar vertebrae in 64 patients. The mean BMI of the subjects was not reported. All of the depths were shallower than those in our study based on the depth of the TPs. The Gharaei et al. study also observed a significant difference in patient position by placing a pillow on the abdomen in a prone position.

Chou et al. described the inconsistency of the existing studies on needling depths for acupuncture points[49] and proposed further research considerations to measure the exact depth of insertion. First, factor regarding sex, age, BMI, left and right side, and insertion angle should be controlled. Second, the number of subjects examined should be as large as possible. Finally, MRI data from living subjects should be used to measure more accurate depths of insertion, as opposed to the use of cadavers, computed tomography (CT), or ultrasound.

4.3. Strengths

There are several strengths of our research. First, the number of subjects was the largest among the existing studies examining the depth of TPs and FJs. We also considered possible factors that might affect the depth, such as sex, age, BMI, and body side in the statistical analysis. Although there were some statistically significant differences in the depth of insertion according to a few factors, the differences were not clinically meaningful and only BMI had a strong positive correlation with the depth of insertion (Table 3). Therefore, the depth of insertion was presented according to BMI subgroups (Supplemental digital content 2), and the depth equation adjusting for BMI is presented in Table 5 to help clinicians make more accurate insertions.

Secondly, previous studies presented data from limited regions of the lumbar vertebrae so that acupotomy practitioners lacked comprehensive information. In this study, depth information for the FJs and TPs at all lumbar levels has been presented comprehensively.

The third strength was the use of MRI. Because MRI is superior to CT and ultrasound in resolution,[50,51] detailed evaluation of soft tissues was possible.[52,53] For this reason, MRI has fewer errors than CT when measuring length, and is more consistent than CT when multiple assessors are involved.[54,55] Ultrasound has the advantage of acquiring real-time images,[56] but it is mainly used for limbs and not the trunk of the body due to the low resolution.[57] Ultrasound is not a suitable method for the measurement of bone structures because of its high acoustic impedance to bone when observing bone margins.[39] Cadavers were also used in some case studies of depth measurement.[58] However, the volume of a cadaver is easily reduced if humidity is low. In addition, the depth values are actually lower than those of CT studies, making cadavers unsuitable for depth measurements.[59,60] For these reasons, MRI is the most appropriate imaging modality when studying the depth of insertion in the lumbar region. Moreover, when measuring the depth by using MRI, some studies have measured depth from the skin to the structure using the transverse plane.[39,61] The transverse plane of the lumbar MRI is imaged parallel to the intervertebral disc.[45] Therefore, the transverse plane does not form a 90-degree angle with the coronal plane, creating the possibility that error can be caused by an angle different from the true vertical depth. Using the sagittal view reduces this measurement error.

Conversely, MRI can cause errors in measurement due to geometric distortion.[62] Geometric distortion increases with distance from isocentre, although the error is within 2% when the length is within 100 mm of the isocentre.[63] Of the 5056 raw data points in this study, there were 4 measurement values over 100 mm, and the mean and standard deviation of the total data was 52.84 ± 9.05 mm; therefore, the actual impact of geometric distortion on the data was insignificant.

4.4. Limitations

One of the limitations of our study was the inconsistency between patient positions during treatment and MRI scanning. For lumbar region acupotomy therapy, patients are generally placed in the prone position, but MRI is performed in the supine position. In the supine position, the soft tissue of the lumbar region can be pressed, which might result in underestimation of the depth. Nevertheless, the depths measured in this study were not as small as those in previous studies. However, contrary to the initial expectation, when we compared a previous ultrasound study (Table 6), the measured depth in our study was not significantly smaller. It might be because of the pressure and weight of the ultrasound acoustic probe pressing the soft tissue. In some ultrasound studies, researchers placed a pillow under the abdomen of the patient in the prone position, different from the usual acupotomy treatment position. Previous ultrasound studies might also have a systemic measurement bias. Therefore, MRI studies with a large sample size are warranted to obtain information on the depth of the lumbar structures.

The second limitation of this study is its lack of generalisability as subjects were limited to Koreans, and the number of underweight (BMI < 18.5) and obese class II (BMI: $\geq$30) patients included in the study was insufficient. Additionally, Asian populations have a higher percentage of body fat than that of European populations with the same BMI.[64] Therefore, the depth of insertion in the lumbar vertebrae might be higher in our study. The number of subjects in our study was higher than that in previous studies; however, the subjects in the underweight (BMI < 18.5) and obese class II (BMI: $\geq$30) groups only had 5 subjects each. It was difficult to draw statistically meaningful conclusions from these two groups. Therefore, patients in the two groups were not included in the regression analysis. It will be necessary to determine the appropriate insertion depths for these two groups via further large-scale studies.

4.5. Considerations for further research

Some additional considerations are needed in the measurement protocol. During MRI imaging, we should consider pressure on the skin due to the patient's clothing. There is also a difference between the body positions for MRI imaging and acupotomy treatment. In addition, for depth measurements using ultrasonic imaging, it is necessary to consider the fact that the tissue could be pressed by an acoustic probe, as mentioned above. Therefore, a prospectively designed cross-sectional imaging study, considering the pressure of probes, the pressure of clothes, as well as the patient position during treatment and imaging, is needed to investigate the exact reference values for determining the appropriate depth for acupuncture or acupotomy treatment. Particularly, in line with the development of medical devices, it is necessary to conduct real-time imaging research using ultrasound devices in the prone position.

4.6. Conclusion

We analysed the depth of insertion on the lumbar TPs and FJs, which are frequently used anatomical structures in acupotomy therapy on the lumbar vertebrae. There was no difference in the depths according to age, sex, or left and right side. However, as BMI decreased, the depth at each location also significantly decreased. The acupotomy practitioner highly recommended reducing the needling depth according to the BMI reduction.

For the convenience of clinicians and researchers, the depth at each location is presented in tables and in a regression equation that can be adjusted for BMI. Using the depth information according to BMI based our study, we hope to reduce adverse events and increase the effectiveness of acupotomy treatment in the lumbar region. In addition, as TPs and FJs are landmarks of lumbar region treatments in general, the accurate depths of the TPs and FJs according to BMI could be utilised for the safe and effective treatment involving other invasive interventions. In the future, a prospectively designed, cross-sectional imaging study is needed to obtain more data for underweight and obese groups.

Acknowledgements

This study was also supported by Chung-Yeon Central Institute Research Program.

Author contributions

Conceptualization: SY. Methodology: HK. Software: HK. Validation: HK. Formal Analysis: J-HL. Investigation: GL SK SY. Resources: J-HL. Data Curation: SY, SK, GL. Writing – Original Draft: SY SK. Writing – Review & Editing: JL. Visualization: HK. Supervision: J-HL. Project Administration: SY. Funding Acquisition: JL.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

This study was funded by the KOREA INSTITUTE OF ORIENTAL MEDICINE (No. K18121). This work was also supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2019R1F1A1059310)

Ethics statement

The retrospective chart review study was approved by the Institutional Review Board of the Chung-Yeon Korean Medicine Hospital, Gwangju, Republic of Korea (CYIRB-2017-12-001). The study was conducted according to the principles of the Declaration of Helsinki. The need for informed consent was waived by the IRB, owing to the study design.

Data availability

Data are available upon request to the corresponding authors and the first author.

Supplementary material

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.imr.2020.100679.

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