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Comparison of human lumbar disc pressure characteristics during simulated spinal manipulation vs. spinal mobilization

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Abstract. The present study aimed to investigate the differences in human lumbar intradiscal pressure (IDP) characteristics during simulated spinal manipulation and spinal mobilization. A total of 12 adult fresh lumbar spinal specimens (T12-S2) were randomly divided into two groups. The parameters of simulated spinal mobilization were as follows: Preload angle, 15˚ (speed, 3˚/sec); maximum angle, 20˚ (speed, 1˚/sec); and 9 N horizontal force to the L5 spinous process. The parameters of simulated spinal manipulation were as follows: Preload angle, 15˚ (speed, 3˚/sec); impulse angle, 20˚ (impulse speed, 33˚/sec) and 22 N horizontal force to the L5 spinous process. The maximal IDP during both techniques was greater than the initial and end pressures (P<0.01). There was no difference between the initial and end IDP (P>0.05). The maximal IDP on the rotating side was greater than that on the contralateral side during the two techniques (P<0.05). There was no difference in both initial and end IDPs between the two sides (P>0.05). There was no difference in the maximal IDP between the two techniques (P>0.05). The ascending speed of IDP during manipulation was faster than during mobilization (P<0.01), while there was no difference in the descending speed between the two techniques (P>0.05). The maximal IDP on the rotating side was greater than the contralateral side during simulated spinal mobilization and manipulation (P<0.05). The ascending speed of IDP was faster during manipulation than mobilization (P<0.01). Therefore, thrust manipulation may have more instant impact to discs than mobilization.

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Key words: spinal manipulative therapy, mobilization, thrusting manipulation, lumbar spine, intervertebral disc, pressure

Introduction

Spinal manipulative therapy (SMT) has been universally applied in the treatment of lumbar degenerative diseases and injuries, with a definite curative effect. Based on the mechanical characteristics of the manipulation, SMT is divided into two main methods (1): i) Mobilization, which has a low speed and low amplitude force; and ii) thrust manipulation, which has a high speed and low amplitude force. It is generally accepted that the purpose of SMT is to correct the mechanical disturbance of the intervertebral joint and to restore intervertebral joint function (2). The lumbar intervertebral joint consists of three joints, including the intervertebral disc and two facet joints (3). The intervertebral disc functions to bear and transmit load, allowing the lumbar vertebra to move in all directions, while limiting excessive movement of the waist (4). The facet joint controls lumbar motion segment activity and limits lumbar spine load. Therefore, determining the characteristics of intradiscal pressure (IDP) and pressure of facet joints is important in distinguishing the mechanical effects of the two techniques, which may provide an experimental basis for their use. Our previous study analyzed the pressure alteration characteristics of the facet joints under simulation of the two techniques (5). In the present study, the characteristics of IDP under simulation of the two techniques were further investigated.

In a previous report, the maximum IDP in the lumbar spine was measured under simulation of the two techniques, but a comparison of the speed of IDP was not clarified (6). Furthermore, due to hydrostatic properties of the nucleus pulposus, the IDP in only a single point is measured (6). However, during SMT, the lumbar vertebrae is in a complex process of movement. Because different parts of the disc are compressed to different degrees, the IDP is also different in the nucleus (7). The finite element study (8) demonstrated that the stress of the rotation side of the lumbar intervertebral disc was significantly greater than the contralateral side during lumbar thrust manipulation. In order to further elaborate the characteristics of the IDP under two simulated techniques, a micro-pressure sensor measurement was performed in the present study to further analyze the differences in velocity, as well as the differences in IDP between the rotating and contralateral side. This may aid the selection of techniques applied in clinical practice provide insight into the underlying mechanism of SMT.

Materials and methods

Experimental specimens. A total of 12 adult male fresh cadaver lumbar sacral segments (T12-S2) were provided by the Department of Human Anatomy of Southern Medical University. Specimens with anatomical variation and osteopathy were excluded. Samples were dissected free of superficial musculature to expose the facet joint capsule. The samples were sealed with double layer plastic wrap at -20˚C. The specimens were placed overnight in the refrigerator 1 day prior to experimentation. The present study was approved by the Medical Ethics Committee of Wang Jing Hospital (Beijing, China). Informed consent to donate the body to medical research was obtained from all donators or their next of kin.

Experimental instruments. Electroforce 3510 test instrument (Bose Corporation-Electroforce Systems Group; TA Instruments, Inc., New Castle, DE, USA). A micro-pressure sensor (060 type; range, 0-6.895 Mpa) with a diameter of 1.5 mm and thickness of 0.3 mm was obtained from Precision Measurements, Inc. (Virginia Beach, VA, USA). The USB7360 data acquisition system was developed by Mingtong Century Science and Technology Co., Ltd. (Tianjin, China).

Specimen preparation. Once thawed, 2 screws were set from the ventral side of S2 with a 1.5 cm exposure, and 2 screws were also set from the ventral side of T12 with 1.5 cm exposure. Specimens were potted at S2 and at T12 using quick-setting methacrylate (Shanghai New Century Dental Material Co., Ltd., Shanghai, China) and the L1-S1 segment was exposed. During the experimental process, the specimens were intermittently sprayed with PBS (pH=7.4) to keep the specimens moist, and wrapped in gauze soaked intermittently with PBS. Lumbar vertebrae (n=12) were randomly divided into two groups, with six specimens each. Simulated mobilization was used in one group and thrust manipulation was used in the other group.

Simulation of SMT. During the experimental process, the room temperature was maintained at ~25˚C. The prepared lumbar specimens were fixed in the Electroforce3510 test instrument with a square head fixture, and the end was fixed in a vice. A 2 mm diameter drill hole was punched at the L5 spinous process. A thin steel wire was tied and fixed through the hole and the wire end was fixed. The other end of the wire was used for hanging weights through a fixed pulley, which enabled the L5 spike to be subjected to a horizontal pulling force, and the finger pointing force of the thumb was simulated (Fig. 1). To minimize the viscoelastic effect of the specimens, a small scale loading/unloading pre-treatment of the specimens was performed prior to the experiment. Torque (10 Nm) was loaded for 10 sec, and subsequently unloaded. The rotation angle was recorded. To restore the specimen to its physiological state, there was a 3 min interval between each measurement (9). Torque (10 Nm) loading/unloading was repeated until three consecutive loads were at the same rotation angle (+0.1˚).

The angle control mode was adopted and the specific parameters were as follows.

Mobilization (rotate to the right): The pre-loading angle was 15˚ at a speed of 3˚/sec. The maximum loading angle was 20˚ at a speed of 1˚/sec, and the return speed was 3˚/sec. The L5 spike level was loaded with 9 N, and 300 N was down-loaded to simulate body weight.

Thrust manipulation (rotate to the right): The pre-loading angle was 15˚ at a speed of 3˚/sec. The maximum loading angle was 20˚ at a speed of 33˚/sec and the return speed was 3˚/sec. The L5 spike level was loaded with 22 N, and 300 N was down-loaded to simulate body weight.

Measurement of the IDPs. Calibrated micro-pressure sensors were located at the right front and left rear of the L4-5 and L5-S1 discs. Using the placement of micro-pressure sensors on the right front of the L5-S1 intervertebral disc as an example, the L5-S1 intervertebral disc was punctured (1.5, 2 and 3 mm diameter one by one) at a depth of 1-1.2 cm. A stainless steel sleeve was fixed to prevent the sensor from being extruded from the intervertebral disc. A 2 mm diameter Kirschner wire was punctured into the sleeve by 2.3 cm, so that the intervertebral disc tissue in the sleeve could be pushed out.

The sensor was pushed in the disc through the sleeve, and then the sleeve was slowly withdrawn. To keep the disc relatively closed and to stabilize the sensor, 502 glue was applied to the puncture entrance. In the left posterior part of the L5-S1 intervertebral disc (from the left of the anterior longitudinal ligament; depth, 2-2.2 cm), the right posterior part of the L4-5 intervertebral disc (from the right side of the anterior longitudinal ligament; depth, 1-1.2 cm) and the left posterior part of the L4-5 intervertebral disc (from the left of the anterior longitudinal ligament; depth, 2-2.2 cm), the #2, #3, and #4 micro-pressure sensors were inserted (Fig. 1). The sensor was connected to the USB7360 data acquisition system.

Main outcome index. During the simulation process, the load torque of the specimen was recorded, as well as the IDP of the left and right sides of the L5-S1 and L4-5 intervertebral discs.

Statistical analysis. SPSS 19.0 software (IBM Corp., Armonk, NY, USA) was used for statistical analysis of the collected data. Each specimen was retested twice using the same protocol, and measurements were reproducible. Data were presented as the mean ± standard error of the mean. All data were tested for normality and homogeneity of variance. $P<0.05$ was considered to indicate a statistically significant difference. A t-test was used to compare the maximum load torque between the manual groups. In each group, the IDP at different stages and different sides was compared by two way analysis of variance followed by the Fisher's Least Significant Difference post-hoc test. Then, a paired t-test was used to compare the IDP of each stage between the left and right sides. An independent sample

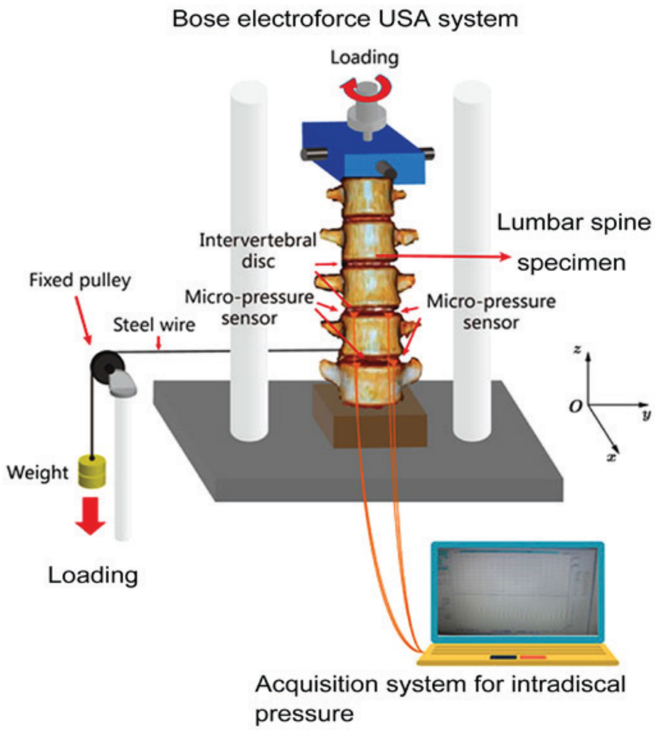

Figure 1. Schematic of spinal manipulative therapy simulation and intradiscal pressure measurement.

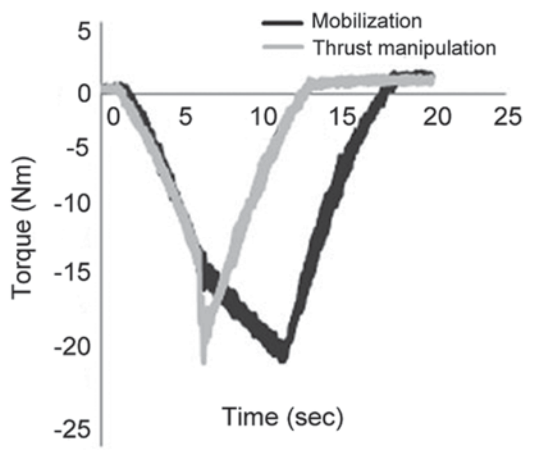

Figure 2. Alterations in loading torque over time under two simulated spinal manipulative therapies.

t-test was used to compare the velocity of IDP between the two groups.

Results

Experimental loading parameters. Loading torque: The load torque during simulated mobilization increased slowly. Once the peak was reached, the load torque decreased. During simulated thrust manipulation, the loading torque increased slowly at first, suddenly reached a peak, then decreased gradually (Fig. 2). There was no significant difference in the maximum load torque (P>0.05; Table I). The results suggested the main difference in loading was torque velocity between the two simulated techniques.

Table I. Comparison of maximum torque of two simulated spinal manipulative therapies under loading ($\bar{x}$±s, Nm).

Group	n	Maximum loading torque
Mobilization	6	18.71±1.25
Thrust manipulation	6	17.61±1.20
T-value	-	1.556
P-value	-	0.151

Distribution characteristics of IDP during simulated SMT. In the simulated mobilization group, IDP alteration was not apparent. The rotation angle increased and the IDP gradually increased to the maximum value. In the thrust manipulation group, IDP alteration was not apparent in the preload phase, and then suddenly reached a peak during the thrust phase (Fig. 3).

The maximum IDP of L4-5 and L5-S1 in the two groups was greater than the initial and end IDP (P<0.01), and there was no significant difference between the initial and end IDPs (P>0.05). The same situation occurred on the rotation and contralateral sides of the intervertebral disc (Fig. 4; Tables II-V). The maximum IDP on the rotating side of L4-5 and L5-S1 was greater than on the contralateral side in two groups (P<0.05), which suggested that the IDP increased transiently during the two techniques, particularly on the rotating side.

Comparison of IDP between two groups. There was no significant difference (P>0.05) in the maximum IDP between the two groups on the L5-S1 or L4-5 rotating side (Fig. 5A and C; Table VI). There was no significant difference in the maximum IDP on the contralateral side between the two groups (P>0.05; Fig. 5B and D).

Comparison of the speed of change of IDP in two groups. The speed of IDP increase on both sides of the L4-5 and L5-S1 intervertebral discs in the simulated thrust manipulation group was higher than the simulated mobilization group (P<0.01), and the speed of IDP decrease was not significantly different (P>0.05; Fig. 6). The results indicated that simulated thrust manipulation may have more of an instant impact to discs than simulated mobilization.

Discussion

A large number of spinal manipulation parameters have been determined *in vivo* (10-14), and the following characteristics have been identified: When the treatment site differs, the force is significantly different. When the operator is different, the force also differs. In the current thrust manipulation experiments, the average level was selected from several studies. The pre-loading force was 88 N for 5 sec, and the peak force was 323 N for 150 msec. Mechanical data of grade IV of mobilization were used as a reference in the present study. According to the results of previous research (6,15), in mobilization the positioning thumb force is 9 N, and in thrust manipulation the positioning thumb force is 22 N. In order to facilitate the comparison of the two methods, the minimum force of

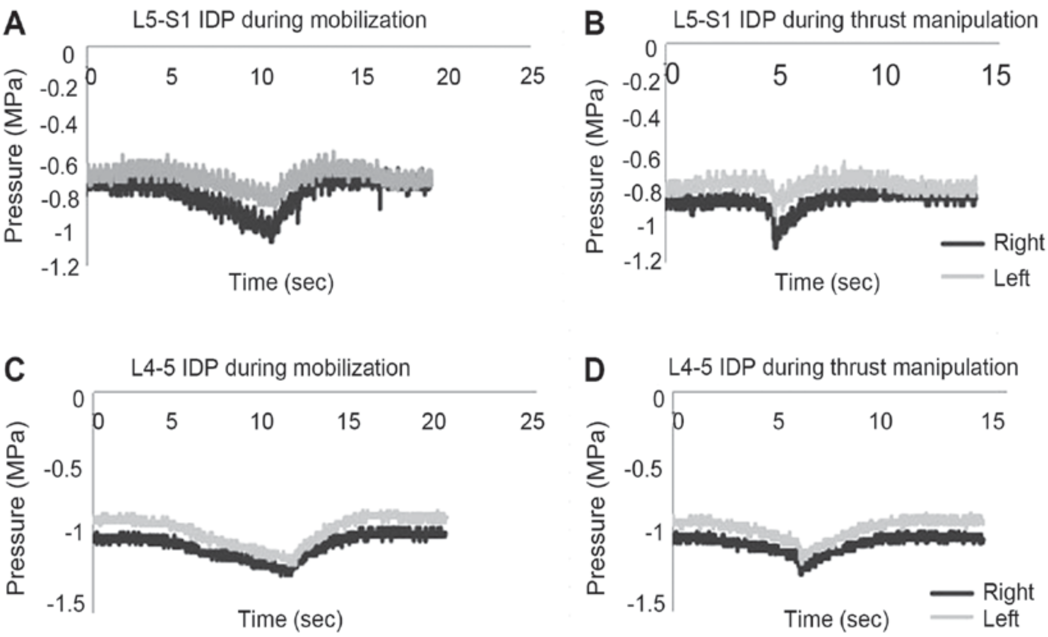

Figure 3. Alterations in IDP over time. Alterations in (A) L5-S1 IDP during simulated mobilization and (B) simulated thrust manipulation. (C) L4-5 IDP alterations during simulated mobilization and (D) simulated thrust manipulation. IDP, intradiscal pressure.

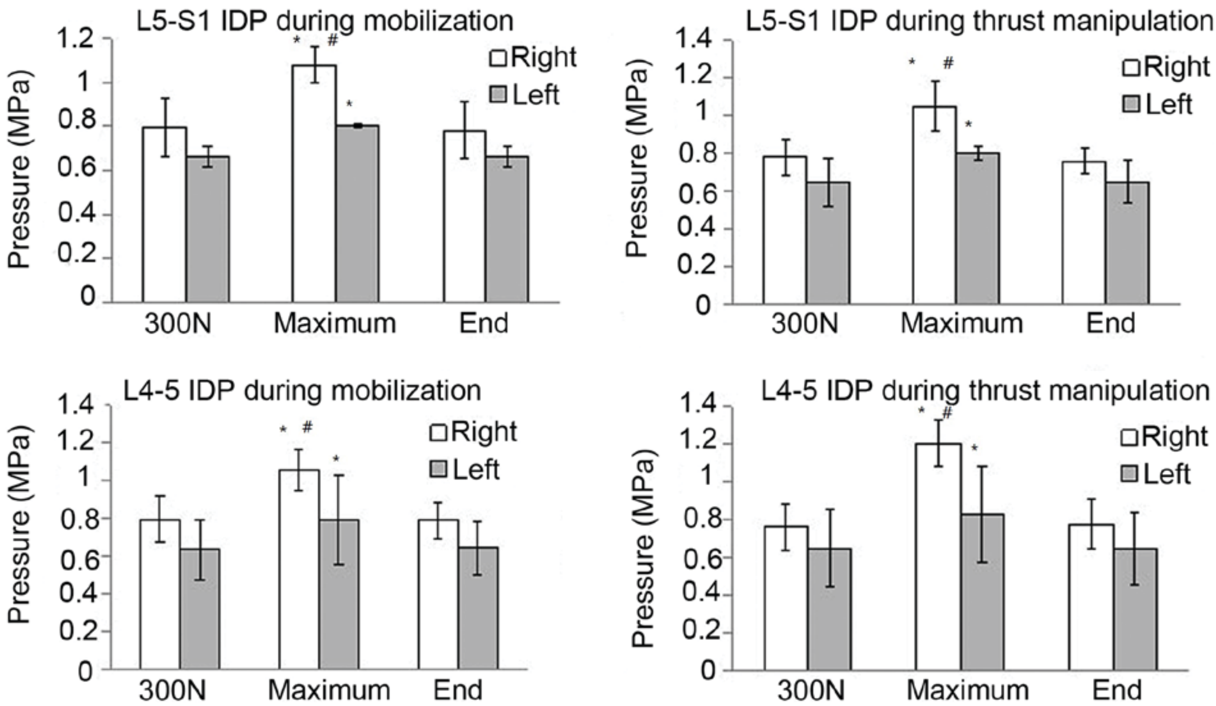

Figure 4. Comparison of maximum, initial and end IDPs in each technique. 300 N indicates the initial IDP used. *P<0.01 vs. initial pressure and end pressure, #P<0.05 vs. maximum pressure of left side. IDP, intradiscal pressure.

mobilization was set to 88 N. Therefore, the mechanical parameters of mobilization in this experiment were as follows: The minimum force was 88 N; the duration was 5 sec; the maximum force was 135 N; and the peak time was 5 sec. The vertical distance from the shoulder to the spine was 25 cm (16). In the present study, the pre-loaded torque was calculated to be 22 Nm in thrust manipulation. The thrust torque was 80.8 Nm. While the minimal torque was 22 Nm, the maximum torque was 33.8 Nm in mobilization. In the preliminary experiment, when the torque reached at 23 Nm, the specimen rotated 23˚ and could not endure more rotation. Therefore, the parameters from *in vivo* investigations could not be set in the *in vitro* experiment of the present study. Combining previous research and pre-experimental conditions (15,16), the torque control was adjusted to the angle control, in which the features of low speed and low amplitude in mobilization were still reflected, and also the characteristics of high speed and low amplitude in thrust manipulation.

Table II. Comparison of the IDP on the rotating right sides and contralateral left sides of the L5-S1 intervertebral disc in different stages of simulated mobilization ($\bar{x}$±s, MPa).

Position	n	300 N pressure	Maximum pressure	End pressure	F-value	P-value
Right	6	0.793±0.134	1.078±0.084	0.783±0.129	24.211	<0.0001[b]
Left	6	0.659±0.047	0.804±0.009	0.662±0.050		
T-value	-	2.317	7.249	1.892	-	-
P-value	-	0.068	0.001[a]	0.117	-	-

300 N indicated the initial pressure. [a]P<0.05 vs. maximum IDP on left side, [b]P<0.01 vs. initial and end IDP. IDP, intradiscal pressure.

Table III. Comparison of the IDP on the rotating right and contralateral left sides of the L4-5 intervertebral disc in different stages of simulated mobilization ($\bar{x}$±s, MPa).

Position	n	300 N	Maximum pressure	End pressure	F-value	P-value
Right	6	0.795±0.127	1.057±0.111	0.788±0.093	7.695	0.002[b]
Left	6	0.632±0.157	0.790±0.235	0.643±0.140		
T-value	-	-1.975	2.969	-2.116	-	-
P-value	-	0.077	0.031[a]	0.060	-	-

300 N indicated the initial pressure. [a]P<0.05 vs. maximum IDP on left side, [b]P<0.01 vs. initial and end IDP. IDP, intradiscal pressure.

Table IV. Comparison of the IDP on the rotating and contralateral sides of the L5-S1 intervertebral disc in different stages of simulated thrust manipulation ($\bar{x}$±s, MPa).

Site	n	300 N	Maximum pressure	End pressure	F-value	P-value
Right	6	0.779±0.098	1.050±0.130	0.756±0.067	19.227	<0.0001[b]
Left	6	0.643±0.126	0.804±0.036	0.648±0.112		
T-value	-	2.091	4.476	2.028	-	-
P value	-	0.063	0.005[a]	0.070	-	-

300 N indicated the initial pressure. [a]P<0.05 vs. maximum IDP on left side, [b]P<0.01 vs. initial and end IDP. IDP, intradiscal pressure.

Table V. Comparison of the IDP on the rotating and contralateral sides of the L4-5 intervertebral disc in different stages of simulated thrust manipulation ($\bar{x}$±s, MPa).

Site	n	300 N	Maximum pressure	End pressure	F-value	P-value
Right	6	0.761±0.121	1.204±0.121	0.777±0.131	11.789	<0.0001[b]
Left	6	0.650±0.205	0.827±0.258	0.648±0.190		
T-value	-	1.147	3.243	1.367	-	-
P-value	-	0.278	0.009[a]	0.202	-	-

300 N indicated the initial pressure. [a]P<0.05 vs. maximum IDP on left side, [b]P<0.01 vs. initial and end IDP. IDP, intradiscal pressure.

In the present study, entire lumbar spine specimens were used to simulate the SMT, which better reflected the biomechanical properties of the spine and the role of macro-mechanical effects. During rotation, lateral bending and rotating angles from the upper to lower vertebral bodies gradually decrease (16). The rotation and lateral bending motion of the L5 vertebral body was the smallest, but the L5 vertebral body and adjacent vertebral body had relative displacement following the application of horizontal thrust (17). Thus, the aim of correcting the mechanical state of the intervertebral joint may be achieved, and the

Table VI. Comparison of the intradiscal pressure of the L5-S1 intervertebral disc on rotating side between the two groups ($\bar{x}$±s, MPa).

Technique	n	300 N	Maximum pressure
Mobilization	6	0.793±0.134	1.078±0.084
Thrust manipulation	6	0.779±0.098	1.050±0.130
T-value	-	0.206	0.450
P-value	-	0.841	0.663

300 N indicated the initial pressure.

function of the intervertebral joint restored (2). Therefore, IDP of L4-5 and L5-S1 intervertebral disc (L5 vertebral adjacent segments) were observed in the present study.

The IDP time curve demonstrated a transient increase under simulation of the two techniques. The peak pressure was increased by 33-58%. The IDP was produced by the extrusion of the upper and lower vertebral bodies. There was no axial compression load in the lumbar rotation process; however, in the rotation process, the coupling motion of the lateral bending may be a certain extrusion to the intervertebral disc. Therefore, the pressure alteration was relatively smaller. In addition, it was revealed that the maximum IDP on the rotating side was higher than the contralateral side (30.6-45.6%) during the simulation of the two techniques. This finding is different from a previous report that the IDP in different sites of the nucleus pulposus were equal under SMT (16). This indicated that the IDPs varied in different sites of the nucleus pulposus during the process of SMT. The difference of IDP distribution between the left and right sides may be associated with the coupling motion of the lumbar spine. In present study, when the lumbar spine was rotated to the right side, it was also accompanied by bending to the right side. The right side of the intervertebral disc was compressed heavier by the upper and lower vertebrae so that the right side of the disc pressure was higher than the left side. Xu *et al* (8,18) reported the phenomenon of variations in IDP distribution during SMT. An L4-5 three-dimensional finite element model was adopted to analyze IDP during SMT in these studies (8,18); the IDP on the rotation side was significantly greater than on the contralateral side. The findings of the present study confirmed the results of the finite element study by means of biomechanics. The IDP may be uneven in the state of intervertebral joint dysfunction (19), and disturbed stress distribution has been detected in degenerated discs (20). Providing that SMT is performed to both left and right sides in practice, during SMT, the IDP difference between the two sides appears twice, which may transiently affect the disturbed stress distribution in discs. By magnetic resonance myelography (MRM), Feng *et al* (21) demonstrated that following spinal manipulation treatment in patients with lumbar disc herniation, the diameter of the nerve root sleeve was significantly increased. The volume of cerebrospinal fluid to the nerve root sleeve increased; however, the morphology of the nucleus pulposus was not altered, which indicated that the stress of the nerve root was decreased after manual treatment. The underlying mechanisms may be associated with adjustment of IDP distribution.

In the current study, there was no difference in the peak IDP between the two methods. It may be related to that there was no difference in the maximum torque between the two methods. Guo *et al* (15) reported that there was no significant difference in the maximum IDP between thrust manipulation and mobilization, which drew a similar conclusion to the present study. However, the present study initially determined that in the thrust manipulation group, the rate of the increase of the IDP was significantly higher than the mobilization group. From the aspect of material safety, compared with mobilization, thrust manipulation may have more of an instant impact to discs, which indicated that attention should be paid to the use of thrust manipulation, particularly the intensity and speed, especially for annular-injured patients.

The results of the present study revealed that IDP was increased, and the maximum IDP on the rotating side was higher than that of the contralateral side. There was no significant difference in the maximum IDP between the two methods, but the rise speed of IDP during the simulated thrust manipulation was higher than the simulated mobilization. The solution to this problem will be helpful to understand the mechanism and the security of the two methods from biomechanics.

In this study, the isolated specimens were used as the research object, so the mechanical state of the intervertebral joint could not be simulated completely. Thus, the results may vary in clinical practice. In the future, modern measuring and virtual simulation technologies will be further combined to measure the IDP distribution of these two techniques *in vivo*. A more detailed understanding of the similarities and differences between the two methods in the field of biomechanics is required, to provide an experimental basis for methods selection.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

JZ, QL and PZ made substantial contributions to the design of the present study. FW, XY, HZ and LH performed the experiments. WF and YM made substantial contributions to the analysis of the data. FW and JZ wrote the manuscript; WF revised the manuscript. All authors read and approved the final version of the manuscript.

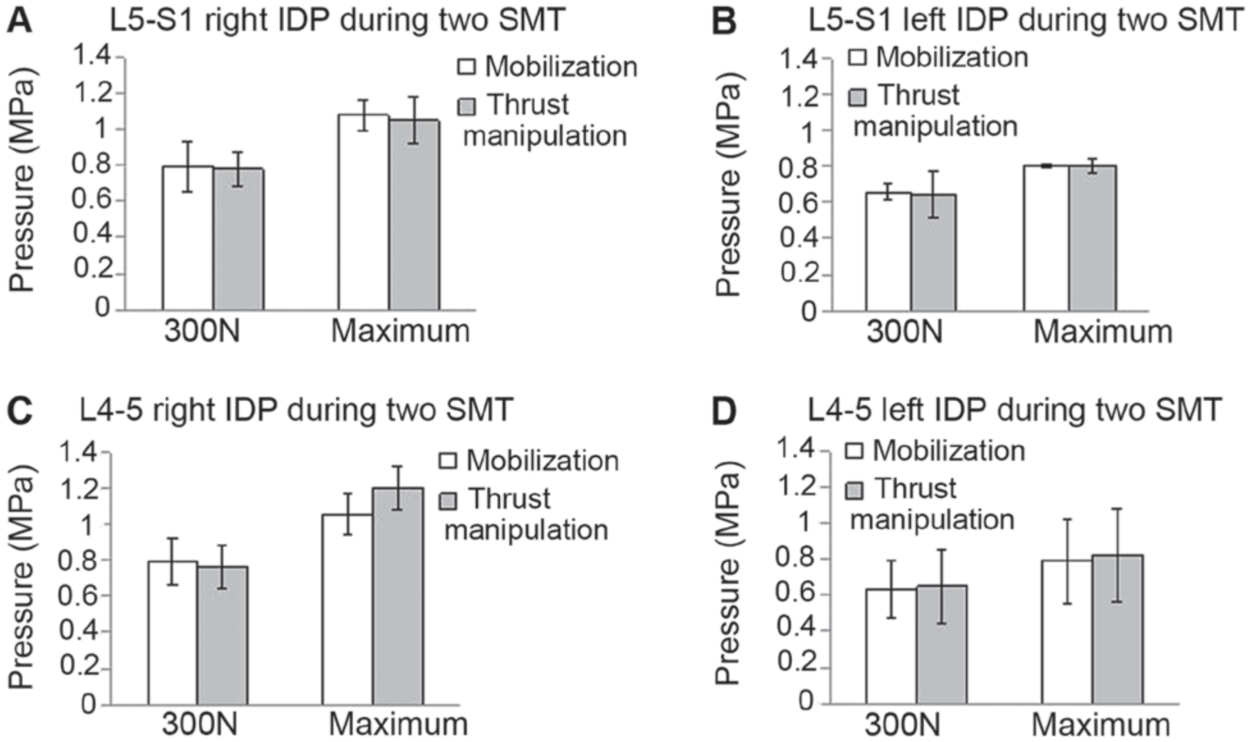

Figure 5. Maximum IDP during the two spinal manipulative therapies. (A) Comparison of the maximum IDP on the right part (rotating side) of the L5-S1 disc and (B) the left part (contralateral side) of the L5-S1 disc between the two groups. (C) Comparison of the maximum IDP on the right part (rotating side) of L4-5 disc and (D) the left part (contralateral side) of L4-5 disc between the two groups. 300 N indicates the initial IDP used. There were no significant difference between groups (P>0.05). IDP, intradiscal pressure.

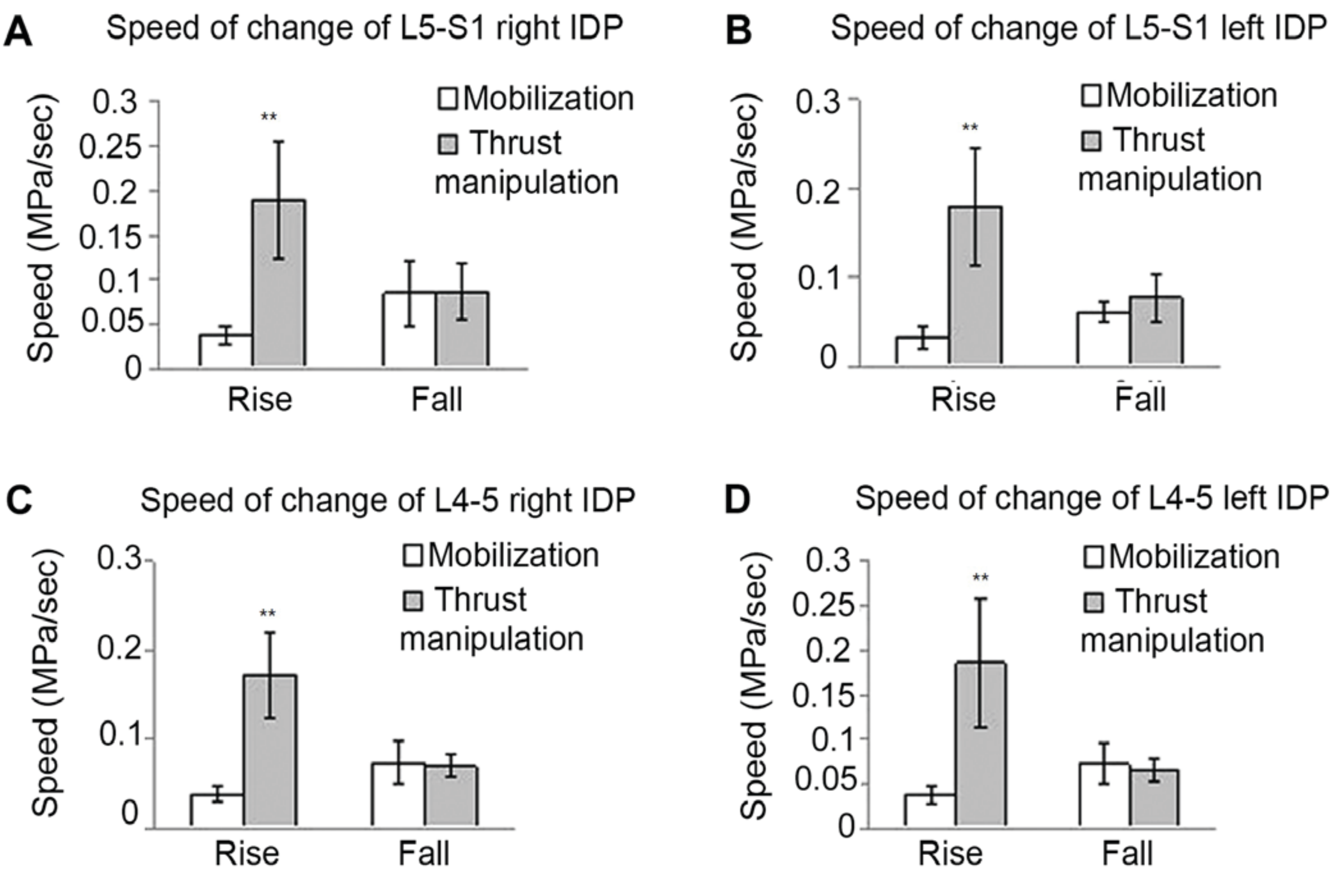

Figure 6. Speed of IDP alterations in two SMTs. (A) Comparison of the speed of IDP on the right part (rotating side) of L5-S1 disc and (B) the left part (contralateral side) of L5-S1 disc between the two groups. (C) Comparison of the speed of IDP on the right part (rotating side) of L4-5 disc and (D) the left part (contralateral side) of L4-5 disc between the two groups. **P<0.01 vs. rise speed of IDP in simulated mobilization group. IDP, intradiscal pressure; SMT, spinal manipulative therapy.

Ethics approval and consent to participate

The present study was approved by the Medical Ethics Committee of Wang Jing Hospital, Beijing, China. Informed consent to donate the body to medical research was obtained from all donators or their next of kin.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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