

PRESSURES GENERATED DURING SPINAL MANIPULATION AND THEIR ASSOCIATION WITH HAND ANATOMY

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ABSTRACT

Background Context: The role of the variation in the application manipulation itself is largely unknown. A greater understanding of its input parameters is necessary to better understand spinal manipulation outcomes.

Purpose: The objective of this study is to determine if pressures generated during manipulation are altered by hand configuration.

Design/Setting: Paired comparison of 2 different variable groups.

Methods: Sixteen chiropractors provided 2 manipulations to a rigid surface using 2 hand configurations used commonly in clinical practice: arched and flat. Interposed between the hand and the rigid surface was a pressure sensor array and radiographic cassette. For each manipulation, pressures were recorded and a radiographic image was captured. Two radiologists then located the osseous features of the hand with respect to the sensor array.

Results: In 15 of 16 cases, arched configurations produced peak pressures that corresponded to the radiographic location of the pisiform bone. In flat configurations, peak pressure migrated about the location of the hamate bone. Radiologists' agreement for bone position was high ($\kappa = 0.96$). Measures of peak pressure, total pressure, and pressure distribution were statistically different between hand configurations.

Conclusions: The results of this study suggest that hand configuration influences the magnitude, location, and distribution of pressure generated by the hand during manipulation. This knowledge may have importance in understanding the relation among application parameters of manipulation, therapeutic benefit, and patient safety. (J Manipulative Physiol Ther 2005;28:265.e1-265.e7)

Key Indexing Terms: Manipulation; Spinal; Biomechanics; Peak Pressure; Hand Configuration

For more than a century, spinal manipulative therapy (SMT) has been advocated for a variety of health concerns, most of which are related to spinal pain.¹ Given the prevalence and cost of spinal pain,² scientific investigations of SMT have tended to focus on its outcomes. These outcomes encompass anatomical, physiological, and clinical phenomena and include cavitation (the popping sound that often accompanies SMT),³⁻⁵ motion segment displacement,^{3,6,7} muscle reflex responses,^{5,8,9} nerve reflex responses,¹⁰⁻¹³ somatovisceral reflexes,¹⁴⁻¹⁶ pain perception,^{17,18} range of motion,¹⁸ and return to work time.¹⁹ As

the number of investigations using similar methodologies increases, it is becoming evident that the variability of SMT outcomes can be significant.² Although many potential explanations for this variability exist (eg, subject heterogeneity), sources of variation related to the biomechanical inputs of SMT are virtually unknown. Therefore, to better understand the variability of spinal manipulation outcomes, a greater understanding of SMT input parameters is necessary.

Spinal manipulation may be defined as a high-velocity low-amplitude application of force with the intent of affecting the underlying articulations.²⁰ Most typically, SMT is applied by a trained practitioner who places the palmar surface of their hand(s) onto the patient, and through this contact interface, applies a force to the region of skin overlaying the assumed position of an anatomic target. Therefore, in the strictest sense, the input parameters of SMT are entirely biomechanical, and as a result, are a common denominator to whatever form of manipulation is applied.¹ Over the years, investigations of these biomechanical input parameters have used a variety of approaches such as instrumented treatment tables²¹ and pressure-sensitive mats.^{3,22,23} From this work, a basic understanding of SMT application has evolved, which includes knowledge of its time duration as well as the total forces applied to the surface of the skin.²⁰

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Sources of support: Canadian Institutes of Health Research, the Canadian Chiropractic Association and the University of Bridgeport College of Chiropractic.

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Paper submitted November 29, 2004.

0161-4754/\$30.00

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doi:10.1016/j.jmpt.2005.03.005



Fig 1. Hand configurations (postures) used for manipulation trials demonstrating the pressure sensor pad: arched configuration (left) and flat configuration (right).

Unfortunately, we know little of the direction these forces take within the body²⁴ or the distributions of these forces with respect to the underlying anatomic targets. Only recently have some investigators begun to fill this knowledge void. Investigators at the University of Calgary (Calgary, Alberta, Canada) observed that the average peak force during manipulation is ~5 N over a 25-mm² area, a decrease of approximately 2 orders of magnitude compared to total forces generated by SMT.²⁵ Furthermore, these investigators observed that these peak forces migrated up to 9.8 mm during SMT delivery, a result supported by our own preliminary study.²⁶

These observations raise several important questions that have yet to be addressed in the SMT literature: (1) does the accuracy of SMT with respect to the anatomic target affect clinical outcomes, and (2) can tissues become injured if the location or magnitude of SMT deviates from what the clinician intended? Although we assume that SMT application is best provided by the accurate placement of a specific force magnitude, we simply have no current understanding of how these factors relate to outcomes or safety let alone how practitioners may or may not control them.

To begin to investigate the relation among SMT input, outcomes, and safety, basic studies are required, which describe these input parameters. Toward this goal, the objective of this study was to determine if pressures generated during manual manipulation are altered by 2 hand configurations (postures) used commonly in clinical settings. We hypothesize that the peak pressure location generated during SMT corresponds to bony prominences of the hand, and secondly, that alterations in the location of peak pressure are a function of hand configuration.

METHODS

Subjects

This study was approved in advance by the University of Calgary Ethics Review Committee. Licensed chiropractors were solicited through e-mail and telephone call for their participation as subjects. Subjects were compensated for parking fees incurred.



Fig 2. Plain film radiographs demonstrating superimposition of osseous anatomy and radiopaque sensor elements imbedded in the pressure sensor pad. The arched configuration is shown on the left and the flat configuration is shown on the right.

Materials

A “target” for SMT delivery was constructed, which consisted of a thin polyester film with a 9.5-mm-diameter circle printed on its surface. This target was aligned to a single sensor of a 99 sensor pressure array (Novel, Munich, Germany). The pressure array was precalibrated with the manufacturer’s recommended device and procedure. The target/array was then placed over an 8×10-in radiographic cassette supported on a rigid platform. This construct was then used to determine the peak pressure exerted by the subjects during single-handed SMT.

Methods

After their provision of written informed consent, each subject donned a protective lead vest and then was instructed to place the pad of the left index finger on the target. The pisiform of the right hand was then located and placed on the left index fingernail, and the left index finger

Table 1. Data for manipulation trials using an arched hand posture

Subject	Total pressure in array when peak pressure is generated (N/cm ²)	No. of sensors activated when peak pressure is generated	Peak pressure (N/cm ²)	Sensor with next highest pressure (N/cm ²)	% Difference	No. of active sensors within 25% of peak pressure
1	270	17	43	35	18.605	2
2	268	15	45	27	40.000	0
3	294	20	62	40	35.484	0
4	101	11	31	17	45.161	0
5	113	12	26	16	38.462	0
6	155	14	37	30	18.919	1
7	209	15	52	29	44.231	0
8	133	12	46	25	45.652	0
9	237	22	56	20	64.286	0
10	203	16	63	21	66.667	0
11	283	24	62	34	45.161	0
12	207	17	64	28	56.250	0
13	177	12	51	50	1.961	0
14	148	16	27	17	37.037	0
15	176	15	30	22	26.667	0
16	88	12	22	18	18.182	1
Mean value	191.38	15.63	44.81	26.81	37.67	0.25
SE	16.56	0.94	3.64	2.36	4.39	0.14

Table 2. Data for manipulation trials using a flat hand posture

Subject	Total pressure in array when peak pressure is generated (N/cm ²)	No. of sensors activated when peak pressure is generated	Peak pressure (N/cm ²)	Sensor with next highest pressure (N/cm ²)	% Difference	No. of active sensors within 25% of peak pressure
1	402	49	23	23	0.000	3
2	384	27	41	39	4.878	3
3	267	26	25	25	0.000	3
4	108	13	20	20	0.000	0
5	172	25	19	18	5.263	3
6	390	44	25	23	8.000	0
7	379	32	60	27	55.000	0
8	207	24	32	28	12.500	1
9	253	26	25	24	4.000	3
10	361	31	43	33	23.256	2
11	329	24	45	44	2.222	2
12	252	25	26	23	11.538	3
13	206	25	56	17	69.643	0
14	219	27	26	24	7.692	2
15	256	31	26	24	7.692	2
16	264	37	22	18	18.182	2
Mean value	278.06	29.13	32.13	25.63	14.37	1.81
SE	21.870	2.127	3.214	1.860	4.995	0.306

removed from under the pisiform allowing the right pisiform to fall onto the target. This technique has been used successfully in the past to improve accuracy in placing the pisiform on the required target.²⁶ The subject was then asked to use an arched hand configuration while performing an SMT (Fig 1). The arched hand configuration is much like the support hand used when shooting billiards. Pressures resulting from this manipulation were recorded directly from the pressure array to a computer at a sampling rate of 50 Hz. Immediately after the arched hand SMT, a

dorsal-palmar radiograph of the hand/sensor array was obtained using standard radiographic techniques. In this manner, the location of the skeletal landmarks could be determined with respect to the radiopaque sensor array (Fig 2). This entire procedure was then repeated with each subject using the flat hand configuration (Fig 1).

The resultant radiographic films were assessed by 2 radiologists who identified 2 osseous landmarks: one carpal bone (pisiform) and a prominence of another (hook of the hamate). The radiologists located the specific sensor where each

Table 3. *P* values for tests of significance (paired *t* test) between data in Tables 1 and 2

Subject	Total pressure in array when peak pressure is generated (N/cm ²)	No. of sensors activated when peak pressure is generated	Peak pressure (N/cm ²)	Sensor with next highest pressure (N/cm ²)	% Difference	No. of active sensors within 25% of peak pressure
<i>P</i> ($\alpha = .05$)	<.000	<.000	.002	.670	.008	<.000

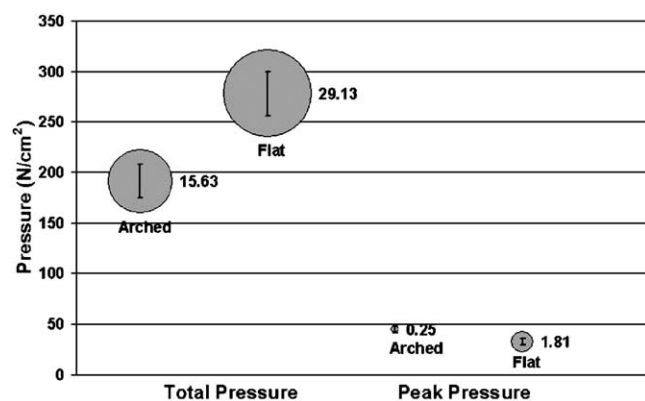


Fig 3. Peak and total pressures with SE bars for manipulations performed with different hand configurations. The size of the circle (with associated value) represents the mean number of active sensors falling within 25% of the peak pressure. Differences between hand configurations were statistically significant for peak pressure, total pressure, and the number of active sensors within 25% of peak pressure.

landmark resided by identifying the sensor that contained more than 50% of the visualized landmark. To assess agreement between radiologists, the κ statistic was used.

For the purposes of this study, data pertaining to pressure and contact area were taken from the point during SMT application where the greatest pressure was generated. These data (eg, peak pressure magnitudes) were analyzed in pairs (arched and flat hand configuration) for each subject using a standard *t* test ($\alpha = .05$).

RESULTS

Sixteen practicing chiropractors agreed to participate in the study. The 16 participants were split equally between sexes. The mean age of the subjects was 34.18 ± 1.38 years whereas the mean years in practice was 6.44 ± 1.35 .

Peak Pressure

During any manipulation, the highest pressure magnitudes observed for any one sensor within the array (peak pressure) were generated with the arched hand posture (44.81 ± 14.54 N/cm²) compared to those performed with the flat hand posture (32.13 ± 12.86 N/cm²) (Tables 1 and 2). Not only were the peak pressures in the arched configuration significantly larger ($P < .000$) (Table 3), they also

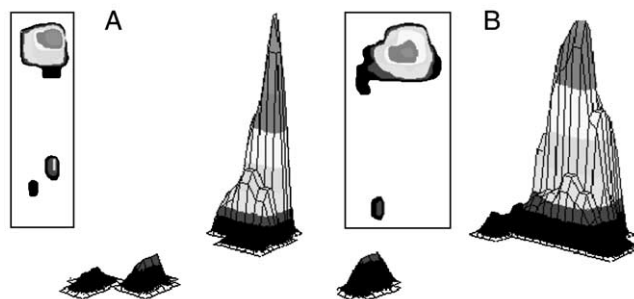


Fig 4. Two-dimensional and 3-dimensional isobar representations of pressures recorded from a single subject during arched hand configuration (A) and flat hand configuration (B). The smaller peaks in the image relate to areas where the fingers made contact with the pressure sensor array.

occurred over a smaller spatial area than the flat hand manipulations. The arched configuration activated, on average, 0.25 additional sensors whose magnitudes were within 25% of the peak. In comparison, the flat posture activated almost 2 additional sensors within 25% of the peak pressure. This relation between peak pressure and the number of additional active sensors is displayed in Fig 3. In addition to this result, a significant difference was observed ($P = .008$) between arched and flat manipulations in that the arched configuration had a 37.67 ± 17.54 N/cm² difference between the sensor displaying peak pressure and the sensor with the next highest pressure magnitude. In comparison, the flat configuration displayed a difference between the peak sensor and the next highest sensor of 14.37 ± 19.98 N/cm².

Total Pressure

With respect to total pressures, the flat hand posture showed a significantly greater pressure magnitude (278.06 ± 87.48 N/cm²) over a larger number of active squares (29.13 ± 8.51 SE) vs the arched contact which had a smaller total pressure (191.38 ± 66.23 N/cm²) distributed over a fewer number of active sensors (15.63 ± 3.76 SE). This relation is displayed in Figs 3 and 4. The differences in total pressure and total active sensors between the arched and the flat configurations were statistically significant ($P < 2.000$).

Anatomic Landmarks in Relation to Sensor Activation

Agreement between radiologists of bone location with respect to an individual sensor of the 99 sensor array was

high ($\kappa = 0.96$). For arched hand postures, the sensor that recorded the peak pressure corresponded spatially to the radiographically identified location of the pisiform in 15 (93.75%) of 16 cases. In the flat hand contact, 5 of 16 cases were a direct match between the location of the sensor having peak pressure and the radiographic location of the hamate (31.25%). In the remaining 11 flat hand trials, the peak pressure was located in one of the sensors immediately adjacent to the sensor associated with the radiographic position of the hamate. Specifically, the peak pressure resided between the hamate and the pisiform in 7 cases. In 4 other cases, the peak pressures resided distal to the hamate toward the center of the hand.

DISCUSSION

The results of this study suggest that hand configuration (posture) influences the magnitude, location, and distribution of pressure generated by the hand during simulated SMT. Furthermore, specific hand configurations generate peak pressures associated spatially with specific anatomic structures. For the arched hand configuration, the peak pressure developed during SMT was localized under the pisiform in most subjects. When the hand was placed in a flattened configuration, the location of peak pressure was more varied although most often associated spatially with the hamate. Our results also describe significant alterations in the pressure magnitudes and pressure distributions between the arched and flat hand configurations. This is the first study that we are aware of that relates the location of the peak pressure generated during SMT to different anatomic structures within the hand.

These results suggest that pressures generated during SMT may not develop at the location intended by the clinician, but instead, may vary as a result of the prominence of different osseous landmarks, a function of hand configuration. The ability of rigid bodies (ie, bone) to facilitate force transmission compared to the attenuating effect of the surrounding soft tissues is a likely explanation for these results.

This study, performed on a flat rigid surface, showed that migration of peak pressure during an arched hand configuration was minimal. We speculate that this observation is the result of (1) a hand configuration that isolates structures other than the pisiform from involvement in the contact interface and (2) a relative absence of soft tissue overlaying the pisiform itself. In contrast, peak pressure migration was significantly greater in the flat hand configuration. We speculate that this result is a function of a greater number of osseous structures in the flat hand being available at the contact interface as potential pressure transducers. In addition, as the soft tissues of the hand become increasingly more compressed and widened as SMT progresses temporally, the rigid constituents of the flat hand involved at the contact interface may change, thereby resulting in peak

pressure migration. Indeed, an increased variability in peak pressure location was seen in flat hand SMT in addition to a greater area of pressure distribution. These observations allude to the possibility that if human subjects replaced the rigid surface used in this study, even greater peak pressure migration may occur as a result of the contribution of nonrigid, heterogeneous soft tissues of the subject to the contact interface. Indirect support for this possibility is provided by the results of others from the University of Calgary who described up to 9.8 mm of peak force migration during SMT delivery in human subjects.²⁵ Unfortunately, the authors of this previous study did not attempt to determine the cause of this migration although they discussed the possibility that their results may be artifacts due to bending of the pressure array caused by subject deformation during SMT. Such an artifact is not possible in this study because of our use of a flat nondeforming surface beneath the pressure array.

As with other forms of physical treatment involving injections or incision, accurate site specificity in SMT is thought to improve clinical outcome and is therefore desirable.^{1,27,28} However, our study reveals the mechanism of a potential source of variation that reduces the site specificity of SMT: peak pressure migration associated with specific hand configurations. Unfortunately, this potential source of SMT variation is but another identified recently. A number of investigators have now shown that clinicians are generally inaccurate when identifying the location of internal spinal targets when using only surface-based anatomy to guide them.²⁹⁻³¹ Others have shown similar findings when clinicians were asked to locate vertebrae targeted for SMT.³²⁻³⁵ In total, these sources of variation conspire against the ability of clinicians to apply SMT accurately. With this in mind, it is not difficult to imagine that these sources of variation may offer a partial explanation as to why SMT outcomes are often inconsistent.^{36,37}

Given the results, this study suggest that use of the arched hand contact by clinicians would decrease pressure variations generated during SMT delivery. Unfortunately, there is a suggestion that the arched configuration, with its smaller area of pressure distribution, results in greater patient discomfort. Kirstukas et al³⁸ found that subjects manipulated with smaller pressure distributions reported that the SMT was less comfortable than SMT performed with a more distributed contact area (written communication from Jerrilyn A. Cambron, DC, MPH, July 16, 2003). The arched contact is also a less stable position for the provider's wrist and potentially exposes the wrist to harmful forces.²⁰ At present, there is no literature of which we are aware that describes if these 2 factors affect the clinical frequency in which the arched or flat hand configuration is applied.

The results of this and other studies suggest that the accuracy of providing SMT to a specific location is marginal. Although it may be argued that this inaccuracy has consequences related to SMT outcomes and patient

safety, there is a contrary evidence that suggests that attempting to create a highly accurate application of SMT may not be important clinically. Haas et al³⁹ have found that the clinical effectiveness of cervical manipulation was independent of whether the manipulation was based upon examination findings or randomized matched motion segments in the cervical spine. In addition, Reggars and Pollard⁴⁰ found that the phenomenon of joint cavitation associated with SMT occurred in joints other than those that were targeted. Although it has been acknowledged that the effect of cavitation produced by SMT is unknown, it is one indication used by practitioners to determine if the application of SMT was successful.¹ Similarly, Ross et al⁴¹ found that during both thoracic and lumbar spine manipulations, cavitation often occurred remote to the targeted articulation and that the chances of the target site cavitating were greatly improved by producing manipulations having multiple cavitations. Therefore, the impact of SMT location accuracy or lack thereof is unknown at this time. However, given that others have assumed that a physiologically relevant SMT contact area is 25 mm,^{2,25} it is possible that inaccurate SMT will have a significant effect on clinical outcome and/or patient safety. Future studies are necessary to further characterize sources of SMT variation and assess its significance in terms of treatment efficacy and patient safety.

CONCLUSIONS

This study shows that hand configuration influences the magnitude, location, and distribution of pressure generated by the hand during manipulation. Specifically, this is the first study that we are aware of that relates the location of the peak pressure generated during SMT to different anatomic structures within the hand. In this study, flat hand configurations tended to transmit pressure through the hook of the hamate whereas arched hand configurations transmitted pressure almost exclusively through the pisiform. These findings may be of significance for a practitioner's ability to deliver a specific force magnitude to a specific target and therefore possibly influence treatment efficacy and patient safety.

ACKNOWLEDGMENTS

The authors thank the Canadian Institutes of Health Research, the Canadian Chiropractic Association, and the University of Bridgeport College of Chiropractic (Bridgeport, Conn) for their financial support of this project. The authors also thank Ms Judy Colpitts for her assistance in taking plain film radiographs and Terence Perrault, DC, DACBR, and Bill Adams, DC, DACBR, for their work in reading the radiographs.

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