Internal Carotid Artery Strains During High-Speed, Low-Amplitude Spinal Manipulations of the Neck

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Abstract

Objective: The primary objective of this study was to quantify the strains applied to the internal carotid artery (ICA) during neck spinal manipulative treatments and range of motion (ROM)/diagnostic testing of the head and neck.

Methods: Strains of the ICA (n = 12) were measured in 6 fresh, unembalmed cadaveric specimens using sonomicrometry. Peak and average strains of the ICA obtained during cervical spinal manipulations given by experienced doctors of chiropractic were compared with the corresponding strains obtained during ROM and diagnostic testing of the head and neck.

Results: Peak and average strains of the ICA for cervical spinal manipulative treatments were significantly smaller ($P < .001$) than the corresponding strains obtained for the ROM and diagnostic testing. All strains during ROM and treatment testing were dramatically smaller than the initial failure strains of the ICA.

Conclusions: This study showed that maximal ICA strains imparted by cervical spinal manipulative treatments were well within the normal ROM. Chiropractic manipulation of the neck did not cause strains to the ICA in excess of those experienced during normal everyday movements. Therefore, cervical spinal manipulative therapy as performed by the trained clinicians in this study, did not appear to place undue strain on the ICA and thus does not seem to be a factor in ICA injuries. (J Manipulative Physiol Ther 2015;38:664-671)

Key Indexing Terms: *Stroke; Manipulation, Cervical; Carotid Artery Injuries; Biomechanics; Safety; Chiropractic*

Spinal manipulative therapy (SMT) has become a widely accepted modality to treat back and neck problems including headaches.[1-4] Spinal manipulative therapy has been shown to be effective, specifically when used with high-speed of force application and a low-amplitude of thrust.[5] Although the peak forces exerted during SMT vary dramatically between clinicians[6] and depend strongly on the area of application,[7,8] the thrust times remain consistent within approximately 100 milliseconds across clinicians and techniques (Fig 1).

Although the total forces applied during SMT can be high, in excess of 1000 N (220 lb) in the thoracic and lumbar spine, the local forces applied to the target area (25 mm^2) are known to be a mere fraction of the total force (5-20 N; 1.1-4.4 lb[9]). Nevertheless, it has been argued that there is the possibility of damaging internal structures at the treatment site.[10-14] However, there is little information on the forces transmitted by internal structures during SMTs, with some exceptions, for example, the forces transmitted by the lumbosacral spine[15] and the stresses and strains transmitted by the vertebral artery[16-18] during high-speed, low-amplitude SMTs of the low back and cervical spine, respectively.

One of the major concerns for safety is SMTs of the neck and the risk of stroke.[19-22] Although the estimates of stroke associated with SMT are small—approximately 1 in a million, based on a systematic review of the literature involving a great

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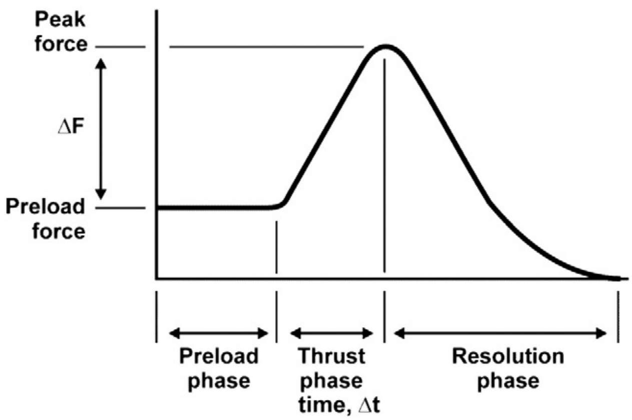

Fig 1. *Definition of selected mechanical variables used to quantify spinal manipulative treatments.*

divergence of values[1]—the severity and irreversible nature of such accidents make this a material risk.[16,17] Most of these accidents involve the vertebrobasilar system, specifically the vertebral artery (VA) between C2/C1 and the cephalad/distal loop as the VA exits the C1 foramen transversarium and travels to the foramen magnum.[23] Because of the specific anatomy of the VA in that region, it has been assumed that the VA experiences considerable stretch during extension and rotation of the neck, which may lead to hemodynamic occlusions and damage to the VA, predisposing the patient to stroke.[16,17] However, recent evidence suggests that such damage appears unlikely.[18,24]

The internal carotid artery (ICA) has also been implicated with stretch-induced damage caused by neck SMTs (eg, Peters et al[25] and Parwar et al[26]), although to a much lesser degree than the vertebral artery. However, there are no data on the mechanics of ICA during neck manipulation that would allow for evaluation of such implications. Therefore, the purpose of this study was to test the hypothesis that stretching of the ICA during cervical SMTs does not cause strains in excess of those experienced during normal everyday movements such as extending the head and neck when looking up at the sky or when rotating the head while backing out a car from the driveway. Because strains cannot be measured directly in live subjects, we measured ICA strains in cadaveric specimens while they were subjected to 10 different neck treatments using high-speed and low-amplitude manipulative techniques and compared the ICA strains of these treatments with the strains observed for eight head/neck range of motion (ROM) tests, as done previously.[16-18,24]

Methods

Subjects

Testing was performed on 8 fresh (< 72 hours after death), unembalmed human cadaveric specimens and 15 ICAs. Specimens were obtained from the donor program of the department of Anatomy at the University of Calgary. The first 2 specimens (and 3 ICAs) were used to refine the strain measurement techniques, and the results of these tests were not included in the analysis, leaving 6 specimens and 12 ICAs for the final results. The characteristics of the cadavers used in this study are shown in Table 1.

ICA Dissection

The ICA was approached by blunt dissection using an anterolateral approach, similar to that described previously for the vertebral artery.[16] Care was taken to leave all structures intact while exposing the ICA. Specifically, no ligaments, muscles, or bones were cut to preserve the in situ mechanical behavior of the ICA.

Range of Motion Testing and Spinal Manipulative Treatments

Range of motion testing was performed in flexion, extension, rotation, and lateral bending (Fig 2). Range of motion was established by moving the head passively from the neutral position (head and neck aligned straight; Fig 2A) to the point where no further movement was possible (Fig 2B, end range of rotational movement). Following that, a Houle's vertebrobasilar insufficiency test[27] was performed by placing the head and neck in a rotated/extended position. All asymmetric tests were performed bilaterally (ie, rotation to the left and right). Following the ROM testing, neck SMTs consisting of a diversified lateral/rotary manipulation with a second metacarpal contact specifically against the articular pillar with the cadaver supine and also a pure lateral manipulation with the force applied in an essentially lateral direction to the neck were performed (Fig 2C). These SMTs were delivered at levels C1/C2, C3/C4, and C6/C7 while measuring strains in the ICAs bilaterally. All ROM testing was repeated 3 times and was performed bilaterally; all SMTs were repeated 3 times, on all levels and both sides of the neck. Therefore, each cadaver was exposed to 60 strain measurements during SMTs (2 arteries × 10 SMTs × 3 repeat measurements) and 48 strain measurements during ROM testing (2 arteries × 8 ROM tests × 3 repeat measurements) per clinician (2-4 clinicians per subject). The corresponding total numbers of strain measurements per cadaver were then multiplied by the number of clinicians to arrive at the number of strain measurements shown in Table 1. In total, we performed 1080 strain measurements during SMTs and 864 during ROM testing resulting from 36 clinician/ICA combinations. Before all testing, the ICAs were injected with ultrasound gel to give the arteries their normal, fluid-filled shape and to enhance ultrasound transmission that was used for the strain measurements.[18]

All ROM and SMT testing was performed by 2, 3, or 4 licensed chiropractors per cadaver (Table 1). A total of 5 different chiropractors, all male, were involved in the study with 3, 3, 14, 22, and 42 years of experience.

Table 1. *Characteristics of the Cadavers Used in This Study (Age, Cause of Death, Sex, ICA Used [Left/Right]), Number of Clinicians Working on Each Cadaver, and Total Number of SMTs and ROM Testing Performed*

ID	Age, y	Sex	Cause of death	ICAs tested	No. of clinicians	SMTs total	ROMs
1	90	M	Stroke	l/r	4	240	192
2	83	F	Respiratory failure	l/r	4	240	192
3	64	M	Cardiac arrest	l/r	3	180	144
4	83	F	Cardiac arrest	l/r	2	120	96
5	68	M	Heart failure	l/r	3	180	144
6	63	F	Breast cancer	l/r	2	120	96

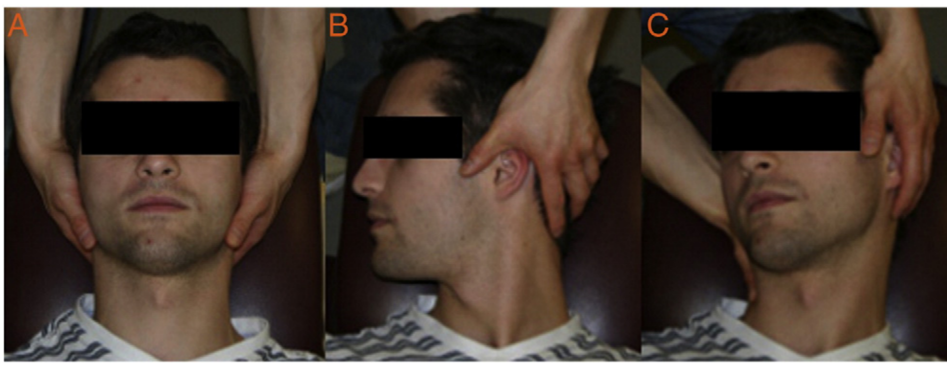

Fig 2. *Illustration of the positioning of the head and neck for some critical measurements of ICA lengths and strains. A, shows the head and neck in the neutral position, B, shows the head and neck rotated to the end range of passive motion, and C, shows the head and neck positioning just before application of a diversified lateral/rotary cervical manipulation. Please note that although the head and neck are correctly positioned, the clinician is not (especially in C where normally the clinician brings the upper body and chest closer to the subject but this was not replicated here so as to not obscure the subject's head and neck). (Color version of figure is available online.)*

ICA Strain Measurements

Strain measurements were made using sonomicrometry, as explained in detail in our earlier works.[16-18] Briefly, 2 sonomicrometry crystals (Sonometrics Corporation, London, Ontario, Canada) of 1.0-mm diameter were inserted into the wall of the ICA at its straight portion in the area between C1 and C7 (Fig 3). Crystals were placed in the lumen of the artery and then sutured to the ICA wall so that they could not move relative to the ICA. Each crystal served as a receiver and a transmitter of short (400 ns) ultrasound pulses. Knowing the time required for traveling from one crystal to the next with the head and neck in the neutral position (Fig 2A; defined as the 0% strain position), strains during ROM and SMT testing were calculated by the increase or decrease in time it took to cover the distance from one crystal (transmitter) to its neighboring crystal (receiver). This approach has the advantage that the strains are independent of the actual speed of sound transmission and that strains can be measured continuously (2000 Hz) during testing. The detailed calculations and the measurements of accuracy and resolution (0.016 mm) can be found in our previous works.[16-18] Percentages of strain (elongations were defined as positive) were then calculated for each ROM and each SMT test from the neutral position to the position of maximal ICA strain. For example, a strain of 3.4% would indicate that the ICA was stretched by 3.4% from its original length at neutral, whereas a strain of −2.1% would indicate a shortening of the ICA of 2.1% from its neutral length.

Maximal strains were calculated for each ICA, each test (SMT or ROM testing), and each chiropractor as the average of the 3 repeat measurements. The peak strains for any of the SMTs in a given ICA and a given clinician were then compared across all ICAs. Furthermore, the mean of all peak strains across all clinicians for a given ICA were also calculated for all SMTs and ROM testing. Finally, the mean of the peak strains across the 10 different SMTs and the 8 different ROM tests for a given clinician were also calculated and compared.

ICA Failure Strain Measurements

Failure strains for the ICA were determined using identical procedures as those described previously by our group for failure strains of the vertebral artery.[16] Briefly, following all SMT and ROM testing, the ICAs were carefully dissected and placed in physiologic saline with the sonomicrometry crystals left intact in the arterial walls. The ICAs were then placed in a materials testing machine (MTS Corporation, Eden Prairie, MN), set at the neutral strain length (determined from the sonomicrometry crystals), and then stretched to failure at a speed of 60% strain/s. Strains

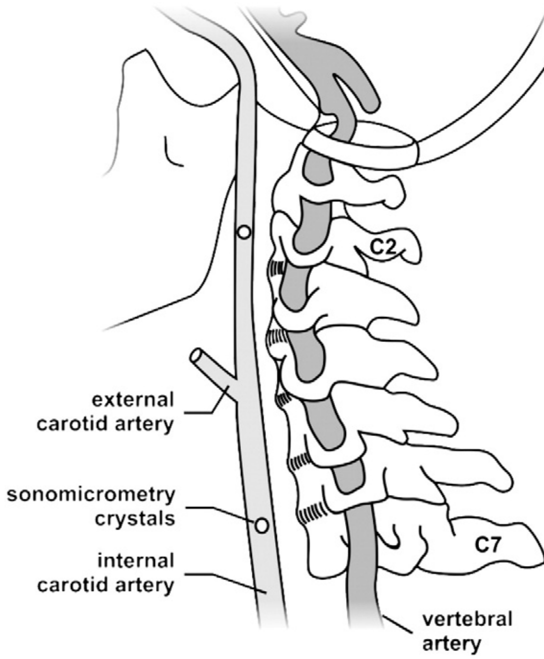

Fig 3. *Placement of sonomicrometry crystals on the ICA. This figure was inspired by an anatomical drawing found at http://www.meddean.luc.edu/lumen/MedEd/Neuro/neurovasc/navigation/vertbas.htm.*

were measured continuously during the stretching protocol, and *failure* was defined as the first appearance of a negative slope on the force-elongation plot.[16]

Statistics

All descriptive results are given as mean values ± 1 SD of the mean. The primary comparisons made here were between the peak and mean strains obtained during the SMTs and the ROM testing. Because the primary hypothesis of this study was that ICA strains during neck SMTs are equal or smaller than the corresponding strains obtained during ROM testing and because variables were not normally distributed and had different variances, we used binomial, 1-tailed, nonparametric χ^2 testing to evaluate this hypothesis. Because of the potential implications of our results on clinical practice, we used a conservative level of significance ($\alpha = .001$) in all our analysis and interpretations, so as to minimize the probability of obtaining significant differences between strains obtained during SMTs and ROM by chance.

Results

The maximal ICA strains (Table 2) and the mean ICA strains (Table 3) across all clinicians were significantly smaller ($P < .001$) for the cervical, high-speed, low-amplitude SMTs compared with the strains measured during ROM testing. The mean of the maximal ICA strain across all clinicians and ICAs during SMTs was 28% of that obtained for the ROM testing. A raw data result of a SMT and ROM test on the same ICA illustrates this result (Fig 4).

The mean failure strain of the ICA was 59% (± 16%).

Discussion

The primary result of this study is that the maximal ICA strains for the ROM testing were significantly ($P < .001$) greater than the corresponding maximal strains for the SMTs. Not only was this result statistically significant, but also it was observed individually for each clinician and each ICA, that is, in 36 different clinician/ICA combinations. The mean of all maximal ICA strains obtained during SMTs was 28% of that measured during the ROM testing and was 10% of the ultimate failure strain of the ICA. These results demonstrate that stretching of the ICA during high-speed, low-amplitude spinal manipulations of the neck is considerably smaller than the stretching of the ICA that occurs when moving the head and neck to the end ROM. Although it might be argued that the active ROM is smaller than the passive ROM measured here in the cadaveric subjects, great care was taken in the passive ROM testing, that it was stopped as soon as the first tangible passive force was detected. Therefore, we believe that the passive ROM, as explored in our study, would have been easily achievable during active movements in our subjects. However, this cannot be verified for obvious reasons and remains one of the limitations of this study.

The mean values (mean values calculated across all SMTs and all ROM tests, respectively) of ICA strains were also significantly ($P < .001$) smaller for the SMTs (2% ± 4%) than the ROM testing (7% ± 9%). This was also observed for each individual clinician and each ICA tested with 1 exception, that is, in 35 of 36 clinician/ICA combinations. The 1 exception (cadaver 2, right ICA, clinician 4, Table 3) showed identical values of 6% strain for the mean ICA strains across all SMTs and ROM tests. These mean strain results demonstrate that the ICA strains are smaller during SMTs than what one would expect during normal everyday movements of the head and neck, which include movements (such as head flexion) that often included little or no strains of the ICA.

In contrast to the results on vertebral artery strains reported previously by our group,[24] for neck SMTs, which were fairly consistent, ICA strains often are quite big, especially during ROM testing, but sometimes also during the SMTs. We assume that these very high values are caused by the substantial slack exhibited by approximately half of the ICAs tested. Slack, in this context, refers to the qualitative observation that the ICA was far from straight in the neutral head and neck position; thus, the neutral length

Table 2. *Maximal Strains (in Percentage of the Neutral Length) for All ICAs and Each Chiropractor During SMT and ROM Testing*

	Cadaver 1					Cadaver 2					Cadaver 3			
Chiropractor	1	2	3	4	Max	1	2	3	4	Max	1	2	3	Max
Adjustment	2.2	3.4	1.6	2.5	3.4	5.0	11.9	5.6	9.1	11.9	15.4	15.8	7.6	15.8
Left ICA	2.2	0.7	1.3	2.1	2.2	2.4	3.5	3.6	1.7	3.6	15.4	15.8	7.6	15.8
Right ICA	2.0	3.4	1.6	2.5	3.4	5.0	11.9	5.6	9.1	11.9	9.0	8.4	5.9	9.0
ROM	13.3	9.6	4.4	5.6	13.3	10.4	12.5	11.5	10.7	12.5	38.4	94.5	32.9	94.5
Left ICA	13.3	9.6	4.4	4.1	13.3	10.4	7.0	11.5	8.4	11.5	38.4	54.3	32.9	54.3
Right ICA	5.3	6.4	3.7	5.6	6.4	8.6	12.5	8.7	10.7	12.5	37.5	94.5	7.9	94.5

	Cadaver 4			Cadaver 5				Cadaver 6			
Chiropractor	2	3	Max	2	3	4	Max	2	5	Max	Grand total
Adjustment	9.3	6.8	9.3	2.9	4.6	4.1	4.6	3.8	3.2	3.8	15.8
Left ICA	9.3	6.8	9.3	2.5	2.0	4.1	4.1	3.1	1.2	3.1	15.8
Right ICA	5.1	6.2	6.2	2.9	4.6	3.9	4.6	3.8	3.2	3.8	11.9
ROM	27.5	16.1	27.5	19.3	39.2	17.3	39.2	19.9	18.8	19.9	94.5
Left ICA	27.5	16.1	27.5	19.3	15.3	13.7	19.3	5.7	7.6	7.6	54.3
Right ICA	10.0	12.0	12.0	14.6	39.2	17.3	39.2	19.9	18.8	19.9	94.5

Table 3. *Mean Strains (in Percentage of the Neutral Length) Across All SMT and ROM Testing for a Given ICA and Chiropractor*

	Cadaver 1					Cadaver 2				
Chiropractor	1	2	3	4	Average	1	2	3	4	Average
Adjustment	0 ± 2	0 ± 3	0 ± 1	1 ± 1	0 ± 2	0 ± 4	2 ± 4	−1 ± 7	2 ± 4	1 ± 5
Left ICA	−1 ± 2	−3 ± 2	0 ± 1	1 ± 1	−1 ± 2	−2 ± 5	−1 ± 3	−4 ± 8	−1 ± 3	−2 ± 5
Right ICA	1 ± 1	2 ± 1	1 ± 1	1 ± 1	1 ± 1	2 ± 2	5 ± 3	3 ± 2	6 ± 2	4 ± 3
ROM	4 ± 3	3 ± 3	2 ± 1	3 ± 1	3 ± 2	5 ± 3	5 ± 3	5 ± 3	5 ± 3	5 ± 3
Left ICA	5 ± 4	4 ± 3	2 ± 1	2 ± 1	3 ± 3	4 ± 3	4 ± 2	5 ± 3	4 ± 2	5 ± 3
Right ICA	2 ± 1	3 ± 2	2 ± 1	3 ± 2	2 ± 1	5 ± 2	6 ± 3	5 ± 2	6 ± 3	6 ± 3

	Cadaver 3				Cadaver 4		
Chiropractor	1	2	3	Average	2	3	Average
Adjustment	5 ± 4	3 ± 7	4 ± 2	4 ± 5	3 ± 5	3 ± 3	3 ± 4
Left ICA	6 ± 5	3 ± 10	4 ± 2	4 ± 6	5 ± 3	4 ± 2	4 ± 3
Right ICA	4 ± 2	3 ± 3	3 ± 1	3 ± 2	1 ± 5	2 ± 4	2 ± 4
ROM	14 ± 11	22 ± 23	9 ± 9	15 ± 16	8 ± 6	10 ± 3	9 ± 5
Left ICA	16 ± 10	20 ± 16	15 ± 10	17 ± 13	12 ± 7	11 ± 4	11 ± 5
Right ICA	12 ± 10	25 ± 28	4 ± 2	13 ± 19	5 ± 3	8 ± 2	7 ± 3

	Cadaver 5				Cadaver 6			
Chiropractor	2	3	4	Average	2	5	Average	Overall average
Adjustment	1 ± 1	2 ± 1	2 ± 1	2 ± 1	2 ± 1	0 ± 2	1 ± 2	2 ± 4
Left ICA	2 ± 1	2 ± 0	3 ± 1	2 ± 1	2 ± 1	−1 ± 2	1 ± 2	1 ± 5
Right ICA	1 ± 1	2 ± 1	2 ± 1	2 ± 1	2 ± 2	1 ± 2	1 ± 2	2 ± 3
ROM	7 ± 5	8 ± 9	6 ± 5	7 ± 7	6 ± 4	5 ± 4	6 ± 4	7 ± 9
Left ICA	8 ± 6	6 ± 4	8 ± 4	7 ± 5	4 ± 2	4 ± 2	4 ± 2	7 ± 8
Right ICA	7 ± 4	9 ± 11	4 ± 5	7 ± 8	9 ± 5	7 ± 5	8 ± 5	7 ± 9

often changed substantially in these specimens as "neutral" length could not be uniquely defined in slack ICAs. We attempted to reposition the ICA as well as possible in the initial configuration, but this proved difficult, so we decided to make all measurements from the neutral position of each individual test. In initially slack ICAs, it was obvious that the strain measured did not actually coincide with a stretch of the ICA but merely reflected an unfolding of the slack artery, and no stress (force) was ever applied to the tissue. Again, this is a limitation of our study, as we did not anticipate that half the ICAs would be slack for all test configurations. Needless to say that such arteries could never be damaged due to longitudinal stress, as stress from stretching the arterial wall would never occur. Note also that for the failure testing, the ICA strains in the neutral position were taken with the ICA in a straight position between the sonomicrometry crystals. This implies that the failure strains, had we taken the slack ICA configurations observed

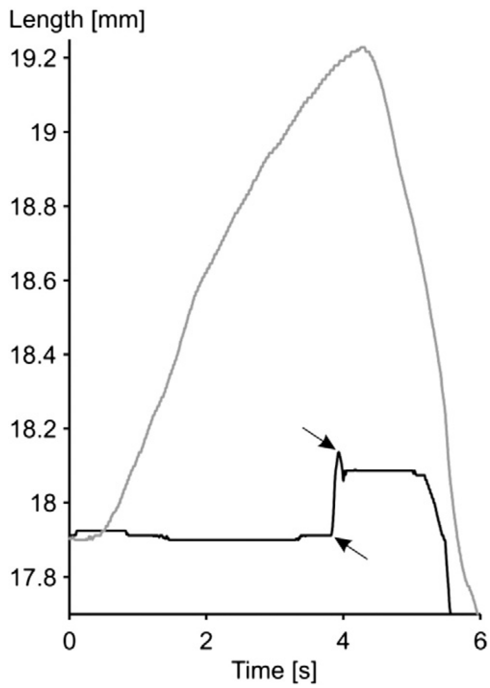

Fig 4. *Example results of ICA strains obtained from a ROM (gray line) and SMT test (black line) performed on a given ICA and the same chiropractor.*

in half of the ICAs, would have been substantially higher than what we measured here. Although from a scientific point of view, having slack ICAs in the neutral position was not a desirable outcome, in terms of our results, it implies that independent of the strains measured in these slack arteries, there never would have been any longitudinal strain in the arterial wall and, thus, no stress that could damage the ICA, further supporting the idea that SMTs to the neck are not likely to induce stretch-induced stress and damage to ICAs. Nevertheless, in future studies, it would be best to define zero strain as the length at which the ICA exhibits first measurable force when stretched. Although this is clearly desirable, it would have meant for this study that most strain and stress values would have been negative and zero, respectively. However, careful quantification of the stress-strain states of the ICA should be made in the future.

Limitations

Aside from the limitations mentioned above in the context of the primary results, there are other limitations that deserve attention. First and maybe foremost, all experiments were performed on cadaveric specimens, which might have affected the results. In fresh, unembalmed human cadavers, as used here, the arteries are deflated and thus do not reflect the actual geometry in the living system. To account for this, we inflated the arteries by injecting ultrasound gel into the ICAs using a syringe. This worked well in restoring the shape of the arteries but, of course, did not restore the pulsating flow that arteries are normally exposed to. Nevertheless, inflating arteries has been shown to cause slightly different results (typically, maximal strains are smaller in inflated compared with empty arterial vessels)[24] possibly because of the improved measurements of sonomicrometry signals in the presence of ultrasound gel.

Another limitation is that the cadavers were relatively old and thus might not represent the normal target population who receives neck SMTs. In addition, the failure strain of the ICAs might have been affected by the age of the specimens and by small disruptions of the arterial walls caused by sonomicrometry crystal implantation. Typically, the ICAs of our cadavers were not in as good shape as one might expect. Furthermore, dissection before testing and removal of the ICAs before failure testing might have compromised the failure strains. However, if anything at all, the increased age, the implantation of the sonomicrometry crystals, the dissection procedures, and the removal of the artery would have compromised the integrity and thus caused failure at smaller strains than one would expect from a normal, intact ICA in a young individual. Therefore, we believe that the mean failure strain of 59% observed here, if anything at all, is a low estimate of the true failure strains of intact ICAs in living people.

In this study, in contrast to others,[28] we did not measure the forces exerted by clinicians on the cadavers during the neck manipulations. It has been argued that these forces might be quite different than those that a clinician would apply to a patient. In a recent study, we confirmed that these forces are different. When asked to give the same neck SMT as we used here to a series of patients in a clinical setting, live subjects without head or neck pain in a laboratory setting, and cadaveric specimens as used here, clinicians tended to give similar forces to both sets of live populations (patients and nonpatients), whereas the forces exerted on the cadavers differed substantially from those given to the live subjects. Specifically, the SMTs to cadavers were significantly more aggressive than the SMTs given to live subjects. This was seen in the higher peak forces and faster rates of force application in the cadavers compared with both live subject populations.[28] Therefore, the SMTs applied on the cadaveric specimens would tend to create greater strains than one would expect in patients visiting a clinic for neck treatments.

Aside from the limitations of the use of cadaveric specimens, there is no reason to believe that the strains measured here would be any different than the strains for the same head and neck movements in live patients. After all, the strain in tissues, such as the ICA, depends entirely on points of fixation of the artery and the relative movements of these points during the ROM and SMT testing. These points of fixation do not change with death. This has been recognized by anatomists decades ago; thus, strain measurements in a variety of tissues, for example, muscle excursions,[29,30] have been obtained routinely in cadaveric specimens for at least the past century, possibly much longer.[31]

We did not measure the head and neck excursion or the displacements of the vertebrae during cervical spinal manipulations. Therefore, we cannot compare the treatments of different clinicians to each other nor can we verify that clinicians who used a greater ROM during SMTs also had bigger ICA strains. Likely, the strains in the ICA (and especially the strains in the vertebral artery, which we have measured on previous occasions) do not depend so much on the overall head and neck movement, but primarily on the local movements imposed by ROM testing and SMT application. It would be of great interest in the future to quantify the strains imposed on arteries and other soft tissue structures and relate them directly to the measured local movements produced by the high-speed, low-amplitude SMT.

We emphasize that the SMTs performed in this study used a starting and finishing position similar to that shown in Figure (1C), that is, a position of the head and neck that is far from the end ROM. We realize that some antiquated SMT techniques involve movement of the head and neck to the very end ROM, and for these treatments, the stresses and strains could possibly exceed those measured during the ROM tests. However, these techniques are discouraged by the profession, and thus, they were not evaluated in this study.

Conclusion

Elongations of the ICA and associated strains are much smaller during high-speed, low-amplitude cervical SMTs than they are during ROM testing. We conclude from this result that SMTs are less likely to produce stretch-induced damage to the ICA than normal, everyday head and neck movements involving the full possible ROM. Therefore, cervical SMT, as performed by the trained doctors of chiropractic in this study, did not appear to place undue strain on the ICA and thus does not seem to be a factor in ICA injuries.

Practical Applications

- The results of this study provide strong evidence that chiropractic cervical spinal manipulations do not pose undue stress and strain on the ICA.
- These findings are relevant for clinicians who use high-speed, low-amplitude cervical spinal manipulation and for the profession when dealing with issues on the dangers and acceptability of cervical spinal manipulation.

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Funding Sources and Potential Conflicts of Interest

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