International Journal of Osteopathic Medicine 29 (2018) 10–14

Contents lists available at ScienceDirect

International Journal of Osteopathic Medicine

journal homepage: www.elsevier.com/locate/ijosm

Original Article

Is digital image correlation able to detect any mechanical effect of cranial osteopathic manipulation? – A preliminary study

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ABSTRACT

Background: Today there is still a controversy surrounding the existence of mobility between the bones of the skull, the foundation on which cranial osteopathy techniques are based. The lack of total closure for the sutures of young people or simply the suture discontinuity of the elderly would mean there is residual mobility or at least a weakness area.

Objectives: The goal of our work was to study skull deformation as an indicator of possible mobility or altered stiffness area under slow loading on either side of the sagittal suture using a digital-image-correlation based system.

Methods: Quasi-static load trials under compression were performed on 4 human skulls at a displacement rate of 0.5 mm/s. The digital image correlation technique was used to measure the maximum and minimum principal strain on the sagittal suture.

Results: The results of this study show that the strain field remains homogeneous in the areas observed, even when compression force reaches values exceeding 100 N.

Conclusion: No particular concentration of strain in the immediate vicinity of the suture was detected with our measurement method, which would have suggested a relative displacement or a weakness area in the region of the two bones margins on the sagittal suture.

1. Introduction

Cranial osteopathy was first described in 1939 by Sutherland [20]; he suggested that there is a certain amount of mobility between the various bones of the skull and face. This mobility is made possible by the histological and biomechanical properties of the cranial and facial sutures which, when not completely fused, allow such movement. This hypothesis gives rise to various lines of research.

On one hand, several authors have looked into the efficiency of "cranial manipulation techniques" in dealing with various symptoms, notably headaches [7], chronic cervical pain [6]; whiplash [22] and caring for cranial deformations in infants [1,14,18,19]. Moreover, while previous studies have produced a consensus as to the efficiency of these techniques, the hypotheses they are based on have been questioned, and some have even been invalidated, as asserted by Hartman and Norton [9]. Likewise, Downey et al. [5] concluded that the small loads applied to the skulls of adult rabbits, similar in amplitude to those used in cranial osteopathy, did not have any significant effect on the movement of the coronal suture.

On the other hand, fusion can occur very late even after the seventh decade [8] and therefore does not contradict the hypothesis of the possibility of movement. Moreover, even if total closure occurs, residual weakness area still could be suspected. Thus, a lack of complete fusion of cranial sutures remains a current debate sustained in recent studies by Maloul et al. [15] who stress the fact that the sagittal and coronal sutures have the least bone connectivity (6.6%).

Lastly, it is widely accepted that sutures are areas of energy absorption and stress transmission, and that the increase in suture interdigitation provides improved resistance to bending forces [13]. Various mechanical characterization trials have been performed on skulls. Studies have shown that suture morphology can be connected to the load that the bone region in question is subjected to, notably compression, traction or flexion [4,10].

There are many techniques for measuring the surface or volume deformation field (image correlation, elastography, etc.). Image correlation [20] can be used to measure rigid body movements and deformations.

Insofar as the controversy as to the existence of joint mobility between the cranial bones continues, the purpose of our study was to identify any possible strain concentration as an indicator of possible bone relative displacement or a weakness area, using a method widely used elsewhere [17] to detect very small strain in biological tissues: digital image correlation.

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https://doi.org/10.1016/j.ijosm.2018.07.004
Received 19 May 2017; Received in revised form 23 April 2018; Accepted 18 July 2018
1746-0689/

Table 1
Characteristics of the subjects.

	Subject 1	Subject 2	Subject 3	Subject 4
Gender	Male	Female	Female	Male
Age	86 years	94 years	72 years	102 years

2. Materials and methods

2.1. Preparation of the subjects

This study was carried out in conformity with French laws and in compliance with Aix-Marseille University's ethical rules relative to the use of biological materials, on skulls taken from bodies donated to science at the embalming service of the Faculty of Medicine of Marseille. The subjects, whose characteristics are summed up in Table 1, had first been embalmed in a Winkler conservation fluid (40% formaldehyde, 90% alcohol and glycerol). A total of four adult skulls were gathered.

The cranial vault was kept intact. Dissection was performed from the rear under the occiput; the cervical spine, the mandible and the teeth on the maxilla were removed to ensure a better support of the skull during the test.

The subjects were removed 24 h before the test, scalped on the vault and the base, and then placed in a refrigerator at a temperature of 4 °C. Six hours before the tests, the skulls were placed at room temperature.

A few minutes before the test, a random motif (speckles) was applied to the skulls with black spray paint.

2.2. Experimental system

The skull was placed on a plate coupled to a hydraulic jack (MTS, Eden Prairie, MN, USA) used to apply the compression force. It was positioned on the left and right mastoid processes, on the upper maxilla in the front and the inion region in the rear.

The skull was then positioned and attached horizontally using the adjusting screw so that the impactor arm came into contact with the skull 5 cm behind the bregma (Fig. 1). The impactor is double-ended and measures 1.5*1.5*0.3 cm. It comes into contact with the 2 parietal bones, on either side of the sagittal suture, as illustrated in Fig. 1. This stress application tool was inspired by a "thumbs crossed" skull suture technique in which the thumbs are placed on either side of the suture.

Two high-resolution digital cameras (FastCam®, Photron, San Diego, CA, USA) were placed in front of the jack.

Force was applied to the skull by translating the impactor at a constant imposed velocity of 0.5 mm/s, until a force of 200 N was reached, i.e. twice the value beforehand measured during a typical pressure palpation performed by an experienced osteopath.

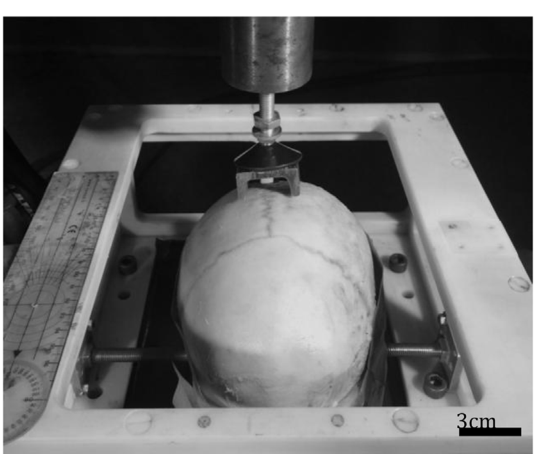

Fig. 1. Installing the skull and positioning the impactor.

2.3. Measurements

The force and displacement of the hydraulic jack were recorded against time. The force sensor is a MTS661.19H-03 model with a ± 13,5 kN range and a relative error (k = 2) of ± 2 N.

The deformation produced by the jack's displacement on the skull was assessed: the strain field on the skull surface was recorded using the VIC 3D® digital image correlation software (Correlated Solutions, Columbia, SC, USA). The VIC 3D® system has a resolution of 1 μm for an analysis field width of 100 mm. The accuracy and precision of this method is widely developed in Palanca et al. [17].

The mean values of the maximum and minimum principal strain were studied.

As the goal was to detect the concentration strain area on the skull bones on either side of a suture, and notably in the context of a cranial osteopathy technique, a preliminary study was carried out to measure the stress produced under finger pressure.

Ten forces measurements were recorded by applying punctiform pressure using the two thumbs on either side of the sagittal suture at 5 cm behind the bregma. This was used to calibrate the resulting force and to keep this value as the reference. This step corresponds to the pressure exerted during a cranial osteopathy technique and provides information as to the stress produced by the pressure applied in this context.

An additional test was realized in static condition to eliminate a possible phenomenon of stress relaxation that may be caused by the dynamic ramp-loading condition.

A first loading was applied on one of the specimen at a rate of 1000 N/min until a force of 100 N was reached in order to let any possible relaxation of the tissues and distribution of the stress occur. The loading was then stopped during 30 s, in order to let any possible relaxation of the tissues and distribution of the stress occur.

3. Results

The force and the principal strains were recorded using the same time scale. The curves for the minimum and maximum principal strains are presented in Fig. 2.

Strain increases linearly as the load increases. The maximum principal strain curves are superimposed from 0 to 50 N. Then the strain rapidly increases from 0 to 1.5%. The positive values indicate a compression of the skull tissues, in the direction normal to the bone surface.

The minimum strain curves are superimposed from 0 to 50 N. The curves for subjects 1 and 2 have comparable behaviors and present a minimal principal strain around 1.2%, whereas subjects 3 and 4 undergo larger strains. The minimum principal strain curves have negative values, which indicate a tearing of the skull tissues with no preferential direction.

The preliminary study recording the force exerted on two punctiform pressure points by human hands shows that the maximum force achieved is 100 N. The deformations on the skull surface around this value were analyzed in order to analyze any possible specific deformation on the sagittal suture around stress that can be produced by the human hand during a "cranial technique", i.e. 50 N at the start of the load, then 100 N, 150 N and up to two times the maximum achieved: 200 N (Fig. 3).

The results of the static loading condition showed no modification of the strain pattern, which allow us to exclude a possible concentration of strain that our loading would have masked.

The vertical analysis of Fig. 4 shows the distribution of the maximum principal strain for a given force. No concentration of strain at the sutures can be observed.

The horizontal analysis in Fig. 4 shows the evolution of the

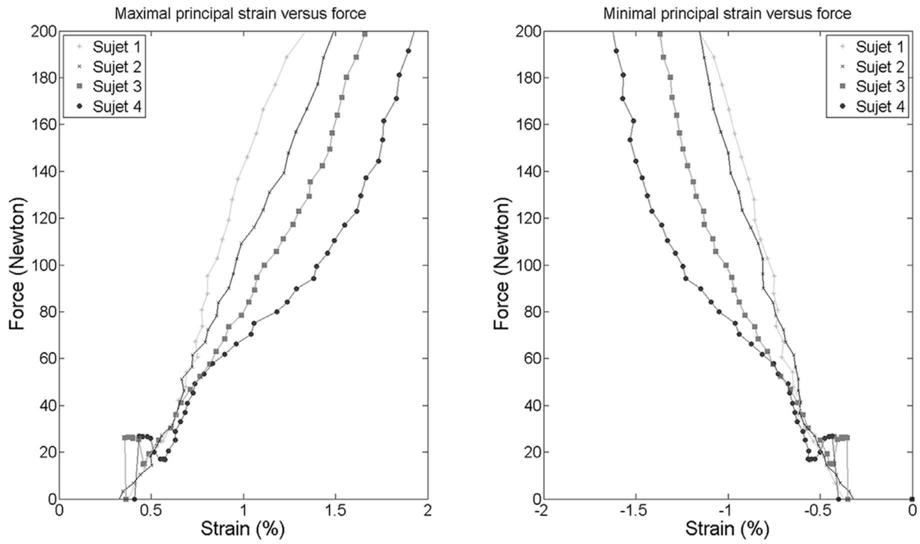

Fig. 2. Curves for the maximum and minimum principal strains as a function of the force exerted for all subjects.

maximum strain for each specimen. While the force applied increases, the mean maximum principal strain also increases but no concentration of this strain in specific areas can be observed. Furthermore, no privileged direction for the maximum principal strain could be observed.

4. Discussion

The analysis of the strain curves for the loads applied on the skulls shows that the four skulls have similar behavior under the load: the strain increases uniformly as the load increases. The skulls were subjected to loads of up to 200 N and no fracture lines were observed. This analysis firstly highlights the resistance capacity of the vault under compression. This capacity can be seen in the increase of the percentage of bone deformation as a function of the increase in the load exerted. The maximum principal strain observed increases up to 2% and the minimum principal strain up to −1.5%, with no detectable fractures.

These results can be explained by the functional requirement for protecting the brain. The skull's convex shape enables it to resist external forces.

The digital image correlation obtained using VIC 3D® software did not show any specific field of strain on the sagittal and coronal sutures compared to the bones concerned by the sutures. The strain's random distribution demonstrates a dispersion of the load applied alternately between compression and traction.

No visible concentration or gradient of ectocranial strain could be observed on the sagittal suture and its periphery, even under loads significantly higher than those previously recorded in palpation pressures [2]. Netherless, endocranial absorption mechanisms can not be excluded. This observation suggests that, on the skulls tested and with the use of digital image correlation, there is no observable mechanical effect caused by the application of pressure on the two bones margins of the sagittal suture. This result corroborates previous literature data [2,4,11] where the suture is defined as an area of energy absorption and force transmission that resists flexion. The results from Mao et al. [16] point in the same direction as the function of the sutures is assumed to keep the various skull bones together while making the mechanical transmission of stress and strain possible.

During the static condition test there was no phenomenon of stress relaxation observed. This point is reinforced by the results of Jasinoski et al. [12] who showed that the collagen fibers may adapt their orientation to resist the load direction. Increasing resistance time would probably have little effect since the loading direction would remain the same and therefore the internal organization of the collagen fibers would as well.

Study limitations include the use of four cadaveric specimens whose ages were high (72–102 years old). Thus, our sample is small and the

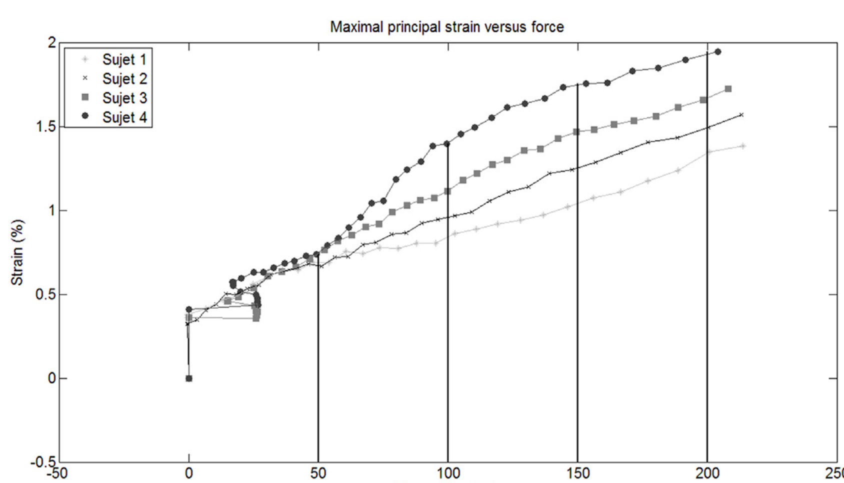

Fig. 3. Evolution of the maximum principal strain for each subject as a function of the force exerted, between 0 and 200 N.

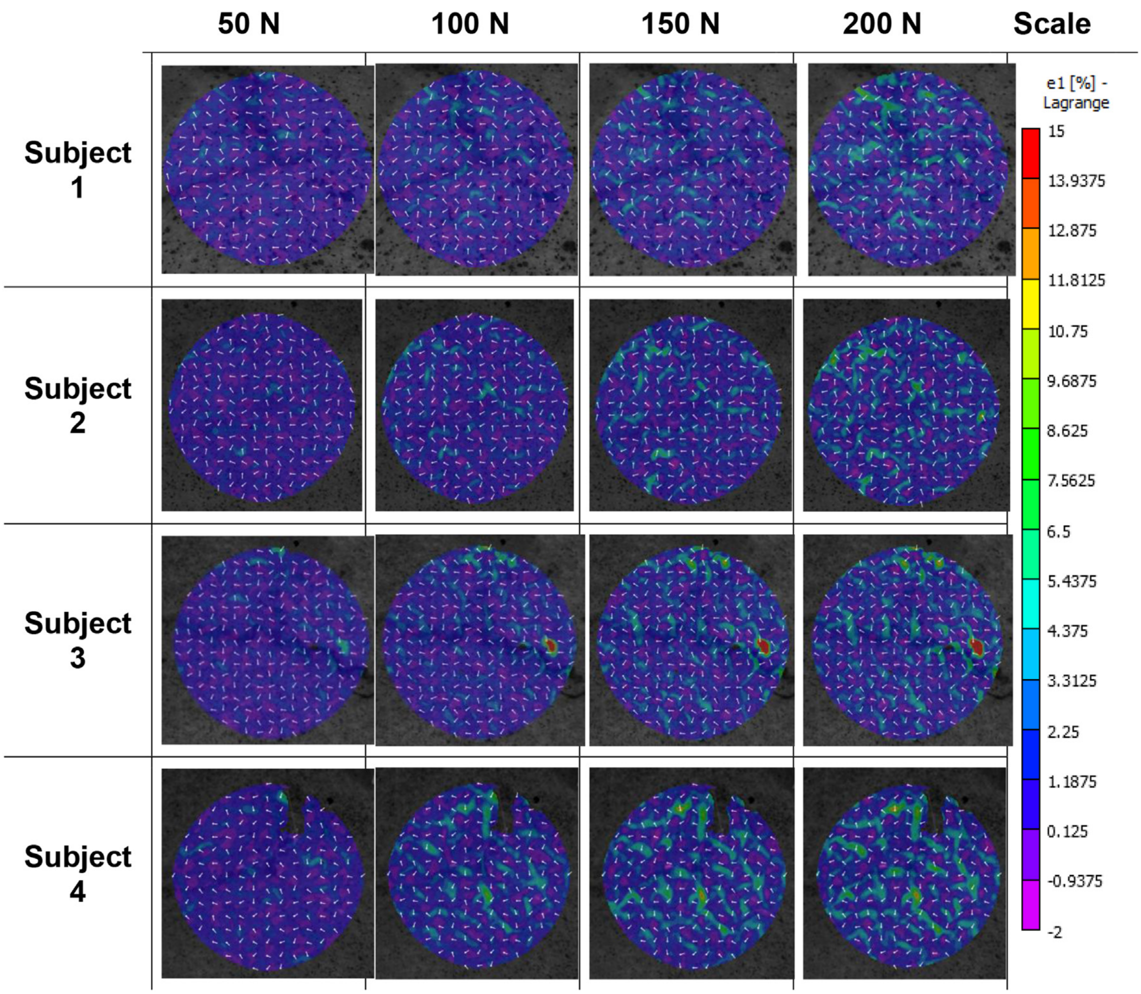

Fig. 4. Evolution (in percentage) of the distribution of the maximum principal strain on all subjects as a function of the force applied.

specimens used are not sufficient to be considered representative of the overall population nor of older adults. With respect to the use of older adult skulls their sutures are likely to be at least partly fused [18] and as a consequence somehow reinforced; energy absorption is probably altered because it is related to the extracellular matrix of the bones, and collagen fibres become increasingly irregular with age [3]. Caution should be used in interpreting and inferring from our results as the level of fusion and the quality of the sutures was not measured in this study and it is probable that the specimen sutures were very stiff. Our results do not exclude the possibility that a mechanical effect may be demonstrable in a larger sample of older adult specimens or in younger adults.

Future work should include assessment of sutural structure using imaging alongside the methodology employed in the current study. A larger sample size would address whether or not our findings are representative of the population of older adults. Additional study is warranted to evaluate the effect of applied loading on younger skulls.

Furthermore, the Faculty of Medicine of Marseille forbids the use of fresh cadavers due to possible risks of infection, meaning that only bodies embalmed with Winckler conservation fluid can be used. Wieding et al. [21] experimentally assessed the influence of freezing and two commonly used conservation fluids (formaldehyde and alcohol) on the intrinsic mechanical properties of samples of ovine cortical bones compared with fresh samples. The results of this study show significant differences in plastic energy absorption, whereas no influence on the elastic property of the samples preserved in formaldehyde and alcohol was demonstrated.

Lastly, the VIC 3D® system's resolution (1 μm for a 100-mm displacement field), or the smallest displacement it is able to detect, appears to be sufficient given the results observed in animal experiments (displacement of the sagittal suture between 5-10 μm), even if this observation should be taken in view of the fact that we do not have any comparable elements in humans.

5. Conclusion

In this study we tested the response to load of the sagittal sutures in four older skulls using a stimulus aimed to model a single cranial osteopathic technique. We demonstrated the potential of a measurement methodology newly applied to this field. There was no mechanical effect of osteocranial pressure manipulation on the exctocranial part of the skull. No significant homogenous deformation was observed on the sagittal suture in comparison with the bones it connects. We did not detect any displacement of the two sagittal suture margins, even for heavy loads largely exceeding therapeutic stress levels in this sample of specimens.

Further larger scale research is indicated to assess whether these findings are representative of the population of older adults. Similar research is indicated to assess the effect of load on younger skulls. In both cases, concurrent assessment of sutural structure using imaging would inform the interpretation of findings.

Conflicts of interest

None.

Funding sources

There is no private financing. But the « collège ostéopathique de provence » paid for schooling of Marie Pellet for the Master.

This work has been done during this Master 2.

Acknowledgments

Authors thanks P.J. Arnoux, LBA, M.Py and College Ostéopathique de Provence Aix-Marseille.

References

[1] Amiel-Tison C, Soyez-Papiernik E. Place de l'ostéopathie dans la correction des déformations crâniennes du nouveau-né et du jeune enfant. Progrès en Néonatologie vol 28. Association de Néonatologie de Port-Royal; 2008. p. 163–72.
[2] Byron CD, Hamrick MW, Borke J Yu J. The mechanobiology of cranial sutures. Am. J. Phys. Anthropol. Suppl. 2004;38:72.
[3] Cohen MMJ. Sutural biology and the correlates of craniosynostosis. Am J Med Genet 1993;47:581–616.
[4] Cohen MMJ. The biology of sutures. Craniosynostosis: diagnosis, evaluation, and management. Raven Press; 2000. p. 81–103.
[5] Downey PA, Barbano T, et al. Craniosacral therapy: the effects of cranial manipulation on intracranial pressure and cranial bone movement. J Orthop Sports Phys Ther 2006;36(11):845–53.
[6] Haller H, Lauche R. Craniosacral therapy for the treatment of chronic neck pain: a randomized sham-controlled trial. Clin J Pain 2015;32(5):441–9.
[7] Hanten PW, Olson SL. The effectiveness of CV-4 and resting position techniques on subjects with tension-type headaches. J Man Manip Ther 2001;7(2):64–70.
[8] Harth S, Obert M, Ramsthaler F, Reuss C, Traupe H, Verhoff MA. Ossification degrees of cranial sutures determined with flat-panel computed tomography: narrowing the ageestimate with extrema. J Forensic Sci 2010;55(3):690–4.
[9] Hartman SE, Norton JM. Interexaminer reliability and cranial osteopathy. Sci Rev Alternative Med 2002;6:23–34.
[10] Herring SW, Teng S. Strain in the braincase and its sutures during function. Am J Phys Anthropol 2000;112:575–93.
[11] Herring SW, Rafferty KL, Liu ZJ, Marshall CD. Jaw muscles and the skull in mammals: the biomechanics of mastication. Comp Biochem Physiol A: Mol. Integr. Physiol. 2001;131:207–19.
[12] Jasinoski SC, Reddy BD, Louw KK, Chinsamy A. Mechanics of cranial sutures using the finite element method. J Biomech 2010;43:3104–11.
[13] Jaslow CR. Mechanical properties of cranial sutures. J Biomech 1990;23:313–21.
[14] Lessard S. Exploring the impact of osteopathic treatment on cranial asymmetries associated with nonsynostotic plagiocephaly in infants. Compl Ther Clin Pract 2011. https://doi.org/10.1016/j.ctcp.2011.02.001.
[15] Maloul A, Fialkov J, Hojjat SP, Whyne CM. A technique for the quantification of the 3D connectivity of thin articulations in bony sutures. J Biomech 2010;43:1227–30.
[16] Mao JJ, Wang X, Kopher RA. Biomechanics of craniofacial sutures: orthopedic implications. Angle Orthod 2003;73:128–35.
[17] Palanca M, Tozzi G, Cristofolini L. The use of digitial image correlation in the biomechanical area: a review. Int. Biomech. 2016;3(1):1–21.
[18] Rice DP. Developmental anatomy of craniofacial sutures. Front. Oral Biol. 2008;12:1–21.
[19] Rosenbaum PL. Infantile Posture asymmetry and osteopathic treatment: a randomized therapeutic trial. Dev Med Child Neurol 2006;48:4.
[20] Sutherland WG. The cranial bowl. first ed. 1944.
[21] Wieding J, Mick E, Wree A, Bader R. Influence of three different preservative techniques on the mechanical properties of the ovine cortical bone. Biomechanics and Implant Technology Research Laboratory vol 17. Department of Orthopaedics; 2015. p. 137–46.
[22] Wilson W. Craniosacral therapy. Posit Health 1999; July:45–7.