**The malleability of cranial sutures, analysis of the relative displacement of the sagittal suture against a low energy stress using stereocorrelation.**


## Abstract

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 of the sutures would mean there is residual mobility. The goal of our work is to study skull deformation under slow loading on either side of the sagittal suture using the stereocorrelation principle.
Quasi-static load trials under compression were performed on 4 human skulls at a rate of movement of 0.5 mm/s. The image stereocorrelation technique was used to measure the maximum and minimum principal deformations on the sagittal suture.
The results of this study show that the deformation field remains homogeneous in the areas observed, even when compression stress reaches values exceeding 1 kN. No particular concentration of deformation in the immediate vicinity of the suture was detected with our measurement method, which would have suggested a relative displacement of the two bone margins on the sagittal suture.


## 1. Introduction

Cranial osteopathy was first described in 1939 by Sutherland (REF), who suggested that there is mobility between the various bones of the skull and face. It 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 the one hand, several authors have looked into the effectiveness of “cranial manipulation techniques” in dealing with various symptoms, notably headaches[9], chronic cervical pain[8]; whiplash[24] and caring for cranial deformations in infants[2, 16, 19, 21].
Moreover, while the studies have produced a consensus as to the effectiveness of these techniques, the hypotheses that they are based on have been criticized, and some have even been invalidated, as asserted by Hartman and Norton[10]. Likewise, Downey et al.[7] concluded that the small loads applied to the skulls of adult rabbits, similar to those used in cranial osteopathy, did not have any significant effect on the movement of the coronal suture. On the other hand, Rice et al.[20] determined that suture fusion can occur up to the seventh decade and therefore does not contradict the hypothesis of the possibility of movement. Thus, a lack of complete fusion of cranial sutures remains a current debate sustained in recent studies by Maloul et al.[17] 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[15]. 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[5,12].
There are many techniques for measuring the surface or volume deformation field (image correlation, elastography, etc.). Image correlation[22] 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 study any relative displacement of skull bones on either side of the sagittal suture using an original measurement method: image stereocorrelation.

## 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 Winckler fluid (40% formaldehyde, 90% alcohol and glycerol). A total of four adult skulls were gathered.

**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 |

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 hours 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 stress. 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 (figure 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 indicated in Figure 2. 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 moving the jack at a constant speed of 0.5 mm/s.

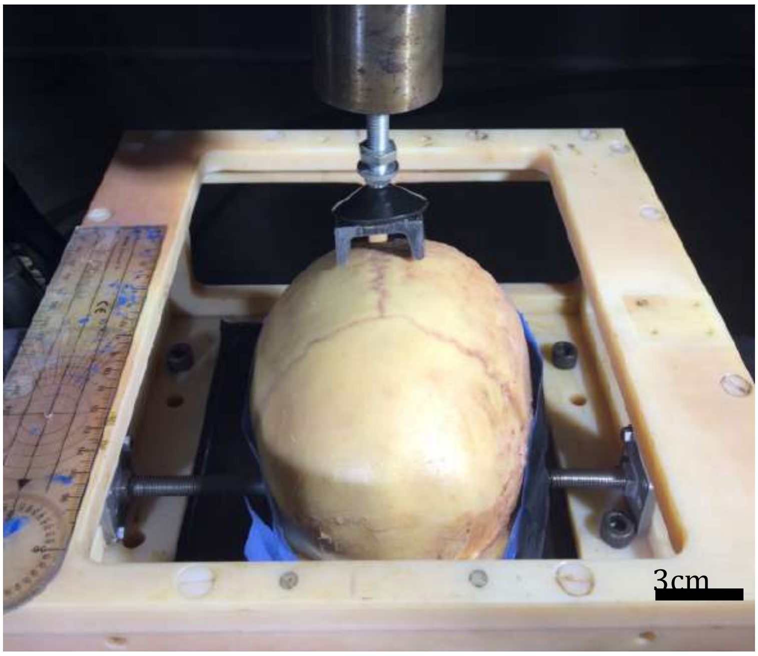

**Figure 2.** Installing the skull and positioning the impactor

### 2.3 Measurements

The stress and displacement of the hydraulic jack were recorded over time.
The deformation produced by the jack’s movement on the skull was assessed: the field of deformation on the skull surface was determined using the VIC 3D® stereocorrelation software (Correlated Solutions, Columbia, SC, USA).
The VIC 3D® system has a resolution of 1 mm for an analysis field width of 100 mm.
The mean values of the maximum and minimum principal deformations were studied.

As the goal was to detect the relative displacement of 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 stress measurements were recorded during stress 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.

## 3. Results

The force and the principal deformations were recorded using the same time scale. The curves for the minimum and maximum principal deformations are presented in Figure 3.

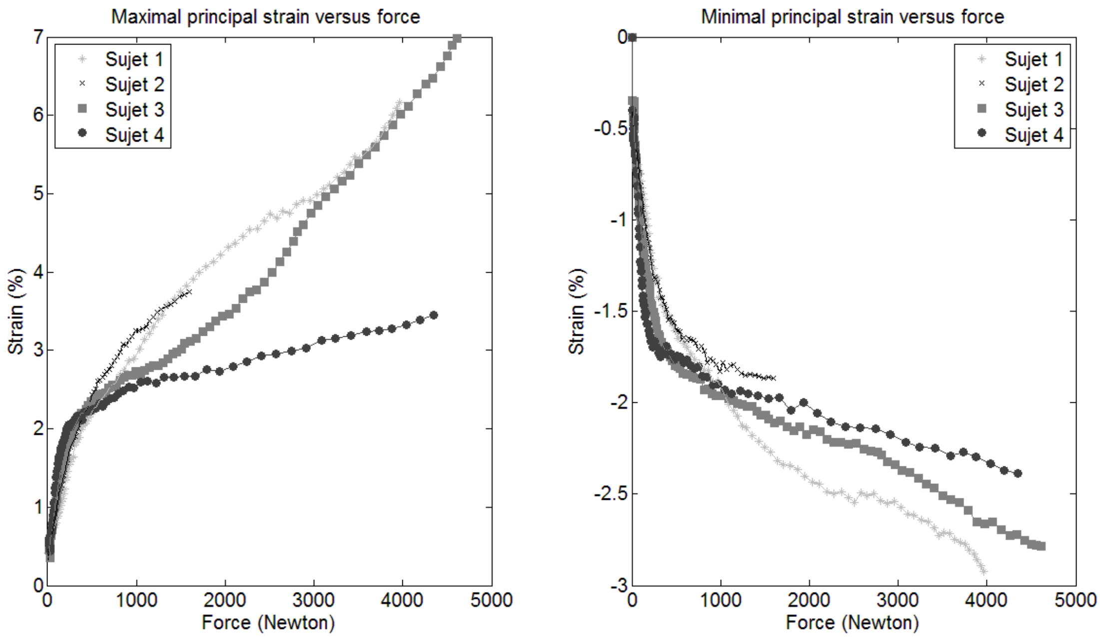


**Figure 3.** Curves for the maximum and minimum principal deformations as a function of the force exerted for all subjects.

Deformation increases linearly as the load increases. The maximum principal deformation curves for the four subjects are comparable in the first load phase, from 0 to 250 N, for which the deformation rapidly increases from 0 to 2%. The maximum deformation energy is relative to a compression.
The minimum deformation curves are superposed from 0 to 50 N. The curves for subjects 1 and 2 have comparable behaviors up to 300 N, whereas subjects 3 and 4 undergo larger deformations. The minimum principal deformation curves have negative values: the minimum deformation energy represents an extension.

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 (Figure 4).

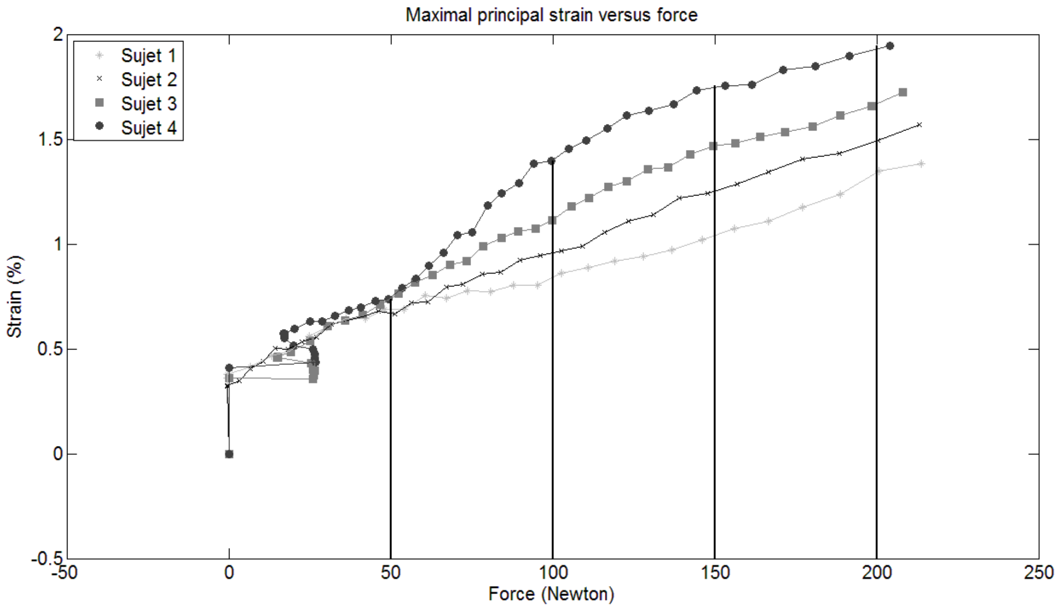


**Figure 4.** Evolution of the maximum principal deformation for each subject as a function of the force exerted, between 0 and 200N.

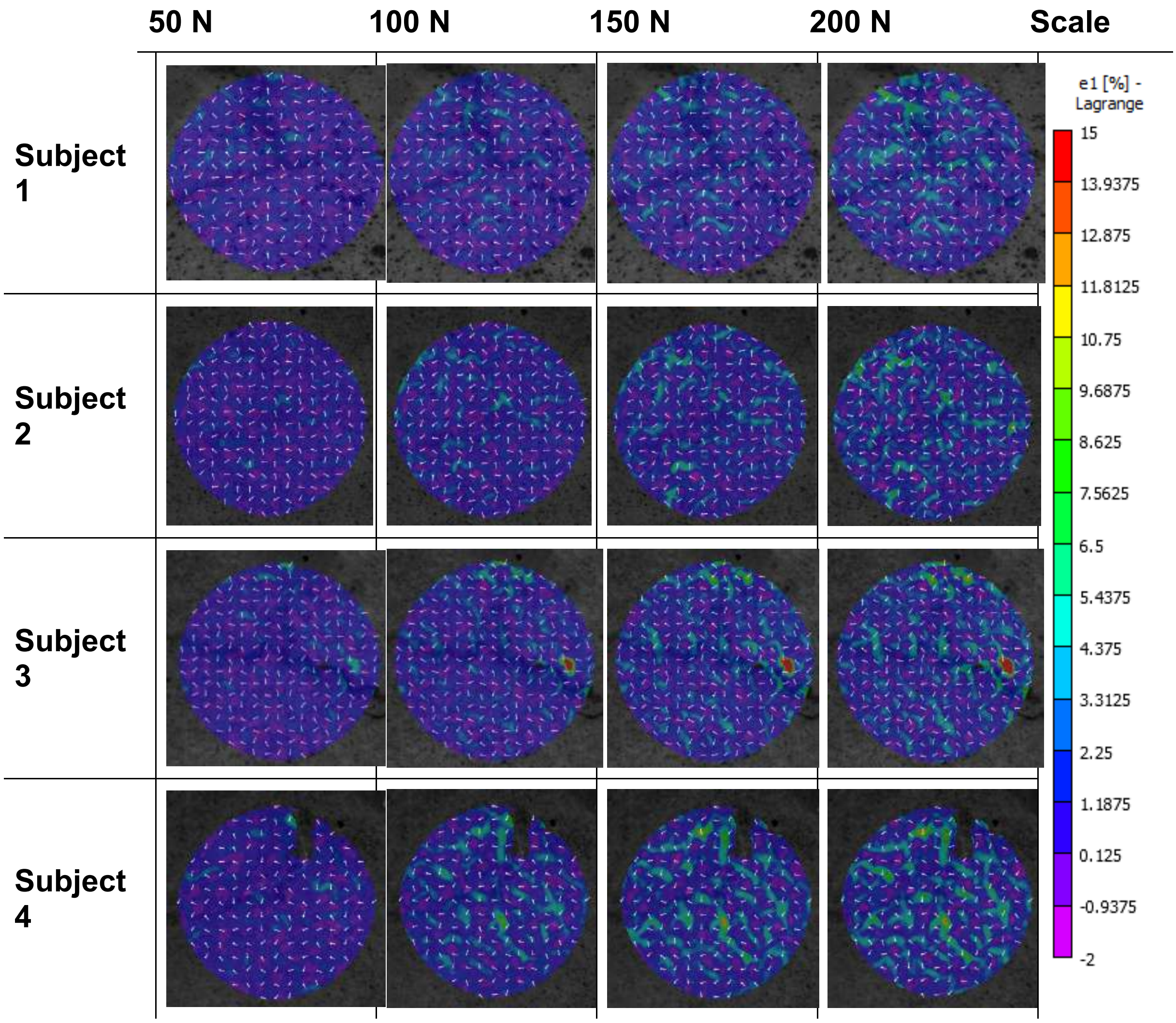


**Figure 5.** Evolution of the distribution of the maximum principal deformation on all subjects as a function of the force applied.

The vertical analysis of Figure 5 shows the distribution of the maximum principal deformation for a given force. No concentration of deformation at the sutures is observed.
The horizontal analysis in Figure 5 shows the evolution of the maximum deformation for each subject. With the evolution of the force applied, we observe an increase in the mean maximum principal deformation but no concentration of this deformation in specific areas. Furthermore, we do not observe any privileged direction for the maximum principal deformation.

## 4. Discussion

The analysis of the deformation curves for the loads exerted on the skulls shows that the four skulls have similar behavior under the load: the deformation increases uniformly as the load increases. The skulls were subjected to loads of up to 5,000 newtons 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 in the percentage of bone deformation as a function of the increase in the load exerted. The maximum principal deformation observed increases up to 7% and the minimum principal deformation up to -3%, 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 stereocorrelation images obtained using VIC 3D® software did not show any specific field of deformation on the sagittal and coronal sutures compared with the bones concerned by the sutures. The deformation's random distribution demonstrates a dispersion of the load exerted alternately between compression and traction.

No difference was observed in the deformation on the sagittal suture and its periphery, even under heavy loads. This observation suggests that there is no observable mobility or relative displacement on the two bone margins of the sagittal suture detectable under the experimental conditions.
The suture may therefore not be a privileged mobility area but rather transmits the constraint at the origin of the deformation. This observation corroborates the results of Jaslow[15] which defined the suture as an area of energy absorption and force transmission that resists flexion. The results from Mao et al.[18] point in the same direction as, according to this team, the function of the sutures is to keep the various skull bones together while making the mechanical transmission of stress and deformation possible.
On the other hand, Herring et al.[13] and Byron et al.[3] described the suture morphology as a shock absorber that dissipates mechanical loads. The notion of shock absorber is in contradiction with our results. If the sutures had the capacity to absorb the shock from mechanical loads, a difference in the deformation on either side of the suture should have been observed.

The absence of mobility observed on the sagittal suture or a capacity for "opening" is contrary to the conclusions by Maloul et al.[17] who showed that cranial sutures remain partially open throughout life with varying degrees of connectivity ranging from 6.6% to 11.6% for the sagittal and coronal sutures. These results are more in line with

Rice[20] who disagreed with the results by Maloul et al.[17], reporting that fusion of the sutures can occur up until the seventh decade, after which they are destined to become completely fused.
To the best of our knowledge, no experimental studies have been carried out on humans seeking to ascertain suture mobility on the cranial vault.

The study by Crow et al.[6] revealed significant differences in the maximum and minimum measurements of vault parameters using MRI measurements on 20 human subjects, but no information on the behavior of the sutures was given. It is therefore difficult to compare our results closely with some of those found in the scientific literature.

On the other hand, a certain number of animal experiments that have assessed suture mobility:

-Downey et al.[7] observed a 0.30-mm separation of the coronal suture in rabbits when a 500-g traction force was applied on microplates attached to either side of the coronal suture.

-Adams et al.[1] also observed movement between 17 and 70 microns on the sagittal suture in anesthetized cats.

-Herniou[11] recorded some 20 to 25 microns in movement on coronal sutures in sheep.

It is obvious that it is hard to make comparisons as the morphological and mechanical characteristics are quite different between humans and animals.

An analysis was made of the maximum and minimum principal deformations while maintaining the same load for 30 seconds on the area where the stress was applied to verify the existence of a resistance time, where reorganization occurs and a spontaneous deformation appears differing from that observed previously.
One single plateau is observed on the deformation curve when the force exerted is constantly maintained. The results from Jasinoski[14] may explain this behavior. The collagen fibers may adapt their orientation to resist the load direction and this configuration may ensure optimal energy storage. 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.

This study has its limits, in that we worked with anatomy subjects whose average age was high (subject 1: ♂ 86 years, subject 2: ♀ 94 years, subject 3:♀ 72 years and subject 4: ♂ 102 years). Thus, according to Rice[20] their sutures should already be fused and the sutures' energy absorption qualities are related to their extracellular matrix and, according to Cohen[4], collagen fibers become increasingly irregular with age. A future study of younger subjects should be carried out to confirm our results. Furthermore, the Faculty of Medicine of Marseille forbids working on fresh cadavers due to the high risk of infection, meaning that only bodies embalmed with Winckler fluid can be used. Wieding et al.[23] experimentally assessed the influence of freezing and two commonly used preservative 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 mm 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 mm), 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 tried to provide answers to the controversial questions surrounding the existence of cranial suture mobility, and notably in the sagittal suture. The non-conclusive debate maintained in the literature on the age of suture closure has reinforced this issue.
We sought to observe sagittal suture deformations during loading similar to the therapeutic levels used in cranial techniques. We presumed that even under small loads there would be mobility on the sagittal suture.
The results of our experiments did not confirm this hypothesis. 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.

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