

Occipital bone thickness: Implications on occipital-cervical fusion. A cadaveric study



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ABSTRACT

Objective: The aim of this study was to create a map of the occipital bone using a cadaveric morphometric analysis.

Material: Twelve heads, from seven male and five female cadavers, were studied. The thickness of the occipital bone was measured with a digital vernier caliper within a coordinate system.

Results: The maximum thickness of the occipital bone could be measured at the external occipital protuberance (mean 15.4 mm; range 9–29.3 mm). All male individuals had higher bone thickness around this point. Further lateral a steady decrease of bone thickness could be observed. Same could be observed in craniocaudal direction. However, values above the superior nuchal line were on average thicker than below.

Conclusion: The measurements demonstrated a great individual variability of bone thickness of the occipital bone. The results emphasize the role of preoperative planning for the feasibility of placement of an occipital screw.

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Introduction

The occipito-cervical junction is the most cephal portion of the axial skeleton, connecting the cranium and the spine. It is a functional unit including the occiput, atlas and axis. The osseous complex allows significant mobility while maintaining biomechanical stability. However numerous conditions can affect the stability of the occipitocervical junction and may manifest as disabling pain, cranial nerve dysfunction, paralysis or even sudden death.^{1–3} The most common reason for acute presentation of instability is the result of trauma with dislocation of the atlantooccipital joint as well as a complex fracture of the atlas and axis. Other common pathological findings include rheumatoid arthritis, infection, tumors, and congenital malformation. In all mentioned conditions occipitocranial fusion is indicated when the craniocervical junction has proved as unstable.

In general, internal craniocervical fixation methods are the vital treatment of choice and can be divided in anterior, posterior and

combined anteroposterior approaches.^{3–5} All of them have to fulfill the biomechanical needs and the kinematics of the craniocervical junction. However, every technique presents a challenge to the attending surgeon. Due to the anatomic complexity of this area a thorough understanding of the bony elements and about the involved soft-tissue elements is essential. Especially when using rigid posterior fixation techniques with rods, screws and plates—a technique which provides superior biomechanical stability and higher fusion rates—knowledge about bone thickness at different occipital points is essential to avoid intracranial injuries.^{6,7} In this context previous investigations have performed cadaveric or CT based measurements of the occipital bone.^{8–11} The aim of the present cadaveric morphometric investigation was to create a complete map of the occipital bone to illustrate the position of greatest bone thickness for safe and effective internal fixation as well as to determine if significant variability exists concerning this matter.

Methods

Twelve cadaveric heads, seven male and five female, were harvested from fresh cadavers and dissected to the level of the cranial

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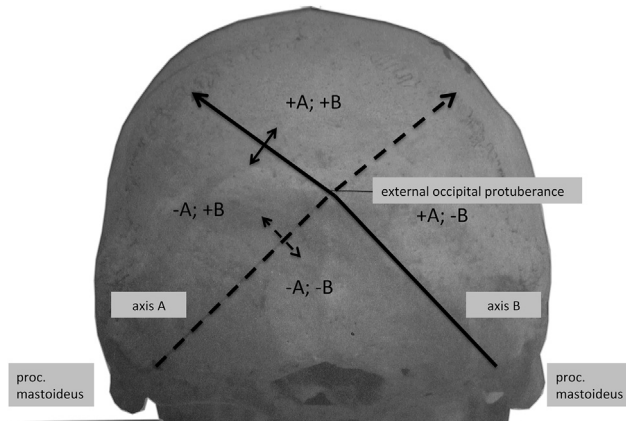


Fig. 1. Construction of a coordinate system of the occipital bone. The axis A and B defines four quadrant (+A; +B/-A; +B/-A; -B/+A; -B).

bone. Only heads without evidence of an occipital fracture, craniotomy or other abnormalities were used. Each head was freed of all soft tissue, leaving intact only the bony structures. Afterward the calotte was removed from the skull base through a horizontal cut.

To secure a unitary coordinate system for each head we define three benchmarks, which can be reliably determined: the right and left processus mastoideus and the external occipital protuberance. Using these landmarks the first axis (axis A) of the coordinate system was positioned between the left processus mastoideus and the external occipital protuberance. Axis B was positioned between the right processus mastoideus and the external occipital protuberance. From the external occipital protuberance both axis were scaled every 5 mm. Starting at every of these points we reconstructed to the perpendicular axis points every 5 mm. Following this procedure a coordinate systems results with defined points every 5 mm (Fig. 1). All points below the axis A and B were represented with negative sign, above with a positive sign (Fig. 1).

The thickness of the occipital bone was measured with a digital vernier caliper with an accuracy of $\pm 0,002$ mm (Digimatic, Mitutoyo, Japan). Due to the round surface of the occipital bone minor errors of this technique appear to be possible. However, previous investigations have demonstrated the accuracy of this technique.^{12,13}

Beside descriptive analysis, Box-plots were created to visualize the thickness of the bone at defined points. Analysis was carried out using SPSS package software (SPSS Inc, Chicago, IL, USA).

Results

The maximum thickness of the occipital bone could be measured at the external occipital protuberance located midline on the superior nuchal line with a mean value of 16.1 mm (SD 3,9). Individually a wide range could be measured with values between 9

and 29.3 mm. Gender differences were obvious, too. In woman the mean thickness was 15.3 mm (SD2.8) with a range of 9–20.3 mm, in men 17.0 mm (SD 4.9) with a range of 9.9–29.3 mm.

Along the axes a decrease of bone thickness could be observed. Table 1 presents the thickness for the quadrant on the right side. As demonstrated, distinct changes appeared within the first 2 cm descending from the protuberance externa. Same could be observed along the axes A starting from the protuberance in cranial direction (Fig. 2).

An overview of occipital bone thickness in the generated coordinate system is demonstrated in Fig. 3. The diameter of the circles corresponds with the thickness of the bone at a ratio of 1:2. The thinnest spot was located in an area within the cerebellar fossa between the foramen magnum and the inferior nuchal line. The thickness below the superior nuchal line ranged between 10,5 and 1,7 mm. In cranial direction the occipital thickness increased gradually to higher values at the superior nuchal line with a maximum at the protuberance externa. In a further cephalad direction thickness gradually diminished. However, values above the superior nuchal line were with a range of 11,6 to 4,3 mm on average thicker than below.

Discussion

Based on the present investigation we concluded in accordance with previous cadaveric and radiographic studies a great individual variability of bone thickness of the occipital bone. In cases were craniocervical fixation is indicated for instability of the craniocervical junction, like rheumatoid disease, tumor, or trauma, preoperative CT scans appear to be essential.

There are many different techniques of internal fixation in order to accommodate the increased spectrum of anatomical variations, to avoid certain adverse events like loss of spinal alignment and to achieve more rigid stabilization in a wider variety of spinal diseases.⁵ Within this context the Luque rod has to be mentioned where intracranial and sublaminar wiring is used.¹⁴

During the last years alternative procedures, which use rigid plates with screw fixation to the occiput and to the lateral mass of the cervical spine, have been developed.^{15,16} Biomechanical investigations of these different fixation techniques demonstrated comparable levels of stability within the craniocervical junction. Nevertheless the mentioned plate-screw construct provides better maintenance of stability under repetitive loading conditions.¹⁷ Especially fixation of the plate in the midline region of the occiput provides more rigid fixation than a plate fixed laterally.¹⁸

Regardless of the technique, understanding of the 3D anatomy of the cervical spine as well as of the occiput is necessary. Due to the anatomy, vertebral fixation is normally more problematical than occipital one. However, last mentioned should not be underestimated, due to the variability of occipital bone thickness. Inadvertent puncture of the underlying sinuses is one of the most serious complications within this technique. Thereby puncture of

Table 1
Overview of mean thickness (in mm) for the quadrant on the right side.

Axis B\A	0	5	10	15	20	25	30	35	40	45
0	12.3	10.9	9.3	7.2	6.0	4.9	4.4	4.2	4.2	4.7
-5	10.2	10.1	8.6	7.1	6.1	4.6	4.2	4.0	4.0	4.4
-10	9.0	7.9	7.2	7.0	6.1	5.0	4.5	4.0	4.0	4.0
-15	6.7	6.1	5.7	5.8	5.9	5.1	4.6	4.2	4.0	4.0
-20	4.7	4.8	4.8	4.8	5.2	4.9	4.7	4.6	4.2	3.7
-25	4.0	4.1	4.2	4.4	4.5	4.9	5.1	4.4	4.2	3.7
-30	3.1	3.6	3.9	3.9	4.3	4.8	4.9	4.5	4.2	3.7
-35	2.2	2.7	3.2	3.4	3.9	4.7	4.9	4.5	4.4	4.3
-45	1.7	2.0	2.9	3.1	3.7	4.3	4.9	5.0	4.7	4.9

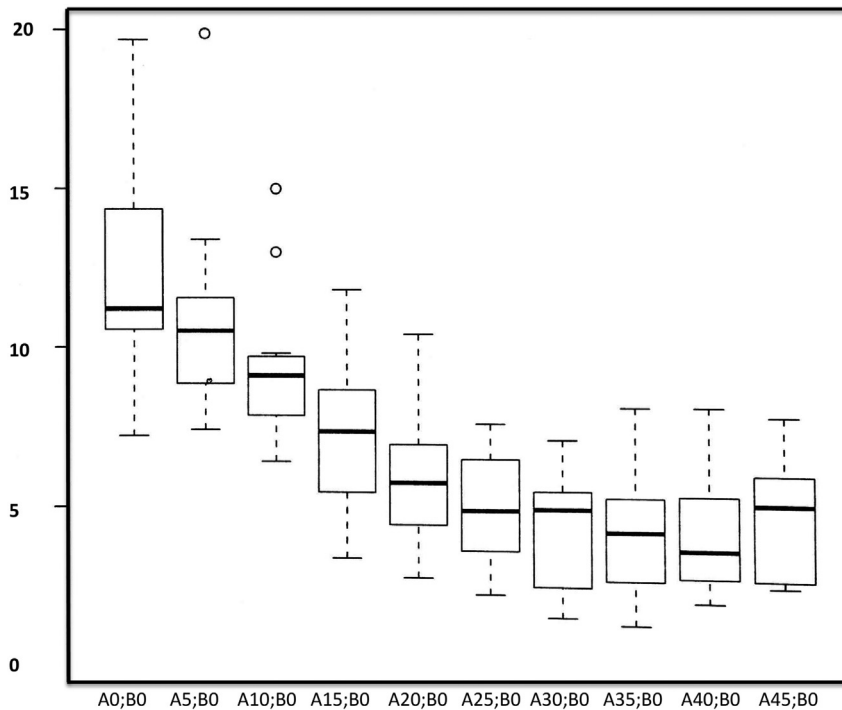


Fig. 2. Decrease of thickness beginning at the external occipital protuberance along the axis A (Ax; B0).

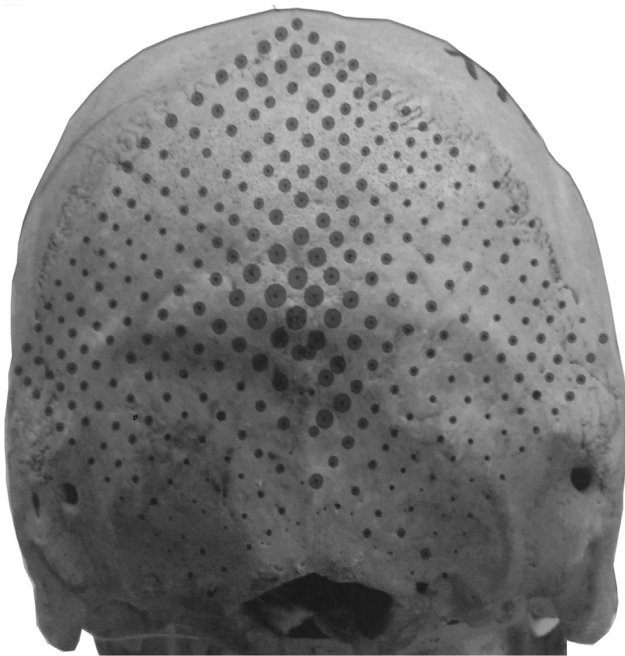


Fig. 3. Map of occipital bone thickness in the generated coordinate system. The diameter of the circles corresponds with the thickness of the bone.

the outer dural wall can cause significant blood loose; puncture of the inner dural wall lead to a fatal subdural hematoma.¹⁷

Despite these serious inadvertent events only a few investigations have evaluated the variability of the bone thickness to avoid them. Further, strength of the bicortical screw fixation is proportional to bone thickness.^{17,19} Therefore, information about thickness is essential to choose screws of maximal length to obtain the strength of the screw plate construct.

Therefore, the aim of the current study was to evaluate occipital bone morphologic characteristics and to determine the presence of any significant variability. Further positions of greatest bone thickness should be described to secure effective internal fixation.

Our measurements of bone distribution in the occiput show maximum thickness in the midline at the external occipital protuberance. The latter structure lies near midline on the superior nuchal line between the skull base and lambdoidal sutures apex. The results were comparable to previous investigations both in location as well as in approximate magnitude. In this context Heywood et al performed measurements of the occipital bone on twenty cadaveric skulls and evaluated about thickness at and below the external occipital protuberance. They concluded that the bone at the external occipital protuberance is thickest with a range from 11 mm to 17 mm-comparable to our results.²⁰ Origin of this range is based on inter-individual differences as well as on the angle from the horizontal skull base where measurements have been performed. Zipnick et al concluded in this context that the thickest occipital proportion is the connecting line between the external and internal occipital protuberance, which is consistently located midline on the superior nuchal line at a 43,4° angle from the horizontal skull base.²¹ Newer designs of occipital plates take this information in account.

Below the superior nuchal line thinnest spot were located in our investigation in an area within the cerebellar fossa between the foramen magnum and the inferior nuchal line. This information correlates well with the results of biomechanical investigations about pullout strength: in this area it was weakest. In contrast, strength of bicortical screw fixation was strongest above the superior nuchal line, an area where we have observed higher bone thickness in comparison to those below. Especially in this area information about thickness is relevant as risk of intracranial venous sinus penetration is high due to the complex anatomy. At or near the level of the superior nuchal line is the right and left transverse sulci, which contain the transverse venous sinus. Both transverse sinuses converge at or near the level of the external occipital protuberance

and form the confluence of sinuses. Ascending from here originates the superior sagittal sinus up to the middle of the occiput. Therefore, the sinuses form a T shape on the inner space of the occiput.²²

Based on the results of previous investigations and the present measurements occipital plates should be fixed near the level of the external occipital protuberance and above the superior nuchal line. Especially around the external occipital protuberance direction of the screws should be around 40° ascending from the horizontal skull base. Plate designs have to take this information in account.

However, we have observed a great individual variability of bone thickness of the occipital bone above and below the superior nuchal line.

Some of the anatomic variations mentioned in the present investigation can be derived to different age and gender of the individual.²³ In case of gender significant difference could be detected, whereby all male individuals had higher bone thickness compared with females. Considering the age of the investigated species data were not available so that interrelation missed.

We acknowledge several limitations of the present investigation. First, the sample size of twelve fresh frozen cadaveric heads is for certain low to give final evidence. However, interindividual differences could be addressed as well as general circumstances, confirming previous results. Second, the thickness of the occipital bone was measured with a digital vernier caliper. Due to the round surface of the occipital bone minor errors of this technique appear to be possible. However, previous investigations have demonstrated the accuracy of this technique. Therefore, we believe that this conceivable error becomes negligible.

Conclusion

In conclusion, great individual variability of bone thickness of the occipital bone has to be mentioned comparable to previous cadaveric and radiographic studies. Therefore, it seems essential to measure bone thickness for every case preoperatively using CT slices to avoid inadvertent events and to secure maximum strength.

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