The Morphological Grading and Comparison of Sutural Patency Among Cranial Sutures in Dry Human Skulls

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Objective: To investigate the degree of fusion (patency) among cranial sutures in human dry skulls in the Anatolia.

Methods: One-hundred fifty-eight human dry skulls that were accepted as adults according to the teeth eruption were macroscopically examined and photographed with Canon 400B (55 mm objective). The grades of fusion of coronal, sagittal, and lambdoid were quantitatively analyzed by using the modified grading scale. According to the extent of patency, the sutures were graded as grade-0 (open), grade-1 (fused but not obliterated), grade-2 (50%< obliterated), grade-3 (50% > obliterated), and grade-4 (100% obliterated). The authors determined and compared the rate for each grade of sutural patency on coronal, sagittal, and lambdoid sutures.

Results: The cranial sutures of 4 cranii (4/158; 2.53%) had grade-4 fusion, whereas there were no any cranii with sutures of grade-0 fusion. The number of each grade of fusion among cranial sutures of 158 skulls, in descending order, was as follows: 171 (grade-3), 145 (grade-1), 133 (grade-2), and 25 (grade-4). The grade-4 fusion was significantly less observed than the others. The grade-1 and grade-4 fusion of lambdoid sutures were established as the most (66/41.8%) and least (5/3.2%) common fusions among cranial sutures, respectively. The frequencies of each grade of fusion for each cranial suture were determined in a descending order: coronal (grade-3 > 2 > 1 > 4), sagittal (grade-3 > 2 > 1 > 4), and lambdoid sutures (grade-1 > 3 > 2 > 4). The frequency of grade-1 fusion of lambdoid suture (66/41.8%) was significantly different when compared with coronal (39/24.7%) and sagittal sutures (40/25.3%), respectively.

Conclusion: The grades of fusion (or sutural patency) vary among cranial sutures.

Key Words: Cranial suture, fusion of suture, sutural patency

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The cranial sutures, which approximate each other during development, are the fibrous tissues combining the skull bones.[1] These sutures are formed during the embryonic development at the contact lines between membranous bones of craniofacial skeleton.[1]

The cranial sutures are simple and straight in young humas.[2] Aging process leads cranial sutures to enormous change,[2–4] and then they become more complex and bring out interdigitations[2–7] through the growth and resorption process of cranial bones.[3,5] The genetic and environmental factors affect the morphology of the skull, and it is also supposed that function of muscles affects the bone shape and size.[7] Rafferty and Herring[8] assume that the growth pattern and morphology of craniofacial sutures reflect their functional environment.

The presence or lack of physical force on the bones of the skull may cause patency or obliteration of cranial sutures, respectively.[1,2,6,9–13] Before the skull completes its own growth, premature closure of the cranial sutures may cause prominent skull malformations (craniostenosis).[14] Craniosynostosis, the premature fusion of 1 ore more cranial sutures, is categorized as nonsyndromic in over 85% of the patients.[15]

The craniometric data are regularly used to characterize and compare human groups and estimate migration.[16–18] The craniometric variations within a certain human population may be determined qualitatively and quantitatively by genetic markers.[19,20]

The Anatolia has been exposed to many migrations along centuries. The effect of the migration on genetic characteristics of the Anatolian Population may create diversities in the suture morphology of the skulls. In the present study, we aim to investigate the degree of fusion (patency) among cranial sutures in human dry skulls in the Anatolia.

METHODS

We have examined 158 human dry skulls that were belonging to the Anatomy Department Laboratory of Dokuz Eylul University Medical School. The exact age and sex of the skulls were not known, whereas they were accepted as adults according to the teeth eruption. The deformed or fractured skulls were excluded from the study. They were evaluated macroscopically and were photographed with Canon 400B (55 mm objective). The official permission was obtained from Dokuz Eylul University Medical School for this study. The grades of cranial suture fusion (or sutural patency) of coronal, sagittal, and lambdoid were quantitatively analyzed by using the modified grading scale[21] (Table 1). Depending on the extent of fusion (or patency), the sutures were accepted as grade-0 (open), grade-1 (fused but not obliterated), grade-2 (50%< obliterated), grade-3 (50% > obliterated), and grade-4 (100% obliterated).

TABLE 1. The Modified Grading Scale Which Determines the Grade of Fusion (or Sutural Patency) of Each Cranial Suture[21]

Grade	Definition
0	Open, not fused
1	Fused but not obliterated
2	Less than 50% obliterated
3	More than 50% obliterated
4	100% obliterated

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TABLE 2. The Number and Percent of Skulls for Each Grade of Fusion (or Sutural Patency) of Each Cranial Suture

	Grade-1		Grade-2		Grade-3		Grade-4			
Name of Surtures	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**	**Total No of Skulls**	**Total No of Sutures**
Coronal	39	24.7*	52	32.9	58	36.7	9	5.7	158	158
Sagittal	40	25.3†	43	27.2	64	40.5	11	7.0	158	158
Lambdoid	66	41.8*,†	38	24.1	49	31.0	5	3.2	158	158
Total no (%) of cranial sutures for each grade of fusion	145	30.60‡	133	28.06	171	39.07	25	5.27‡	158	474

*$P = 0.008$.
†$P = 0.012$.
‡$P = 0.002$.

We determined and compared the frequency for each grade of fusion (or sutural patency) of coronal, sagittal, and lambdoid sutures. The SPSS-16.0 (SPSS Inc, Chicago, IL) program was used for statistical analysis; χ^2 and 2-tailed test were carried out on the data ($P < 0.05$ was considered significant).

RESULTS

The number and percent of skulls for each grade of fusion of each cranial suture are summarized in Table 2; furthermore, they were arranged in a descending order in Table 3. We observed 4 patients of the cranii (4/158; 2.53%) with completely closed (grade-4 fusion) cranial sutures, whereas as our study specimens were only composed of dry adult skulls (no infant skulls), there were no any cranii with completely open (grade-0 fusion) cranial sutures. The number of each grade of fusion among cranial sutures of 158 skulls, in descending order, was as follows: 171 (grade-3), 145 (grade-1), 133 (grade-2), and 25 (grade-4) (Table 2). We determined that the grade-4 fusion was significantly less observed than the others. The grade-1 and grade-4 fusions of lambdoid sutures were established as the most (66/41.8%) and least (5/3.2%) common fusions among cranial sutures, respectively (Table 2). The frequencies of each grade of fusion for each cranial suture were determined in a descending order as follows: coronal (grade-$3 > 2 > 1 > 4$), sagittal (grade-$3 > 2 > 1 > 4$), and lambdoid sutures (grade-$1 > 3 > 2 > 4$). The frequency of grade-1 fusion was significantly higher in lambdoid suture (66/41.8%) compared with coronal (39/24.7%) and sagittal sutures (40/25.3%), whereas there were no significant differences between grade-2, grade-3, and grade-4 fusion among cranial sutures. The representative images of different grades of cranial suture patency are shown in Figure 1.

DISCUSSION

The individual bones of the calvaria (roof and lateral walls of the neurocranium) are formed entirely by intramembranous ossification of head mesenchyme from the neural crest.[22]

The ossification centers in the fetal skull approximately appear 2nd and 3rd months of gestation.[23]

From mid to late gestation, fronts of the cranial bones approximate each other, and they either abut or overlap, and it results in the formation of the suture lines between the cranial bones.[1] It is supposed that the cranial sutures remain patent throughout the development process to allow the cranial vault to accommodate the expansion of the growing brain. After the cessation of growth, cranial bones fuse with each other, and the intervening cranial sutures are obliterated by calcified connective tissue (synostosis).[24] Besides, the intrinsic factors, extrinsic, or environmental factors (such as tensile forces, growing brain, and the effect of active muscles) are more likely to affect the features of cranial sutures.[1,2,6,9–13,25,26]

In some patients, the complete closure obscures any signs of the cranial suture. Patency or obliteration of sutures may be determined by the presence or lack of physical forces acting on the skull.[1,27]

There are more muscles to affect the occipital bone than the frontal and parietal bones. These muscles that affect the occipital bone are as follows: obliquus capitis superior, rectus capitis posterior major and minor, rectus capitis anterior and lateralis, semispinalis capitis, splenius capitis, longissimus capitis, occipitalis, and sternocleidomastoid.[28]

TABLE 3. The Number and Percent of Skulls for Each Grade of Fusion (or Sutural Patency) of Each Cranial Suture in Descending Order

Name of Cranial Sutures Including for Each Grade of Fusion	Grade of Fusion of the Cranial Sutures	No of Skulls for Each Grade of Fusion of Cranial Sutures in Descending Order	% (No of Skulls for Each Grade of Fusion of Cranial Sutures/Total No of Skulls)
Lambdoid	1	66	41.8*,†
Sagittal	3	64	40.5
Coronal	3	58	36.7
Coronal	2	52	32.9
Lambdoid	3	49	31.0
Sagittal	2	43	27.2
Sagittal	1	40	25.3†
Coronal	1	39	24.7*
Lambdoid	2	38	24.1
Sagittal	4	11	7.0
Coronal	4	9	5.7
Lambdoid	4	5	3.2

*$P = 0.008$.
†$P = 0.012$.

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FIGURE 1. The representative images of different grades of cranial suture patency. (A) Fused but not obliterated. (B) Fused and obliterated less than 50%. (C) Fused and obliterated more than 50%. (D) Obliterated 100%.

It was suggested that the closure of cranial sutures first took place in less serrated sutures and that there were not any differences in closure periods of the cranial sutures located left or right side of the skull and that the last vault suture that attained complete closure was the lambdoid suture.[29] It was stated that the closure of ectocranial sutures proceeds sequentially: sagittal, lambdoid, and then coronal.[29] In our study, the grade-1 fusion of the cranial sutures was established in an ascending order as follows: lamdoid (41.8%), sagittal (25.3%), and coronal (24.7%) sutures.

As compared with other sutures, Sabini and Elkowitz[21] said that a delay in the obliteration of the lambdoid suture, and the rate of the obliterated sutures were reported as lambdoid (0.27%), coronal (0.65%), and sagittal (3.9%) sutures. In the present study, we observed the rate of exact obliteration among cranial sutures in an ascending order as lambdoid (3.2%), coronal (5.7%), and sagittal (7.0%) sutures, and our results were compatible with their results. According to the classification of cranial sutural patency defined by Sabini and Elkowitz,[21] Murlimanju et al[24] also observed that the lambdoid suture was more likely to be patent, as compared with the other sutures. In other words, in our study, the rate of grade-1 (fused but not obliterated) fusion was also established significantly higher in lambdoid (66/41.8%) sutures than coronal (39/24.7%) and sagittal sutures (40/25.3%), whereas there were no significant differences between the rates of grade-2, grade-3, and grade-4 fusions among cranial sutures.

Compared with the lambdoid suture, the sagittal suture is exposed to less force, as it is affected by fewer muscular attachments (temporalis and occipitalis muscles); therefore, the sagittal suture shows a tendency of being more obliterated than lambdoid suture. In other words, the lambdoid suture remains more patent than the sagittal suture, as the muscles and ligaments that attach to the occipital bone and that confer mobility to the cervical spine can contribute to the lambdoid suture being under more physical pressure than the sagittal suture.[21]

In a recent study, Khandare et al[30] studied cranial sutures on postmortem patients referred to Government Hospital (Mumbai) and determined that the sagittal, coronal, and lambdoid sutures begin to fuse in between 25 and 30 years and almost completely close at the 61 to 65, 56 to 60, and 66 to 70 years of age, respectively. They also reported that cranial suture closure was observed earlier in males than in females. We examined 158 human dry skulls accepted as adults according to the teeth eruption, whereas we did not know the exact age and the sex of the skulls; therefore, it might be the reason that the percentages of grade-3 and 4 fusion of sagittal sutures were observed more than coronal.

Harth et al[31] examined 221 calvaria (148 men and 73 women) aged between 0.3 and 100.0 years that were gathered from autopsies at the Department of Legal Medicine at the University Hospital of Gießen and Marburg (Germany) during 2007/2008. To be able to estimate chronological age of the specimens accurately, the skullcaps of 221 calvaria have been scanned with the flat-panel computed tomography (CT) eXplore Locus Ultra System. Based on the division of cranial sutures by Oppenheim,[32,33] they partitioned the cranial sutures into 16 segments. They also determined the degree of suture closure of each segment according to Broca classification of the degree of suture obliteration as follows: stage 0—totally open 0%, stage 1—open, beginning closure $<10\%$, stage 2—moderate closure 10% to 33%, stage 3—evident closure 34% to 66%, stage 4—considerable closure 67% to 90%, stage 5—closed, relics of the ossification process visible $>90\%$, stage 6—total closure 100%.[32,34] They found that only 1 (%2.7) individual, 42.7-year-old man, youngest among patients including stage 6, had stage 6 in all segments and 5 female infants, and a 38.2-year-old woman had stage 0 in all the segments.[31] In the present study, we observed 4 patients of the skulls (4/158; 2.53%) having completely closed cranial sutures, whereas as our study population did not include infant skulls (only adult dry skulls), there were no skulls having completely open cranial sutures.

The cranial sutures have the ability to accommodate the forces being exposed to them; it has been demonstrated that the rat skulls show no sign of obliteration whether the mechanical stress are applied on them.[26] Moss[12] observed that whether the cranial sutures of rats were transplanted to different suture locations, they adapted to meet the demands of the new location. Washburn[13] showed that surgical removal of the temporal muscle in rats results in not only decreased growth, but also decreased development (simpler structure) of the sutures located in this region.

Premature closure of single (simple form) or multiple cranial sutures (complex form), called craniosynostosis, is identified as a wide and heterogeneous group of entities and nonsyndromic in over 85% of the patients.[15,35,36] Bilateral lambdoid and sagittal synostosis results in a characteristic skull shape (frontal bossing, turribrachycephaly, biparietal narrowing, occipital concavity, inferior displacement of the ears); however, patients with bilateral lambdoid and sagittal synostosis indicate an improved overall neurological outcome and generally normal growth.[37] Premature closure of single suture (simple form) represents over 70% of all patients of craniosynostosis CRS, and simple forms are classified both according to involved suture and corresponding abnormal skull shape: scaphocephaly (sagittal suture), trigonocephaly (metopic suture), anterior plagiocephaly (unilateral coronal suture), posterior plagiocephaly (unilateral lambdoid suture).[38] Although a positive family history may be found in about 2% of the patients for scaphecephaly and up to 10% of both coronal and metopic craniosynostosis, all the patients of nonsyndromic craniosynostosis (NSCs) are determined sporadically.[39–43]

The lambdoid synostosis is observed extremely rare (accounting for about 3% of NSC patients) and is hardly defined.[40] Although up to 30% of complex and syndromic craniosynostosis may have a genetic basis, NSCs often has no obvious etiological explanation.[44] The NSCs is considered a multifactorial disorder that has a strong genetic component interacting with epigenetic and environmental factors during intrauterine life.[40] It is most frequently observed in sagittal suture ($>50\%$) with a prevalence of 1.9 to 2.3/10,000 live births and a male/female ratio of 2.5/1.[36,39,40] Three-dimensional cranial bone models reconstructed from CT scan images are used to explore craniosynostosis, skull variants, and skull dysmorphy.[45–48] Moore et al[49] alternatively termed the association of bilateral lambdoid and posterior sagittal synostosis as "Mercedes Benz"

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syndrome due to its characteristic appearance of fused sutures on three-dimensional CT imaging.

In conclusion, we claim that there may be many factors that affect the grade of patency of cranial sutures, and to determine these factors further studies are needed to be designed.

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