Lambdoid synostosis

Part 1: The lambdoid suture: normal development and pathology of “synostosis”

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The microscopic development of the normal lambdoid suture was studied in autopsy specimens from 19
normal subjects ranging in age from 20 weeks' gestation to 60 years. The cellular activity at the suture varied
considerably with age; however, maximal activity was seen in specimens approximately 3 months of age. There
were several unusual features, including a high incidence of cartilaginous differentiation and the presence of
intr sutural Wormian bones. Forty-one specimens from 37 patients with isolated lambdoid synostosis were
also studied pathologically. Only three cases showed bone union across the suture, which appears to be a result
of closure rather than fusion as in other synostoses. The remainder of the cases showed varying degrees of
increased cellular proliferation at the suture line, resulting in exaggerated and prolonged sutural activity.
Morphologically, this produced increased interdigitation and fibrous adhesion between the suture margins.

KEY WORDS □9 craniosynostosis □9 lambdoid suture □9 pathology □9 skull growth □9
synostosis

ALTHOUGH the role of the cranial sutures in normal calvarial growth10,14,17,20-22 and in experimen-
tal and clinical craniosynostosis2,5,12,13,16,19 has been widely studied, little attention has been paid
to suture pathology. This is in part due to a lack of pathological material because of the often fragmented
results of suture removal, and in part because careful autopsy studies in patients with isolated synostoses
are rare. Recently, lambdoid synostosis has been recognized as a distinct clinical entity.15 The only previous report
of lambdoid suture pathology in isolated lambdoid synostosis is a brief description of one case by David,
et al.,3 in which a suture that appeared sclerotic on roentgenography showed unusually active bone growth
with cartilage formation and endochondral ossification on histological study. Synostosis of the lambdoid suture
as part of a syndrome or in association with other synostoses has been more widely reported, but in such
cases the pathology is similar to that seen in other fused sutures.9

Recognition and early surgery of lambdoid synostosis at our institution provided us with considerable patho-
logical material for study. It was also necessary to investigate normal lambdoid sutures in age-matched
control subjects because of the subtle and often quantitative nature of the pathological lesion found. Normal
microscopic development of the lambdoid suture has been described previously,22 but not in sufficient detail
at various ages to provide adequate control data for this study. Therefore, we studied microscopic development
of the normal lambdoid suture to establish a comparable control population.

Materials and Methods

Normal Lambdoid Suture Development

The normal development of the lambdoid suture was studied in an autopsy population of 19 patients varying
in age from 20 weeks' gestation to 60 years. None of the patients had obvious abnormalities of cranial size
or shape and all died of causes unrelated to the central nervous system. Specimens of various sizes were re-
sected from the midportion of the left lambdoid suture at autopsy. After photography and, in some cases, roent-
genography, the resected sutures were fixed in 10%
buffered formalin, decalcified, and embedded in paraffin. Tissue sections 5-μm thick prepared from this material were stained with hematoxylin and eosin (H & E). In eight cases ranging in age from birth to 9 months old, a portion of fresh suture was frozen and then stained histochemically for alkaline phosphatase analysis.

**Synostosis Sutures**

The clinical profile of the patients from whom the sutures were removed has been reported.15 Forty-one sutures from 37 patients were received over the years 1968 through 1983, including bilateral sutures from four patients.

The size of the specimens varied considerably ranging from 1.5 x 1 cm to 8 x 5 cm. The method of examination was also variable. Specimen roentgenograms were obtained in four cases. The number of blocks submitted for tissue section varied from one to six, but in all cases sections were taken from the region believed to be most involved and stained with H & E. In addition, frozen sections were cut from the two specimens that were received fresh, and examined histochemically for the presence of alkaline phosphatase.

**Suture Thickness Index**

The thickness of the soft tissues at the suture relative to the thickness of the adjacent bone was taken as an indicator of suture activity. Suture thickness was measured as a vertical distance through the soft tissue of the suture between the periosteum and dura. The value was expressed in a ratio with the suture thickness as the numerator and the average bone thickness of the adjacent parietal and occipital bones 0.5 to 1 cm from the suture as the denominator.

**Results**

**Normal Suture Development**

**Microscopic Studies.** Normal development of the midportion of the lambdoid suture was followed grossly and microscopically from 20 weeks’ gestation to 60 years of age.

At 20 weeks’ gestation (Fig. 1A), the parietal and occipital bones adjacent to the suture had a horizontal arrangement of islands of woven bone lined by osteoblasts. The islands were separated by widely dilated capillary channels and loose connective tissue was incorporated into the islands of bone in the formation of inner and outer tables. The suture region itself was narrow and had a loose poorly cellular uniting layer. It contained transversely oriented collagen and was bound on either side by periosteum and dura.

All the other sutures, which were postnatal, had a five-layered structure as described by Pritchard, et al.,21 with two cambian and capsular layers and one uniting layer. By the time of birth (Fig. 1C), the bone islands had fused on either side of the suture and, although most of the bone was woven, some lamellar bone was also formed. The suture itself had widened and was developing the five-layered structure. At the edge of the suture, the bone tips were pointed and lined by a low-cellularity cambian layer containing occasional osteoblasts. The overlying capsular layer was incomplete. The uniting layer was of low cellularity and vascularity, and continued to have transversely oriented collagen. Alkaline phosphatase activity was localized to a subperiosteal, subdural, and sutural rim; however, there was no accentuation at the suture line.

At 2 months of age, the bone adjacent to the suture formed a broad front of new bone. The cambian layer was made up of rows of osteoblasts with focal cartilaginous differentiation. The capsular layer was well formed and appeared to arise from the periosteum. It was occasionally interrupted in the subperiosteal region by Sharpey’s fibers. The uniting layer was more cellular than in the earlier samples. Adjacent to this region of new bone formation, the actively remodeling bone islands were identified, separated by capillaries and loose connective tissue. They merged with the now well-organized lamellar bone of the parietal and occipital bones, which had capillary-filled marrow spaces and haversian systems.

By 3 months of age (Fig. 1E), the active front of new bone formation adjacent to the suture was wider, resulting in a hump on the inner (dural) side of the suture. The bone front consisted of one or more tongues of bone on each side, which overlapped and showed early interdigitation. They were capped by a very active cambian layer containing a layer of cartilage. The well-formed capsular layer was often interrupted by Sharpey’s fibers, particularly arising from the bone front opposite a protruding tongue of bone. The uniting layer was now more cellular and contained dilated vascular channels, often circumferentially surrounded by collagen. Alkaline phosphatase activity was localized to an intense broad band at the suture line and in the juxta-sutural periosteum. Much less activity was apparent away from the suture.

By 6 months of age, the wide bone front adjacent to the suture was much less apparent and the hump on the dural surface was no longer seen. The bone front continued to show protruding tongues of woven bone; however, the cambian layer was less cellular and no longer capped by cartilage. The capsular layer showed frequent penetration by Sharpey’s fibers. The uniting layer was moderately cellular and contained central blood vessels surrounded by collagen. The woven bone adjacent to the suture rapidly merged with mature bone that had large marrow spaces filled with hematopoietic cells. Alkaline phosphatase activity was preserved in a similar distribution to that seen at 3 months but was much less intense at the suture margin.

By 9 months, the suture had narrowed further. The woven bone adjacent to the suture showed less active remodeling and was being rapidly transformed into more mature bone. The cambian layer was thin with only occasional osteoblasts. The capsular layer was...
again penetrated by Sharpey’s fibers, which extended to a uniting layer of low cellularity.

At 1 year, the even narrower suture was lined by woven bone, which only formed a cap on the more mature bone. Osteoblastic activity in the cambian layer was minimal and the capsular and uniting layers were unchanged. The woven bone had virtually disappeared by 2 years of age, and after this period the cambian layer was no longer apparent. The capsular layer was still well defined but Sharpey’s fibers were no longer present. The uniting layer was less cellular and contained collapsed vascular spaces close to the periosteum. By 20 years of age, there was partial bone union across the suture, while by 60 years, the bone union was complete and the site of the suture was identified by a dimple on the dural side and a vertical orientation of fibrosed marrow spaces at the same site (Fig. 2A).

**Suture Thickness Index.** The suture thickness index (Fig. 3) was 1 at birth, with a maximum of 1.6 to 2.0 at about 3 months of age. The index then decreased to 1 at 2 years and eventually to less than 1 at 20 years.

**Roentgenography.** Roentgenograms of the specimens were obtained in seven cases. At 20 weeks’ gestation (Fig. 1B), the entire suture appeared uniform with a smooth-edged contour. By the time of birth (Fig. 1D), the suture had widened and had a finely serrated margin. Multiple intrasutural ossicles were present. At 3 months of age (Fig. 1F), the suture had narrowed considerably, and there was prominent interdigitation of the serrations. In several areas, the serrations overlapped. By 18 months (Fig. 1H), there was considerable overlap, and the contour of the inner table was much less serrated than that of the outer table. At 20 years, the suture was replaced by a sinusoidal sclerotic band with a thin lucent center. By 60 years, the site of the suture was only slightly sclerotic, and a thin lucent suture line was only focally apparent.

**Synostosis Patients**

**Histology.** Forty-one sutures from 37 patients were examined (in four patients both sutures were examined). In only three cases was bone union across the suture seen; in two, it was across the entire suture front, while in the other it was only focal. Where this union occurred, the site of the suture could be identified by a focal vertical orientation of marrow spaces showing focal fibrosis (Fig. 2B). In all three cases, a double hump of bone was identified on the side of the skull at the site of the previous suture, which was not seen in any other sutures examined.

The remaining 38 sutures all showed the following features but in varying degrees. The soft tissue was increased in thickness at the suture line, resulting in a hump on the dural side (Fig. 2C). Microscopically, the sutures appeared similar to normal sutures at a similar age except their activity was more pronounced and there was more prominent interdigitation of the bone processes (Fig. 2D). These sutures were characterized by increased activity and cellularity of the cambian layer (Fig. 2F and G), which also contained areas of cartilagenous differentiation in 21 cases.

In most cases, the cartilage was focal and lined protruding tongues of bone, but in several examples it formed a broad band along the suture front. The well defined capsular layer was interrupted by increased numbers of Sharpey’s fibers (Fig. 2H). The uniting layer was similar to that in age-matched controls, except the cellularity appeared to be slightly increased. Vascularity appeared unchanged. The adjacent bone was similar to that of normal controls except marrow spaces tended to be more vertically oriented as they approached the thickened soft tissue of the suture.

**Suture Thickness Index.** The suture thickness index (Fig. 3) was greater than that of the controls in all cases in which no bone union was seen. This correlates with the increased hump at the suture line identified grossly.

**Roentgenography.** Roentgenograms were obtained in four cases. They showed focal sclerosis along the suture line and more prominent interdigitation than in control specimens (Fig. 2E).

**Discussion**

The sutures of the cranial vault primarily provide a firm yet flexible mechanical union between skull bones, and a site for bone growth.

Recent experimental evidence has suggested that they may also partially moderate the effects of external forces, such as the increasing neural mass, and thereby modify the rate of separation of adjacent bones.

The origin of the sutures has generated considerable controversy over the years. Moss, et al., stated that all of the morphological attributes of the cranial bones and their sutures are extrinsically determined and regulated. Markens and Oudhof, however, believed that a genetically controlled blastema precedes the formation of a suture and results in the tissue from which it develops. Recently, Oudhof suggested that sutural structures are determined by heredity but that environmental factors are required for these qualities to manifest themselves.

The normal microscopic anatomy of the cranial sutures has been the subject of a number of investigations. The most complete of these was published by Pritchard, et al., who examined serial sections through the heads of six species in various stages of development. They described the presently accepted five-layer model of a cranial suture and divided suture maturation into five broad stages but did not differentiate between sutures and provided only limited detail about the development of the suture at each stage.

One of the earliest studies of skull growth, by Sitzen, provided the only comprehensive study of normal lambdoid suture development. He examined development of the lambdoid suture from 8 months’ gestation to 12 years of age. His description of suture develop-
FIG. 2. Normal (A) and abnormal (B to H) lambdoid sutures. A: Photomicrograph of a normal lambdoid suture at 60 years of age showing a dimple at the site of the previous suture and focal vertical orientation of marrow spaces. H & E, × 5. B: Suture at age 4½ months showing complete bone union with a double hump (arrows) at the site of the previous suture. H & E, × 10. C: Suture at age 4 months showing increased thickness of bone and soft tissue at the suture producing a hump on the dural (lower) side. H & E, × 9. D to H: Suture at age 6 months. D: Very prominent bone and fibrous interdigitations. H & E, × 11. E: Roentgenogram with focal sclerosis at the suture and increased interdigitations. × 4.5. F: Photomicrograph showing prominent activity of the cambian layer with cartilaginous differentiation. H & E, × 64. G: Photomicrograph showing a widened cambian layer with cells aligned along parallel fibrous processes. H & E, × 64. H: Uniting layer showing prominent interdigitations of opposing Sharpey's fibers (arrows). H & E, × 64.
Sutures without bone union showed accentuated but normal histology for the subject's age with increased interdigitation of the suture edges, increased proliferative activity of the cambian layer, and increased Sharpey's fiber formation. These changes were associated with an increased suture thickness ratio. Cartilage was present in the cambian layer in half of the cases ranging in age from 4 to 13½ months. Its presence in many of the older cases but in none of the control specimens over 6 months old suggests that factors such as increased tension, ischemia, or anoxia may play a role in the increased proliferative activity. Roentgenograms showed increased interdigitation and sclerosis along the suture margin. Interdigitation is thought to play a role in transmission of tensile forces and so its widespread presence suggests that the suture is under increased tension.

Although the exact etiology of lambdoid synostosis cannot be determined from this study, several important conclusions can be drawn. This is not a synostosis reporting primarily on sagittal and coronal sutures, have been consistent in observations but variable in interpretation. Grossly, fused sutures of the cranial vault demonstrate either a broad ridge of overgrowth of solid bone along the previous suture or complete obliteration of the suture indistinguishable from the surrounding bone. The external ridge of bone is characteristic of the fused sagittal suture, but may also be seen in the coronal suture. Microscopically, localized areas of complete bone fusion with obliteration of the previously present suture are seen. The primary site of fusion is often focal.

David, et al., stated that histologically premature synostosis and physiological obliteration are the same process. Albright and Byrd, however, believed that since the suture is completely obliterated the histology of the fusion is abnormal and does not simply reflect early closure of a normal suture. Latham, et al., also suggested that synostotic sutures may be histologically abnormal, and concluded that defective collagen remodeling or periosteal metaplasia resulting in localized sutural replacement by cartilage may be occurring. The only report of an isolated lambdoid synostosis describes active osteoblastic growth including possibly a nodule of cartilage, which the authors believed could represent the earliest stage of active sutural fusion.

Our examination of 41 isolated lambdoid synostosis sutures revealed that bone union was an unusual feature, occurring in less than 10% of the specimens. The bone union that did occur was different from that described in other synostoses in that remnants of the suture could still be identified. The sutures were similar in appearance to that of the 60-year-old control specimen except the bone was not as thick. Also, in the synostosis cases the dimple similar to the one found on the dural side of the suture in the 60-year-old specimen was more pronounced, resulting in a double hump appearance. Therefore, bone union appears to be closer to premature closure than to fusion.

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as seen with coronal or sagittal sutures, but an exaggeration and prolongation of the normal state. Bone union of lambdoid synostosis sutures is an unusual event, but when it occurs there is closure rather than fusion. The presence of a normal but hyperactive suture suggests that a blastemic defect is not present. The finding of increased sutural activity including cartilage, however, suggests that localized increased tensile forces or tissue anoxia may play a role in its pathogenesis. These factors are not believed to arise from primary cranial base abnormalities, but may be secondary to positional abnormalities, but may be secondary to positional

Fetal head restraint has been proposed as a cause of isolated nonsyndromic craniosynostosis. Experimental studies in rabbits have shown that mechanical immobilization of a suture alone does not induce fusion, however, cellular activity at the suture fronts in these studies was not specifically examined. Another interesting possibility is a localized metabolic abnormality. Experimental studies on rats fed with calcium- and vitamin D-deficient diets have shown an increased thickness of osteoid at the intranasal suture, as well as increased alkaline phosphatase activity and decreased collagen synthesis. The role of such factors in lambdoid synostosis is unknown.

The effect of increased sutural activity seems at first paradoxical, since the suture acts as if it is fused. This may be related to increased sutural adhesion due to more numerous interdigitations and Sharpey's fibers resulting in an increased modulation effect of the suture on bone separation.

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References


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