# Efficient Symbolic Signatures for Classifying Craniosynostosis Skull Deformities

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**Abstract.** Craniosynostosis is a serious and common pediatric disease caused by the premature fusion of the sutures of the skull. Early fusion results in severe deformities in skull shape due to the restriction of bone growth perpendicular to the fused suture and compensatory growth in unfused skull plates. Calvarial (skull) abnormalities are frequently associated with severe impaired central nervous system functions due to brain abnormalities, increased intra-cranial pressure and abnormal build-up of cerebrospinal fluid. In this work, we develop a novel approach to efficiently classify skull deformities caused by metopic and sagittal synostoses using our newly introduced symbolic shape descriptors. We demonstrate the efficacy of our methodology in a series of large-scale classification experiments that compare the performance of our symbolic-signature-based approach to those of traditional numeric descriptors that are frequently used in clinical research. We also demonstrate an application of our symbolic descriptors in shape-based retrieval of skull morphologies.

## 1 Introduction

Craniosynostosis, the premature fusion of the fibrous skull joints or sutures, is a common condition of childhood, affecting 1 in 2500 individuals. As an infant's brain grows, open sutures allow the skull to develop normally. The early closure of one or more sutures results in abnormal head shapes due to the restriction of osseous growth perpendicular to the closed sutures and compensative growth of unaffected calvarial plates. Sagittal synostosis is the most common form of isolated suture synostosis with an incidence of approximately 1 in 5000 [8]. Early closure of the sagittal suture results in scaphocephaly, denoting a long narrow skull often associated with prominent ridges along the prematurely ossified sagittal suture (Fig. 1b). Metopic synostosis is less common than sagittal synostosis, affecting 1 in 15,000 individuals [8]. The premature fusion of the metopic suture produces trigonocephaly, denoting a triangular shaped head (Fig. 1c).

The diagnosis of craniosynostosis is typically made on the basis of clinical judgments, with CT imaging to confirm the clinician's impression. Although quantitative measures of head shape are not often used for clinical diagnosis,

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research has been conducted to compare the timing [12] and outcomes of serious surgical procedures that involve the complete reconstruction of the skull (Fig. 1b and c), sometimes in combination with cranial molding techniques [4] [5] [12].

Recent advances in multi-detector computed tomography (CT) technology enable unprecedented accuracy in the detection of fused skull sutures. However, image interpretation remains largely confined to subjective description. Most imaging studies in patients with craniosynostosis emphasize qualitative shape features and relegate quantitative assessments to the measurement of a ratio or an angle between anthropometric landmarks, therefore disregarding the broad range of shape variations that are of fundamental interest in understanding the pathogenesis and clinical course of affected patients.

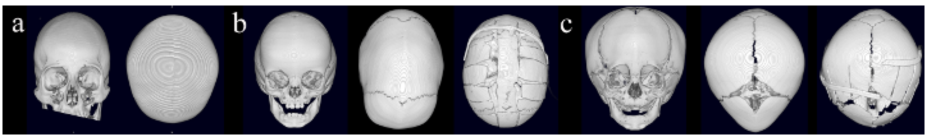


**Fig. 1.** Frontal and top views of a) a normal skull, b) a patient affected with sagittal synotosis, and c) a patient affected with metopic synostosis. Post-surgical reconstructions are also shown.

Attempts to classify craniosynostosis malformations by combining morphometric techniques [2][9] and likelihood-based or dissimilarity-based classification methods have been published in [9], with high cross-validation error rates (32-40% average for sagittal synostosis and 18-27% average for metopic synostosis), likely due to the limited sampling of skull anatomy. More recently, alternative numeric shape descriptors have been proposed to predict sagittal synostosis with high true positive (TP) and true negative (TN) classification rates [15] [16] [17].

In this paper, we develop a novel methodology to accurately and efficiently predict sagittal and metopic synostosis diagnosis using off-the-shelf support vector machines and our newly introduced *symbolic shape descriptors* [10]. Our approach utilizes a *folding* technique proposed in [7] to significantly reduce the computational complexity at classification time as compared to that of the algorithm described in [10]. Furthermore, we utilize bootstrap [3] and cross-validation techniques for model selection [19] to show that our efficient algorithm does not compromise classification accuracy, and outperforms numeric descriptors that are traditionally used in clinical settings. Finally, we suggest that our proposed technique to quantify synostotic phenotypes will be important for future studies to determine correlations with surgical planning, long term outcome measurements, deficits in neurocognition and potential genetic and environmental causes.

The task we want to approach can be formally described as follows. We are given a random sample of $M$ skull shapes labeled as sagittal (1), metopic (2) and normal (3), respectively. Using the skull shape information, we wish to construct a set of symbolic shape descriptors and a classification function in order to accurately and efficiently predict the label of a new skull shape.