Fractal analysis of cranial suture during growth

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頭蓋冠の縫合におけるフラクタル解析

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抄録

成長発育期の患者を治療する上で，頭蓋顎顔面の発育を捉えることは重要である。頭蓋顎顔面の成長発育は，様々な手法により解析されてきた。頭蓋骨の骨形成様式は膜内骨形成で，前頭骨，側頭骨，後頭骨および頭頂間骨からなる。各部は，結合組織性に縫合部によって連結される。頭蓋の成長は，縫合部での成長が大きく関与すると考えられ様々な手法により解析されてきたが，頭蓋の縫合部を定量的に評価した報告はない。そこで本研究は，乾燥頭蓋を用いて縫合部をフラクタル解析にて数値化し，Dental Age と比較検討し頭蓋の縫合性成長を明らかにすることを目的とした。

奥羽大学生体構造学講座所蔵のインド人乾燥頭蓋 80 顆 (Hellman の歯年齢ⅡA，ⅢA，ⅢB およびⅣA 各 20 顆）を用いた。資料をフランクフルト平面が床と平行になるように固定し，上方より頭蓋冠全体をデジタルカメラにて撮影した。撮影に際して，頭蓋冠の最高点と同一の高さに定規を設置して距離計測の基準とした。得られた画像データ上で左右冠状縫合および矢状縫合の前後に関心領域を設定した。関心領域の画像を Image J にて，フラクタルの計測を Box-counting 法により D 値を算出し，各 Dental Age との関連性について統計学的検討を行った。

結果，縫合の複雑性を表すフラクタル次元 (D) は，成長に伴い増加しており，頭蓋冠の発育における部位差はそれぞれの縫合での D 値の変化に影響を与えて

いることが考えられた。したがって，頭蓋冠のフラクタル解析による縫合部の定量的評価により，成長発育を評価できる可能性が示唆された。

Abstract

It is important to understand the manner of craniofacial growth when treating a patient in the growth period. Cranial sutures have been investigated with a variety of methods, with fractal dimensions used to elucidate the complexity of the suture. However, the relationship between fractal dimension and dentition during growth has not been investigated. In the present study, we analyzed the fractal dimensions of calvarial sutures with different types of Hellman's dentition.

We examined 80 skulls obtained from India in this study, which were divided into 4 groups based on Hellman's dentition (IIA, IIIA, IIIB, IVA). The FH plane of each specimen was set parallel to the horizontal plane, then imaging was performed from the upper part using a digital camera. Following binarization, the fractal dimensions were calculated. The region of interests were set in the left and right sides of the coronal suture, and anterior and posterior regions of the sagittal suture.

The fractal dimensions increased according to the advance of dentition. Each side of the coronal suture and anterior region of the sagittal suture were significantly increased in stage IVA. In the posterior region of the sagittal suture, the fractal dimension began to increase from stage IIA.

Our results showed that advances in the calvaria fractal dimensions occurred according to the increase in dentition in all regions.

Key words : Fractal analysis, Cranial suture, Craniofacial growth

Introduction

Cranial sutures have been investigated with a variety of methods. For anthropological studies, a scoring system is used to evaluate suture obliteration[1), though it seems to be rather subjective. In biomechanical examinations, it is assumed that a suture with high interdigitation is more resistant to bending[2)]. Construction of a mathematical model for pattern forming in cranial sutures has also been attempted[3)].

To quantify the degree of interdigitation in cranial sutures, fractal dimension (FDs) have been used in many studies[4-10)], with fractal analysis performed to quantify suture complexity in cranial regions. A straight line has a fractal dimension of 1 and a solid plane a fractal dimension of 2 [4]. Fractal analysis of 31 complete skulls was performed to determine whether suture FD measurements are related to age, though no correlation was found[5]. However, no known previous studies have investigated the relationship between dentition and suture FDs in the cranium. In the present study, we determined the FDs of sutures in the cranium of specimens classified according to Hellman's dental age to determine whether FD increase occurs in accordance with dentition growth.

Materials and methods

We examined 80 skulls from India in the possession of the Division of Oral Anatomy, Ohu University School of Dentistry. None of the skulls had missing teeth, deformation, or dental caries. There were categorized into 4 groups of 20 skulls each based on Hellman's dental stage IIA, IIIA, IIIB, and IVA.

For the examinations, each skull were set according to the FH plane, including the upper margin of each side of the external auditory meatus (po) and left lower margin of the orbitale (or). The FH plane was set parallel to the floor. The ruler was set at the point of the highest position of the skull as a reference for length. All images of the skulls were obtained by use of a digital camera (EOS 7D Mark II, Canon, Japan). Regions of interest (ROIs) were set on each side of the coronal suture, while those for sagittal suture were set on anterior and posterior positions.

On each side of the coronal suture a reference line were placed from the coronale, the lateral margin of the coronal suture in the skull to a point on the coronal suture 1 cm from the bregma, the node point of the cranial suture. The center of the ROIs on the left (Fig. 1A) and right (Fig. 1B) sides of the coronal suture were set at points in a medial one-third position. On the sagittal sutures from a point 1 cm from the bregma to the opisthocranion, the posterior margin of the skull was divided into 3 parts. The center of the ROIs in the anterior (Fig. 1C) and posterior (Fig. 1D) regions were set at points in the anterior and posterior one-third positions, respectively. The ROIs were rectangles set at 15×20 mm, parallel to the long axis of the suture. All images of the

ROIs were binarized and FDs were measured using a box-counting method with Image J (US National Institutes of Health, http://rsb.info.nih.gov/nih-image).

For statistical analysis, comparisons between groups were performed using Mann-Whitney's U-test.

Results

On the left side of the coronal suture (Fig. A), the FD was 1.125 in Hellman dental stage IIA and then increased to 1.316 in stage IVA. Similarly, on the right side of the coronal suture (B), the FD was 1.133 in stage IIA and increased to 1.317 in stage IVA. In the coronal suture, the FD was increased significantly from IIIA to IIIB on the left side and from IIIB on the right.

As for the sagittal suture, the FD increased from 1.211 in stage IIA to 1.344 in stage IVA in the anterior region (Fig. 1C) and from 1.313 to 1.475 in the posterior region (Fig. 1D). In the sagittal suture, the FD in the anterior region significantly increased from stage IIIB, while in the posterior region a significant increase began from stage

IIA (Table 1, 2).

Discussion

Fractal geometry computations have been used to examine the spatial complexity of cranial sutures[4-10]. FD is an index of the space filling properties of the measured object, in which a straight line has a fractal dimension of 1 and a solid plane a fractal dimension of 2. As the line becomes more complex, the FD value increases towards 2 [4]. In dentistry, fractal geometry is used for many purposes including maxillofacial radiology examinations[6]. With mixed dentition, to investigate changes of the internal structure of the articular eminence in temporal bone during growth, the FD is measured for creation of a morphological index[7]. To objectively evaluate mandibular bone healing following surgical treatment with digitized panoramic radiograph images, FDs have been used[6].

In a previous anthropological study, FD values for human sagittal and coronal sutures were used to estimate age, though no correlation was found with either of those values and age[5]. In another study, 103 dry skulls from humans aged 14 to 60 years were used to compare FDs and age, and those results also found a lack of correlation[7]. In our study, FD values for the coronal and sagittal sutures were increased according to the growth of dentition. Naitoh et al. divided 100 human dry skulls into 4 groups according to Hellman's dental age and performed measurements using CT images. They found that the size of the calvaria was remarkably increased from the stage IA to IC, then increased only slightly up to stage IIIA[11].

In the present study, the FD of the calvaria suture increased significantly after stage IIIA. Accordingly, the period of remarkable size increase was shown to occur in the early period. In addition, the complexity of the suture increased during the mixed dentition stage.

Fractal dimensions in white-tailed deer were measured from the antler to the morphology of the cranial suture to examine the effects of biomechanical factors. There was no significant increase in the FD of the calvarial suture with age, and no significance between males and females in regard to suture complexity[5]. Also, a biomechanical investigation revealed an increase in energy absorption by the suture in correlation with a significant increase in suture complexity[2]. In morphological findings, by determining the length ratio, calculated as the overall length of the suture divided by its straight length, the complexity of the zygomatic temporal suture in the visceral cranium was found to increase from stage IIA[12]. The zygomatic arch including the zygomatic temporal suture is attached by the masseter to the mastication muscle. The ROIs in this study were also effected by the temporal mastication muscle. Mechanical stress might have effects on the morphology of these sutures. Nevertheless, the calvaria is affected by growth of the central nervous system. Coronal and sagittal sutures exist in the calvaria, and the zygomatic temporal suture is present in the visceral cranium. Thus, there are differences between these sutures in regard to the period when increase occurs.

In the human sagittal suture, the anterior portion seems to have less amplitude width than the posterior portion[8]. In our study, the sagittal suture was quantified by FDs and the posterior region was shown to be larger than the anterior region in all stages of dentition.

To quantitatively and objectively evaluate the maturation of the mid-palatal suture, FDs in cone-beam CT images were analyzed[10], then those results were compared to the maturation classification suggested by Angelieri[13], which uses CBCT images and divides into 5 types. The FD values were considered reasonable for determining the maturation of the mid-palatal suture. They found a strong negative correlation between fractal dimension and maturation stage of the mid-palatal suture. Thus, instead of directly comparing the FDs, use of another cranial suture for specific reference would likely increase the accuracy of the evaluation[10].

In the present study, we investigated changes in the FDs of calvaria according to dentition stage. During growth, the FD increased in all regions. In the future, the relationships among FD values of the sutures should be used to more accurately evaluate suture maturation.

Conclusion

Our results showed that FD values increase according to the advance of dentition. While those values for all regions of the coronal and sagittal sutures were significantly increased, regional differences were noted. In the posterior region of the sagittal suture, FDs were found to increase from the early period.

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Disclosure

The authors declare no conflict of interest associated with this manuscript.

References

1) Key, CA., Aiello, LC., Molleson, T. : Cranial suture closure and its implications for age estimation. Int J Osteoarchaeol. 4 ; 193-208 1994.

2) Jaslow, CR. : Mechanical properties of cranial sutures. J. Biomech. 23 ; 313-21 1990.

3) Yamamura, K., Kobayashi, R., Ohmura, T., Kajimoto, Y., Miura, T. : A new mathematical model for pattern formation by cranial sutures. J. Theor. Biol. 408 ; 66-74 2016.

4) Sánchez, I., Uzcátegui, G. : Fractals in dentistry. J. Dent. 39 ; 273-92 2011.

5) Lynnerup, N., Jacobsen, CB. : Brief communication: Age and fractal dimensions of human sagittal and coronal suture. Am. J. Phys. Anthropol. 121 ; 332-6 2003.

6) Koca, H., Ergün, S., Güeri, P., Boyacìoglu, H. : Evaluation of trabecular bone healing by fractal analysis and digital subtraction radiography on digitized panoramic radiographs: a preliminary study. Oral Radiol. 26 ; 1-8 2010.

7) Ichikawa, J., Hara, T., Ide, Y. : Morphological changes in the internal structure of articular eminence of the temporal bone during growth from deciduous to early mixed dentition. J. Biomech. 40 ; 3541-7 2007.

8) Yu, JC., Wright, R., Williamson, MA., Braselton, JP., Abell, ML. : A fractal analysis

of human cranial sutures. Cleft Palate Craniofac J. 40 ; 409-15 2003.

9) Nicolay, CW., Vaders, MJ. : Cranial suture complexity in white-tailed deer (Odocoileus virginianus). J. Morphol. 267 ; 841-9 2006.

10) Kwak, KH., Kim, SS., Kim, YI., Kim, YD. : Quantitative evaluation of midpalatal suture maturation via fractal analysis. Korean J. Orthod. 46 ; 323-30 2016.

11) Naitoh, H., Inoue, H. : Roentgenographic study on growth and development of the inner side of the zygomatic arch in relation to dental age. Meikai Univ. Dent. J. 29 ; 49-59 2000. (in Japanese with English abstract)

12) Usami, A., Itoh I. : Morphological changes in the zygomatic arch during growth. Ped. Dent. J. 16 ; 179-183 2006.

13) Angelieri, F., Cevidanes, LH., Franchi, L., Gonçalves, JR., Benavides, E., McNamara, JA Jr. : Midpalatal suture maturation: classification method for individual assessment before rapid maxillary expansion. Am. J. Orthod. Dentfacial Orthop. 144 ; 759-69 2013.

Figure legends

Fig. 1

Setting of regions of interest in calvarial sutures.

A. Coronal suture, left side.

B. Coronal suture, right side.

C. Sagittal suture, anterior.

D. Sagittal suture, posterior.

Table 1

Fractal dimensions of each suture

Table 2

Results of statistical analysis

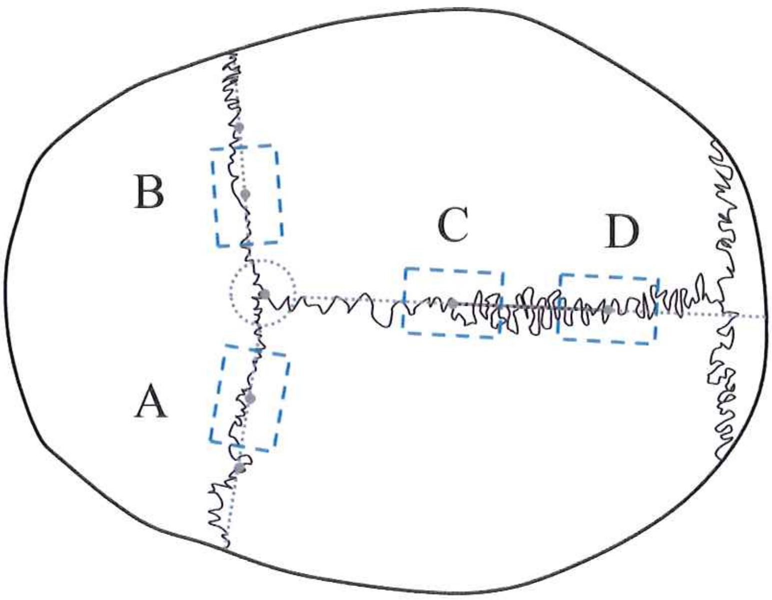

Fig.1

	Ⅱ A (n=20)	Ⅲ A (n=20)	Ⅲ B (n=20)	Ⅳ A (n=20)
Left coronal suture (A)	1.125 ±0.079	1.133 ±0.071	1.201 ±0.081	1.316 ±0.115
Right coronal suture (B)	1.133 ±0.087	1.163 ±0.087	1.190 ±0.088	1.317 ±0.159
Anterior sagittal suture (C)	1.211 ±0.072	1.234 ±0.098	1.275 ±0.091	1.344 ±0.143
Posterior sagittal suture (D)	1.313 ±0.093	1.382 ±0.088	1.394 ±0.092	1.475 ±0.084

Table 1

	ⅡA	ⅢA	ⅢB	ⅣA
ⅡA				
ⅢA				
ⅢB	*	*		
ⅣA	* *	* *	*	

	ⅡA	ⅢA	ⅢB	ⅣA
ⅡA				
ⅢA				
ⅢB				
ⅣA	* *	* *	*	

	ⅡA	ⅢA	ⅢB	ⅣA
ⅡA				
ⅢA				
ⅢB				
ⅣA	* *	* *	* *	

	ⅡA	ⅢA	ⅢB	ⅣA
ⅡA				
ⅢA	*			
ⅢB	*			
ⅣA	* *	* *	* *	

*** : <0.05 , ** : < 0.01**

Table 2