Review of Past Reports and Current Concepts of Surgical Management for Craniosynostosis

Shigeo KYUTOKU,1 and Takayuki INAGAKI2

1Division of Reconstructive Plastic Surgery, Nara City Hospital, Nara, Nara, Japan; 2Division of Pediatric Neurosurgery, Ibaraki Children’s Hospital, Mito, Ibaraki, Japan

Abstract

The purposes of surgery for craniosynostosis are to release increased intracranial pressure and to normalize cranial shape. The procedure was developed from a simple strip craniectomy in practice which ranged from the removal of the fused suture before the 1960s to total calvarial remodeling after 1970s and later methods of the 1990s, such as distraction and its modifications. According to its history, craniofacial surgeons might be changing their procedures with more effective, than less invasive ways. Since the late 1990s, when the distraction was applied to the craniofacial surgery, the gradual expansion, in particular of the anterior cranium, common in Japan, has long been controversial until the Caucasians accepted its use for the posterior cranium. Currently, the method may revert to the old procedure because a more sophisticated and better morphological result can be obtained depending on the types of deformity, even if a little more invasive maneuver is required. In other words, if treatment can be performed in optimal time, the procedures that were developed in the last half a century should be altered to each condition.

Key words: craniosynostosis, suturectomy, intracranial pressure, distraction osteogenesis, mental development

Introduction

Craniosynostosis is the premature fusion of one or more sutures in either the cranial vault or anterior skull base, resulting in an abnormal head shape and intracranial pressure increasing in one-third of all cases that may have a mental mal-development.1–5 This pathologic process occurs in approximately 1 in 2000 to 2500 births in Western countries and less in Orientals.6 The first surgical treatment was reported in 1890s, with linear craniectomy for opening the fused suture, and had long been done by neurosurgeons, until Tessier started craniofacial surgery in 1960s, with a frontal bone repositioning for the purpose of cranial volume expansion.7–9 Since this revolutionary medical event, the surgical procedure for the craniosynostosis has been developed in a variety of ways based on several ideas, by surgeons’ intrepid and prudent “trial and error” up to the current time.10–15 We sought to review the historical reports of our predecessors, discussing the transition of concepts and methods in Japan as well as in the rest of the world.

History of Craniosynostosis: Its Diagnosis, Management and Surgical Procedure

Except Hippocrates’ first historical description of craniosynostosis in 100 BC, Sömmerring and Otto initially described in 1800 and in 1830, that premature cranial sutural fusion would result in deformity, and the etiology was thought to be based on either fetal or birth trauma.16,17 In 1851, Virchow first introduced the term of ‘craniosynostosis’ and formulated what is today known as Virchow’s law: there is a cessation of growth occurs in the direction perpendicular to that of the affected suture while growth proceeds in a parallel direction.18 Based on the concept, the abnormal calvarial growth due to a premature fusion of the sutures, provided the basis for early operative treatment of craniosynostosis, with removing the offending suture in an attempt to release the constricted brain. In 1890, Lannelongue in Paris described bilateral strip craniectomies for the treatment of craniosynostosis, and Lane followed the intervention two years later in the United States.19,20 Two years later, Jacobi reported alarming outcomes and high morbidity and mortality in 33, open strip craniectomies on craniosynostosis patients, due to major blood loss. The concept of brain-releasing
from contracted cranium was not wrong, but this surgery had not been performed until 1927, when Faber and Towne reported their successful more extensive craniotomy. Since then the development of anesthetic and blood management over the years, has provided the opportunity for more difficult and advanced craniosynostosis surgery. The modern era of craniofacial surgery started in the 1960s with Tessier, who first established multidisciplinary craniofacial teams in Paris. In 1967, he showed a procedure of fronto-orbital advancement with cranial vault remodeling, with reshaped removal bone pieces stabilizing back to the cranium and established new protocols that followed and consisted in Moss's functional matrix theory in 1959, and the concept of compensatory cranial vault growth by Vollmer(1984) and Delashaw(1989). On the other hand, similar groups of the craniosynostosis had been reported and classified in terms of each characteristic problem over the years. In 1906, although brachycephalic craniosynostosis with syndactyly had already been reported toward the end of the nineteenth century, the French pediatrician Apert is generally credited with describing the condition. In 1912, Crouzon, a neurologist, reported the condition that is named after him. Those syndromic diseases were suffered the skull base sutures’ fusion besides cranium, ended with a facial retrocession or jaw deformities, that needs craniofacial surgeons to manage the middle third of the face after an operation of cranium in infants. As multidisciplinary teams developed all over the world, clinical geneticists became involved and studied inheritance patterns and syndromic features. In 1993 the first genetic lesion, a specific missense mutation in the MSX2 gene, was identified by Melville et al. in a large family with autosomal dominant craniosynostosis, known as Boston type. This discovery launched molecular diagnostics by identifying a key gene in calvarial development. And in the late 1990s, some craniofacial anomalies, like Crouzon or Pfeiffer syndromes, have been elucidated to be caused by a mutation of FGFR gene, but its phenotype does not correspond to one location by one, so that prenatal gene analysis may not lead a definite diagnosis. Furthermore, other responsible genes have been found out such as Saethre-Chotzen syndrome by TWIST. In the near future, these studies of responsible gene location or clone hopefully reveals each minute pathology and prognosis, and be a foundation and application of gene therapy.

Since early craniofacial neurosurgery had focused on cranial sutures, leading to suturectomies, the new idea by surgeons of the new generation has led more successful reconstruction not only for cranial form, but also orbit or midface from the needs. And so the patients with craniosynostosis or craniofacial dysostosis syndromes, who have gained more stable results, over the ensuring years, have been required better cosmetic results, mainly facial part. Namely technological development by craniofacial surgeons has reported respectively, monobloc advancement (fronto-facial advancement), RED(rigid external distraction) frames and those modifications for the facial reconstruction over the past decade. In the 1990s, several minimally invasive methods had been introduced. Those methods had a common concept of not separating a cranial bone from a dura mater.

In 1992, McCarthy introduced Illizarov bone expansion into the craniofacial area, with his first

---

Fig. 1 Representative case treated with conventional primary surgery and later mid facial correction; Crouzon disease female underwent a conventional forehead advancement (moved anteriorly in 2.1 cm) in 1 year and Le Fort III mid-face advancement in 10 years of age. X-ray of 1(pre-operatively), 4(3 years after forehead advancement), 12(2 years after mid-face advancement), 20 years of age (right to left in order).
application being a 5-year-old boy’s mandible of hemifacial macrosomia. And this technique was applied to the forehead advancement by Sugawara and Hirabayashi 5 years later, and widely spread mainly in Orientals (Fig. 2). In addition to the surgery itself, a postoperative cranial molding orthosis is an alternative. In 1999, Jimenez and Barone presented an endoscopic strip craniectomy under a small incision. That provides a significant reduction in blood loss and avoids transfusion. In 1998, Lauritzen introduced the use of internal spring distractors to widen the fused suture. In 2009, White reported the posterior carvarial expansion that has been now widely accepted for a syndromic craniosynostosis, such as Apert syndrome and Crouzon disease, but it requires more cranial space expansion, otherwise they may require poly-surgery due to relapse and additional volume necessity. Where is craniofacial surgery heading, when all the procedures and concepts has been appeared out? Practical gene therapy or endoscopy-assisted skull base suturectomy in infancy hopefully will take place.

**Surgical management of craniosynostosis in Japan**

The surgery for the craniosynostosis in Japan may divide into 4 eras, since the management has been practically started with wide-suturectomy, mainly done by neurosurgeons, as follows;

**Period I (dawn era of surgery, since late 1960s)**

Because of the low incidence of the disease, the linear suturectomy had been started generally in Japan since around 1980. But its advent actually goes back to more than a decade, the author had noticed the tiny pair of wires migrated in the calvarium of patient who suffered Apert syndrome that I operated on more than 25 years ago, and have long been wondered who left those steel wires in her head; I found the technique and the surgeon by chance from

---

**Fig. 2** Representative case treated with distraction; A 8 month-old female with brachycephaly underwent a forehead advancement with gradual distraction. X-ray of pre-ope, during distraction, full expansion (2.3 cm anteriorly) and 10 years after (right to left in order).

**Fig. 3** Illustrative case with posterior distraction; Follow-up conditions of before to 2 years after of posterior expansion applied to a 4 year-old male with oxycephaly who underwent a frontal advancement in 1 year. X-ray of pre-ope, during distraction, full-expansion (2.3 cm posteriorly) and 2 years after (right to left in order).
a Japanese article from 1967 (Fig. 4). Thirty-one years before Lauritzen,49) Uejima had reported the linear craniectomy with pairs of spring that maintained the gap and prevented re-fusing.51) He applied this operation to 60 cases and compared them with 64 cases with simple suturectomy, and concluded the most effective results. Removal of the fused suture had been done to release the constricted brain in this era.12,52)

Period II (development of craniofacial surgery, 1983-)

After Tessier, the world’s first craniofacial surgeon developed an extensive and more whole cranial work. In 1978, Marchac reported a frontal advancement procedure and followed and established the method as a common treatment for the craniosynostosis in all over the world as well as in Japan. Plastic surgeons had started this work in association with neurosurgeons during this period, when the international society of Craniofacial Surgery was founded by Tessier and his disciples in 1983.53)

Period III (evolution by distraction 1998-)

Five years after McCarthy’s introduction of the Ilizarov technique into a craniofacial surgery,42) Japanese craniofacial surgeons, Sugawara and Hirabayashi published their preliminary successful application to the calvarium and pushed many Japanese craniofacial surgeons to follow along.43–45,47) Up to 2009, 312 cases had been combinedly reported and showed on the advantages of a distraction for the craniosynostosis from Japan,46) since it is less invasiveness, without a bone flap separation from a dura, with less bleeding and smaller relapse, compared with conventional procedure, length, speed, direction of expansion valuably regulated. But the Western surgeons still seemed not to accept a distraction to the calvarium, probably because of low bleeding tendency or other differences between Japanese and Westerns.54)

Period IV (reflection and revolution 2009-)

But White’s report in 2009 of the posterior calvarial expansion has been rapidly accepted by Western surgeons; it is interesting that cranial distraction the Caucasians did not accept for decades has been finally started by a report from England.50) The method which is thought to be a good indication for the syndromic craniosynostosis, because of the amount of cranial expansion is much more effective than frontal distraction advancement or conventional procedure.45,55) And in this era, the procedure may look back to the calvarial remodeling, in terms of more sophisticated way with less invasiveness rather than one direction elongation. That51) is to say; the distraction method should not be applied to severely distorted clinocephaly or asymmetrical supra-orbital area which required morphologically satisfied results.35,56,57,58) Nowadays operation has been safer with the development of technique of an anesthesia with an auto-transfusion or other equipment. And the surgical management is needless to say preferable when lesser invasive and shorter duration.15,36,46,59)

Timing of the surgery and selection of surgical procedures

“Earlier surgical treatment will have better results with functional and morphological improvement by means of releasing of brain contraction” is the well-known rule among surgeons, except for a few objections.60–62) But, how early and which procedure to choose for every type of craniosynostosis?

“The early surgery” defines when? Less than sixth months59,63) may give more alternatives for surgeons, but some earlier reports of a retrospective study recommend64,65) early surgery, for craniosynostosis less than 9 to 18 months of age, could improve morphology and prevent functional disturbances, with low perioperative complications and no mortality, when pan synostosis and craniofacial dysostosis syndromes have gotten worse results with recurrence or cranial vault mal development that needed major secondary operations. It should be kept in mind that the authors of those papers chose calvarial remodeling.66,67) In particular to the suturectomy for a scaphocephaly, some reports recommend that it be done at less than 3 month old and the Pi procedure (Greek letter \( \pi \) shaped ostectomy) in less than 2 month old7,68) and comparative study with cranial remodeling proved to be worse, if operated later than 1 year.13,56)
To summarize timing, in recent years, most of the Western surgeons roughly do cranial remodeling at less than one year of age, suturectomy with helmet at less than 3 month old and cranial distraction at less than 6 month old, as a first surgery.\textsuperscript{66,67} Regarding the types of deformity of the cranium, Marchac recommends 2 to 4 months operation for scaphocephaly, brachycephaly, and syndromic synostosis, and 6 to 9 months for plagiocephaly and trigonocephaly with calvarial remodeling.\textsuperscript{69,70} Even in Japan where the fronto-orbital distraction has been common since early 2000, some surgeons still choose a conventional method for plagiocephaly and trigonocephaly, that requires symmetrical supraorbital remodeling as well as, frontal advancement; the authors agree with this adaption.\textsuperscript{14,32,46} And the synostosis, such as brachycephaly, scaphocephaly, is good indication for distraction, because one direction expansion can resolve those conditions, if performed in early age. Another advantage of the distraction method is its tiny adjustment contrary to on-time conventional repair; the elongation could stop anytime you like according to an extra-dural space or releasing the increased intracranial pressure. The authors have applied subtle expansion for a mild form trigonocephaly with increased ICP, indicated for surgery with over 15 mmHg (mean) in an extra dural monitoring.\textsuperscript{71–73} Khechoyan reported the characteristic distortion of scaphocephaly of frontal bossing could be avoided, if the Pi procedure is done at less than 3 months.\textsuperscript{74} Conversely older scaphocephaly should not be treated by one direction distraction, because narrow frontal bossing would remain and anterior-posterior elongation is not treatable. The older the patient, whose cranium is the harder.\textsuperscript{75–77} For the scaphocephaly, a\textsuperscript{31,56,78–80} variable strategy is needed, based on its age or severity.\textsuperscript{31,56,78–80}

Syndromic craniosynostosis usually requires more operations than simple one, because the cranium needs more space and tends to relapse, and the midface advancement will surely be required, moreover hand surgery as well; first time operation for the craniofacial dysostosis syndrome should be treated with reliably effective cranial expansion until the second surgery is performed. In 2015, Derderian et al. reported a comparative study between fronto-
orbital advancement and posterior cranial vault distraction; volumetric change by posterior distraction is approximately twice as big as the former method, and concluded the posterior expansion gains highly significant volume\(^5\) (Fig. 3). In the last decade, the procedure has been used generally in Western and Japan and additional contributions seemed to be produced, such as improvement of Chiari malformation or fronto-facial impression.

Summarizing above, the authors’ policy for the optimal timing of the surgery is 3 to 6 months of age, and the procedure would be varied by the type of craniosynostosis; scaphocephaly may be treated with suturectomy, before 3 months, the distraction could be helpful, if not, as brachycephaly, plagiocephaly and trigonocephaly is desirable to choose conventional fronto-orbital advancement, for syndromic cases, posterior calvarial expansion should be applied at first.

**Summary**

Looking back on around two centuries of history on craniosynostosis, its character, symptoms and surgical treatments are listed according to the eras, divided by breakthrough developments: craniofacial surgeons seem to be changing methods with more sophisticated than less invasive ways.

**Acknowledgement**

The authors thank Dr. H. Kamiishi, Dr. Y. Yamanouchi, Dr. S. Kajimoto and Dr. K. Ueda for their excellent instruction and cooperation.

**Conflicts of Interest Disclosure**

The authors declare no conflict of interest regarding this review article.

**References**

1) Jacobi A: Non nocere. Med Rec 45: 609–618, 1894
2) Ingraham FD, Alexander E, Matson DD: Clinical studies in craniosynostosis analysis of fifty cases and description of a method of surgical treatment. Surg 24: 518–541, 1948
3) Albright AL, Byrd RP: Suture pathology in craniosynostosis. J Neurosurg 54: 384–387, 1981
4) Arnaud E, Renier D, Marchac D: Prognosis for mental function in scaphocephaly. J Neurosurg 83: 476–479, 1995
5) Thompson DN, Malcolm GP, Jones BM, Harkness WJ, Hayward RD: Intracranial pressure in single-suture craniosynostosis. Pediatr Neurosurg 22: 235–240, 1995
6) Cohen SR, Cho DC, Nichols SL, Simms C, Cross KP, Burstein FD: American society of maxillofacial surgeons outcome study: preoperative and postoperative neurodevelopmental findings in single-suture craniosynostosis. Plast Reconstr Surg 114: 841–847, 2004
7) Alvarez-Garjo JA, Cavadas PC, Vila MM, Alvarez-Llanas A: Sagittal synostosis: results of surgical treatment in 210 patients. Childs Nerv Syst 17: 64–68, 2001
8) Tessier P, Delaire J, Billet J, Landais H: Considerations on the development of the orbit; its incidences on facial development. Rev Stomat 66: 27–39, 1965
9) Tessier P, Guiot G, Rougerie J, Delbet JP, Pastoriza J: Cranio-naso-orbito-facial osteotomies. Hypertelorism. Ann Chir Plast 12: 103–116, 1967
10) Barritt J, Brooksbank M, Simpson D: Scaphocephaly: aesthetic and psychosocial considerations. Develop Med Child Neurol 23: 183–191, 1981
11) Mohr G, Hoffman HJ, Munro IR, Hendrick EB, Humphreys RP: Surgical management of unilateral and bilateral coronal craniosynostosis: 21 years of experience. Neurosurg 2: 83–92, 1978
12) Nishimoto H, Makiyama Y, Nishimura J, Watanabe S: Long-term surgical results of craniosynostosis and its related therapeutic problems. Ipyn J Neurosurg 10: 92–98, 2001
13) Seruya M, Oh AK, Boyajian MJ, Posnik JC, Myseros JS, Yaun AL, Keating RF: Long-term outcomes of primary craniofacial reconstruction for craniosynostosis: a 12-year experience. Plast Reconstr Surg 127: 2397–2406, 2011
14) Taylor JA, Paliga JT, Wes AM, Tahiri Y, Goldstein JA, Whitaker LA, Bartlett SP: A critical evaluation of long-term aesthetic outcomes of front—orbito cranial vault remodeling in nonsyndromic unicoronal craniosynostosis. Plast Reconstr Surg 135: 229–231, 2015
15) Whitaker LA, Bartlett SP, Schut L, Bruce D: Craniosynostosis: an analysis of the timing, treatment, and complications in 164 consecutive patients. Plast Reconstr Surg 80: 195–212, 1987
16) Sömmering ST: Vom Baue des menschlichen Körpers. Leipzig, Germany: Voss, 1800 (German)
17) Otto AW: Lehrbuch der pathologischen Anatomie. Berlin: Rücker, 1830 (German)
18) Virchow R: Uber den Cretinismus, namentlich in Franken und über pathologische schadelformen. Ver Physikalisch Med Ges Wurzburg 2:230, 1851 (German)
19) Lannelongue M: Dela craniectomie dans la microcephalie. Compt Rend Seances Acad Sci 50: 1382–1385, 1890
20) Lane LC: Pioneer craniectomy for relief of mental imbecility due to premature sutural closure and microcephalus. JAMA 18: 49–50, 1892
21) Faber HK, Towne EB: Early craniectomy as a preventive measure in oxycephaly and allied conditions with special reference to the prevention of blindness. Am J Med Sci 173: 701–711, 1927
22) Delashaw JB, Persing JA, Broaddus WC, Jane JA: Cranial vault growth in craniosynostosis. J Neurosurg 70: 159–165, 1989
23) Moss ML: Functional anatomy of cranial synostosis. Child's Brain 1: 22–33, 1975
24) Moss ML: New studies of cranial growth. Birth Defects 11: 283–295, 1975
25) Vollmer DG, Jane JA, Park TS, Persing JA: Variants of sagittal synostosis: strategies for surgical correction. J Neurosurg 61: 557–562, 1984
26) Apert E: De l'acrocéphalosyndactylie. Bull Soc Méd Hôp Paris 36: 3110, 1906 (French)
27) Tessier P: The definitive plastic surgical treatment of the severe facial deformities of craniofacial dysostosis Crouson's and Apert’s diseases. Plast Reconstr Surg 48: 419–442, 1971
28) Crouzon O: Dysostose craniofaciale hereditaire. Bull Soc Méd Hôp Paris 33: 545–555, 1912
29) Melville H, Wang Y, Taub PJ, Jabs EW: Genetic basis of potential therapeutic strategies for craniosynostosis. Am J Med Genet A 152A: 3007–3015, 2010
30) Heutink P, Vermeij-Keers C, Oostra BA: The genetic background of craniosynostosis syndromes. Eur J Hum Genet 3: 312–323, 1995
31) Bartlett SP, Whitaker LA, Marchac D: The operative treatment of ilosted craniofacial dysostosis (plagiocephaly): a comparison of the unilateral and bilateral techniques. Plast Reconstr Surg 85: 677–683, 1990
32) Hoffman HJ, Mohr G: lateral canthal advancement of the supraorbital margin. A new corrective technique in the treatment of coronal synostosis. J Neurosurg 45: 376–381, 1976
33) Kaiser G: Sagittal synostosis–its clinical significance and the results of three different methods of craniectomy. Child Nerv Syst 4: 223–230, 1988
34) Marchac D: Radical forehead remodeling for craniosynostosis. Plast Reconstr Surg 61: 823–835, 1978
35) Persing JA, Edgerton MT, Park TS, Jane JA: Barrel stave osteotomy for correction of turribrachycephaly craniosynostosis deformity. Ann Plast Surg 18: 488–493, 1987
36) Whitaker LA, Munro IR, Salyer KE, Jackson IT, Ortiz-Monasterio F, Marchac D: Combined report of problems and complications in 793 craniofacial operations. Plast Reconstr Surg 64: 198–203, 1979
37) Cohen MM: Epidemiology of craniosynostosis. Craniosynostosis: Diagnosis, evaluation and management (2nd) Cohen MM ed. pp 112–118, Oxford University Press, New York, 2000
38) Czerwinski M, Hopper RA, Gruss J, Fearon JA: Major morbidity and mortality rates in craniofacial surgery: an analysis of 8101 major procedures. Plast Reconstr Surg 126: 181–186, 2010
39) Arnaud E, Marchac D, Renier D: Reduction of morbidity of the frontofacial monobloc advancement in children by the use of internal distraction. Plast Reconstr Surg 120: 1009–1026, 2007
40) Polly JW, Figueroa AA: Rigid external distraction: its application in cleft maxillary deformities. Plast Reconstr Surg 102: 1360–1372, 1998
41) Bradley JP, Gabbay JS, Taub PJ, Heller JB, O’Hara CM, Benhaim P, Kawamoto HK: Monobloc advancement by distraction osteogenesis decreases morbidity and relapse. Plast Reconstr Surg 2006; 118: 1585–1597
42) McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH: Lengthening the human mandible by gradual distraction. Plast Reconstr Surg 89: 1–8, 1992
43) Hirabayashi S, Sugawara Y, Sakurai A, Harii K, Park S: Frontoorbital advancement by gradual distraction. Technical note. J Neurosurg 89: 1058–1061, 1998
44) Sugawara Y, Hirabayashi S, Sakurai A, Harii K: Gradual cranial vault expansion for the treatment of craniofacial synostosis: a preliminary report. Ann Plast Surg 40: 554–565, 1998
45) Komuro Y, Yanai A, Hayashi A, Nakanishi M, Miyajima M, Arai H: Cranial reshaping employing distraction and contraction in the treatment of sagittal synostosis. Br J Plast Surg 58: 196–201, 2005
46) Kyutoku S, Komuro Y, Sugawara Y, Imai K, Hirano A, Miyawaki T, Satoh K, Yamouchi Y, Inagaki T, Arai H, Sakamoto H, Yano H, Oi S: Cranial expansion by distraction for craniosynostosis combined report of 231 operations and our consensus in Japan. Craniofacial Surgery 13, Steven A Wall ed, pp 121–123, Medimond, Italy, 2009
47) Kyutoku S: Evidence-based approach to craniosynostosis–distraction method and its evaluation. Nerv Syst Child 37: 329–331, 2012
48) Jimenes DE, Barone CM: Endoscopic craniectomy for early surgical correction of sagittal craniosynostosis. J Neurosurg 88: 77–81, 1998
49) Lauritzen C, Sugawara Y, Kocabalkan O, Olsson R: Spring mediated dynamic craniofacial reshaping. Case report. Scand J Plast Reconstr Surg Hand Surg 32: 331–338, 1998
50) White N, Evans E, Dover MS, Noons P, Solanki G, Nishikawa H: Posterior calvarial vault expansion using distraction osteogenesis. Childs Nerv Syst 25: 231–236, 2009
51) Fearon JA, Ruotolo RA, Kolar JC: Single sutural craniosynostoses: surgical outcomes and long-term growth. Plast Reconstr Surg 123: 635–642, 2009
52) Starr RJ, Kapp-Simon KA, Cloonan YK, Collett BR, Cradock MM, Buono L, Cunningham ML, Speltz ML: Presurgical and postsurgical assessment of the neurodevelopment of infants with single-suture craniosynostosis: comparison with controls. J Neurosurg 107: 103–110, 2007
53) Van der Vlugt JJ, van der Meulen JJ, Creemers HE, Verhulst FC, Hovius SE, Okkerse JM: Cognitive and behavioral functioning in 82 patients with trigonocephaly. Plast Reconstr Surg 130: 885–893, 2012
54) Friede H, Lilija J, Lauritzen C, Andersson H, Johanson B: Skull morphology after early craniotomy in patients with premature synostosis of the coronal suture. Cleft Palate J 23 Suppl 1: 1–8, 1986

Neurol Med Chir (Tokyo) 57, May, 2017
55) Shillito J, Matson DD: Craniosynostosis: a review of 519 surgical patients. *Pediatrics* 41: 829–853, 1968

56) Marchac D, Renier D, Jones BM: Experience with the “floating forehead”. *Br J Plast Surg* 41: 1–15, 1988

57) McCarthy JG, Glasberg SB, Cutting CB, Epstein FJ, Grayson BH, Ruff G, Thorne CH, Wisoff J, Zide BM: Twenty-year experience with early surgery for craniosynostosis: I. isolated craniofacial synostosis results and unsolved problems. *Plast Reconstr Surg* 96: 272–283, 1995

58) McLaurin RL, Matson DD: Importance of early surgical treatment of craniosynostosis: review of 36 cases treated during the first six months of life. *Pediatrics* 10: 637–652, 1952

59) Patel A, Yang JF, Hashim PW, Travieso R, Terner J, Mayes LC, Kanev P, Duncan C, Jane J Jr, Jane J Sr, Pollack I, Losee JE, Bridgett DJ, Persing JA: The impact of age at surgery on long-term neuropsychological outcomes in sagittal craniosynostosis. *Plast Reconstr Surg* 134: 608e–617e, 2015

60) Boop FA, Chadduck WM, Shewmake K, Teo C: Outcome analysis of 85 patients undergoing the pin procedure for correction of sagittal synostosis. *J Neurosurg* 85: 50–55, 1996

61) Panchal J, Marsh JL, Park TS, Kaufman B, Pilgram T, Huang SH: Sagittal craniosynostosis outcome assessment for two methods and timing of intervention. *Plast Reconstr Surg* 103: 1574–1584, 1999

62) Dec W, Warren SM: Current concepts in deformational plagiocephaly. *J Craniocfac Surg* 22: 6–8, 2011

63) Havlik RJ, Azurin DJ, Bartlett SP, Whitaker LA: Analysis and treatment of severe trigonocephaly. *Plast Reconstr Surg* 103: 381–390, 1999

64) Winston KR, Ketch LL, Dowlati D: Cranial vault expansion by distraction osteogenesis. *J Neurosurg Pediatr* 7: 351–361, 2011

65) Renier D, Sainte-Rose C, Marchac D, Hirsch JF: Intracranial pressure in craniosynostosis. *J Neurosurg* 57: 370–377, 1982

66) Shimoji T, Shimabukuro S, Sugama S, Ochiai Y: Mild trigonocephaly with clinical symptoms: analysis of surgical results in 65 patients. *Childs Nerv Syst* 18: 215–224, 2002

67) Inagaki T, Kyutoku S, Seno T, Kawaguchi T, Yamahara T, Oshige H, Yamanouchi Y, Kamawoto K: The intracranial pressure of the patients with mild form of craniosynostosis. *Childs Nerv Syst* 23: 1455–1459, 2007

68) Khechoyan D, Schook C, Birgfeld C, Khosla R, Saltzmann B, Teng CC, Ettinger R, Gruss JS, Ellenbogen R, Hopper RA: Changes in frontal morphology after single-stage open posterior-middle vault expansion for sagittal craniosynostosis. *Plast Reconstr Surg* 129: 504–516, 2012

69) Hashim PW, Patel A, Yang JF, Travieso R, Terner J, Jane J Jr, Jane J Sr, Pollack I, Losee JE, Kanev P, Mayes LC, Duncan C, Bridgett DJ, Persing JA: The effect of whole-vault cranioplasty versus strip craniectomy on long-term neuropsychological outcomes in sagittal craniosynostosis. *Plast Reconstr Surg* 134: 491–501, 2014

70) Hudgins RJ, Burstein FD, Boydston WR: Total calvarial reconstruction for sagittal synostosis in older infants and children. *J Neurosurg* 78: 199–204, 1993

71) Jane JA, Edgerton MT, Futrell JW, Park TS: Immediate correction of sagittal synostosis. *J Neurosurg* 49: 705–710, 1978

72) Maugans TA, McComb JG, Levy ML: Surgical management of sagittal synostosis: a comparative analysis of strip craniectomy and calvarial vault remodeling. *Pediatr Neurol* 27: 137–148, 1997

73) Olds MV, Storrs B, Walker ML: Surgical treatment of sagittal synostosis. *Neurosurv* 18: 345–347, 1986

74) Stein SC, Schut L: Management of scaphocephaly. *Surgical Neurol* 7: 153–155, 1977

75) Dederian GA, Wink JD, McGrath JL, Collinsworth A, Bartlett SP, Taylor JA: Volumetric changes in cranial vault expansion: comparison of fronto-orbital advancement and posterior cranial vault distraction osteogenesis. *Plast Reconstr Surg* 135: 1665–1672, 2015

76) Uejima O: “Expansive linear craniotomy” as a new operation method for the infants with small head. *J Nara Med* 18: 287–306, 1967

77) Mori K, Sakamoto T, Nakai K: Present status of craniosacial surgery in Japan—results of questionnaire. *Nerv Syst Child* 16: 1–4, 1991 (Japanese)

78) Tsukuno M, Kurihara K: Clinical findings of Japanese craniosynostosis syndrome patients. *Jpn PRIS* 19: 572–575, 1999

79) Chim H, Gosain AK: An evidence-based approach to craniosynostosis. *Plast Reconstr Surg* 127: 910–917, 2011

80) Sutton LN, Bartlett SP, Duhaime AC, Markakis D: Total cranial vault reconstruction for the older child with scaphocephaly. *Pediatr Neurosurg* 19: 63–72, 1993

Address reprint requests to: Shigeo Kyutoku, MD, PhD, Division of Reconstructive Plastic Surgery, Nara City Hospital, 1-50-1 Higashi-Kidera-cho, Nara, Nara, 630-8305 Japan.

E-mail: s-kyutoku@nara-jadecom.jp