

Exploration of an Easy and Simple Method for Decompressive Craniectomy: The “Spiral Dural Incision Method”

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Abstract

Decompressive craniectomy (DC) is performed to alleviate intracranial hypertension as much as possible. There are two additional goals that surgeons should strive to achieve: minimization of operating time (i.e., the time issue) and avoidance of manually pushing on the surface of the bulging brain to prevent iatrogenic brain injury (i.e., “stuffing risk”). Many authors have made progress on the time issue, but stuffing risk remains largely unmitigated. We recently presented a new DC method that resolved both issues, but the incision design was too complicated for general use. A recent study has presented a duraplasty method that does not use watertight sutures and does not exacerbate the risk associated with DC. Employing the simplified method without sutures, we developed a new, easy-to-perform DC method that resolves stuffing risk. We analyzed the incision design geometrically and verified it by simulations generated with a physics engine. Three patients with massive cerebral infarction, subarachnoid hemorrhage, and hemorrhagic infarction underwent the new procedure. The targeted incision design was composed of four or five curved incision lines. Expansion of the dura resulted in transformation into a centroclinal form with spiral rifts and canopy. The dura expanded as expected in each case, and no cases required manual stuffing of the bulging brain. The operative time was acceptable, and no complications were reported. The concept of the incision design could be applied to any polygonal duraplasty in DC. We developed a new DC method that involves a simple and easily executed incision design, avoided stuffing risk.

Keywords: decompressive craniectomy, dural incision design, geometrical analysis, spiral incision

Introduction

Decompressive craniectomy (DC) is performed on patients with intracranial hypertension to reduce critically high pressure resulting from severe head trauma, subarachnoid hemorrhage, or a large territorial cerebral infarction that causes swelling in the brain. The most important goal of DC is to reduce intracranial pressure as much as possible. This type of operation is performed by surgeons in emergency situations. Consequently, DC methods are continually

being developed to shorten the operative time,^{1–3)} but there remains a persistent issue that must be addressed. The issue is that if a large volume of swollen brain prolapses beyond the capacity volume that the scalp can cover, it is difficult for surgeons to return the prolapsing brain into intracranial space. If the surgeon stuffs the swollen brain back into place by hand with nonuniform pressure, iatrogenic brain injury sometimes results; this risk can be described as “stuffing risk.”

Opening a single, wide dural window allows the swollen brain to prolapse, leading to stuffing risk. Some authors have presented new dural incision designs for DC that consist of several independent incision lines.^{1,3)} The methods avoided stuffing risk, although their main purpose was to simplify the operational procedure. The incision designs are

Received December 14, 2019; Accepted April 9, 2020

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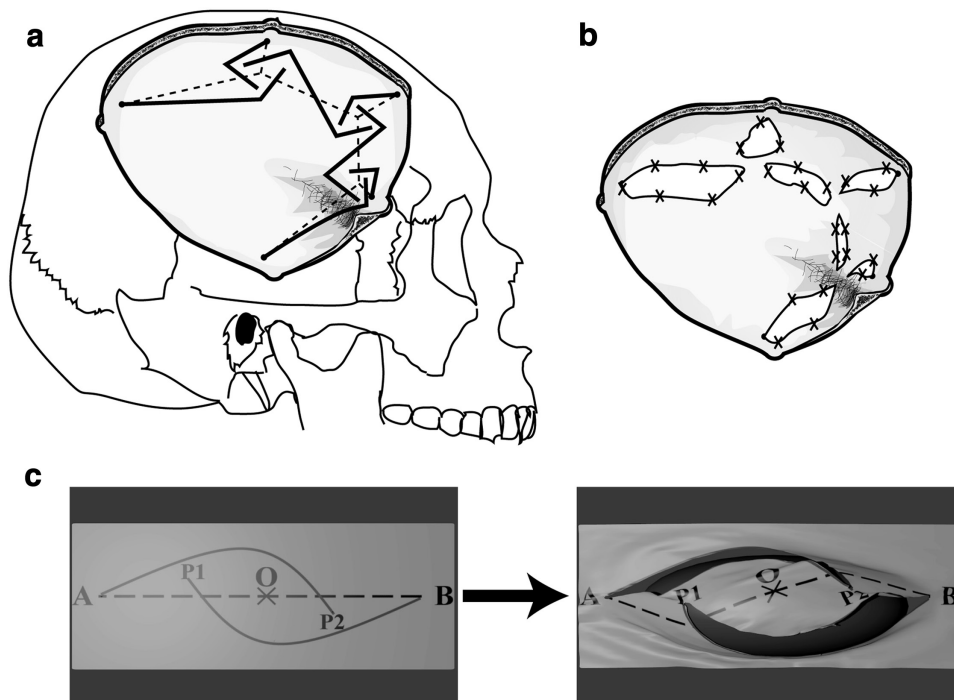


Fig. 1 Duraplasty in DC with the previous method. The previous method for a pentagonal decompressive duraplasty is illustrated. (a) The incision design consists of seven independent curved lines (solid line). The broken line indicates the shortest set of line segments connecting each vertex of the pentagon. (b) The transformed dura mater is patched with seven pieces of dural substitute. (c) Expanding dura mater incised by BIDE is simulated by the computer physics engine. Left: no pressure from beneath the dura. The broken line indicates the line connecting A and B with the shortest distance. The solid lines indicate cutting lines. Right: The dura is compressed by bulging the brain from beneath it. The rotated center area of the dura covers the projected part of the bulging brain while maintaining its continuity. BIDE: basic incision designs for expansion.

good for preventing stuffing risk but do not provide sufficient volume of subdural space for severely bulging brain. Recently, we presented a new dural incision design for DC, aiming for a short operative time while providing sufficient volume of the subdural space. The method shortened the operative time by reducing the total dural incision length which surgeons must suture with patches of dural substitute. The incision design consisted of some independent short curved incision lines, which reduced stuffing risk.⁴⁾ The method provides space for bulging brain and also reduces stuffing risk simultaneously, but the incision design is too complicated for general use because surgeons have to draw a precise set of line segments on dura as an auxiliary conductor, then draw again some curved incision lines based on it (Figs. 1a and 1b).⁴⁾

Recently, a randomized controlled trial (RCT) comparing DC with duraplasty with or without water-tight suturing was reported. The author disclosed that the procedure without water-tight suturing shortened the operation without exacerbating risk.⁵⁾ Accordingly, it is not necessary to

consider reducing total length of dural incision line which we had to repair by suture in the previously reported our method. We plan to reconsider a simpler dural incision design in DC.

Principle of the dural incision design which provides sufficient subdural space volume and avoids stuffing risk

In DC, regardless of how loosely the dura is transformed, the overlaying scalp determines the expansion limits of both the transformed dura and the underlying bulging brain. Previously reported, our method prevents the extended transformation of them automatically at the maximum limit within the overlaying scalp. The method has both the characteristics of automatically halting the transformation at the expansion limit (Ch. 1) and a maximized subdural space volume upon the pushing and stretching of dura by the underlying bulging brain (Ch. 2). A dural incision design by which transformed dura mater holds Ch. 1 and Ch. 2 consists of some independent incision lines, thus avoids making unnecessarily wide dural window

in DC, prevents bulging brain prolapsing out. This is the principle of the dural incision design which provides sufficient subdural space volume and avoids stuffing risk in DC. We reconsidered a simpler incision design suitable for general use with adhering the principle.

Exploration of a simple incision design retaining

Ch. 1

Ch. 1 is achieved by a combination of mechanisms involving basic incision designs for expansion (BIDEs), as described previously (Fig. 1c).⁴⁾ Briefly, if a pair of symmetrically curved incision lines between two points on the dura cut across the line segment between these points while maintaining the plane continuity, both of these points can be extended parallel to the line between them by the pressure from the underlying bulging brain. In addition, we can adjust the limit of the expansion between these two points by determining the pair of cutting depths beyond the line segment. If surgeons try to expand a line segment that has a distance of L on the dura, gaining $2d$ by this concept, they should set the two cutting end points (**P1** and **P2**) to the point at which the sum of the two distances from **P1** (or **P2**) to one end and the center of the line segment is equal to $d + L/2$. Such a point, that is, **P1** (or **P2**), must be on an ellipse that has a pair of foci composed of the end and center of the line segment and has $d + L/2$ of the reflecting distance (reflecting at **P** on the elliptical outline) between the foci.

Exploration of an incision design retaining Ch. 2

The targeted form and area of the transformed dura were also discussed previously.⁴⁾ The limit to which the brain can expand is determined by the scalp, which is extended up to 30 mm in normal adults based on a review of the plastic surgery literature.⁶⁾ Accordingly, surgeons should transform the dura width by $2t + 30$ mm (t : thickness of the skull bone) at the lowest limit omnidirectionally.

Supposing a pentagon counterclockwise **ABCDE** on dura, the area a surgeon plans to transform, and point **O** around the center of **ABCDE**, the ideal shape for enveloping the swollen brain under the maximally extended scalp is provided if the dura is transformed such that each line segment from **O** to each vertex (radiation) can gain $(2t + 30)/2$ mm parallel to their direction and expand more in the other directions. If we apply the BIDE mechanism concept to the five radiations of pentagon **ABCDE**, we can determine the accurate incision design for the pentagonal dural expansion.

Briefly, we can draw five ellipses with a pair of foci, **O** and **A–E**, set as the sum of the distances from

a point **P** (**P1–P5**) on the ellipses to their foci (reflecting distance) with d mm being longer than the direct distance between the foci (Figs. 2a–2c). If we cut the dura from each vertex to **P** on the next counterclockwise ellipse while crossing over the next radiation, the crossed radiation line enables the dural plane to stretch up to d mm more than the original by rotation of the remaining center plane (like a canopy). Accordingly, we can transform the dura to a centroclinal expanding form by determining d as $(2t + 30)/2 = 21$ mm (6.7 mm for average skull thickness t) for the targeted pentagonal dural expansion.

In other words, five ellipses are drawn with a pair of foci **O** and **A–E**, whose reflecting distances are the direct distance between each foci + 21 mm. **P1–5** are set on the elliptic curves, followed by cutting from each vertex and advancement across the next radiation in a counterclockwise direction, ending at **P1–5**. These five incision lines form a spiral pattern and must not touch each other. This procedure provides surgeons with the dural transformation targeted for pentagonal dural expansion. The centroclinal expansion was verified by simulations using the physics engine Blender (version 2.7, Amsterdam, Netherlands) (Fig. 2d).

We regarded the extension capacity of adult scalp and average skull thickness as 30 mm and 6.7 mm in the above discussion, but there are some individual variations in practice. Surgeons can check the volume of decompression with eyes concurrently. We can easily adjust the decompression volume by adjusting the cutting length within several millimeters under monitoring the effect depending on the variations. Looking the bulging dura mater from the side parallel to the craniectomy plane helps the monitoring.

Case Report

DC

The novel procedure was approved by the ethics committee of International University of Health and Welfare group (approval cord. 13-B-397). Three patients have undergone DC in our hospital. All patients underwent DC within 4 hours of clinicians noticing their critical state when the patients presented with impending herniation of the brain on CT. Skin incision and craniectomy were performed in a conventional manner with an emphasis on a large question-mark-shaped skin incision and wide removal of the temporal bone. The designed incision line was drawn on the dura and cut along with it. For an expanding duraplasty, when rifts in the dura mater were created by the pressure of the bulging brain from beneath, these rifts were covered with the dural substitute DURA WAVE (Gunze, Osaka,

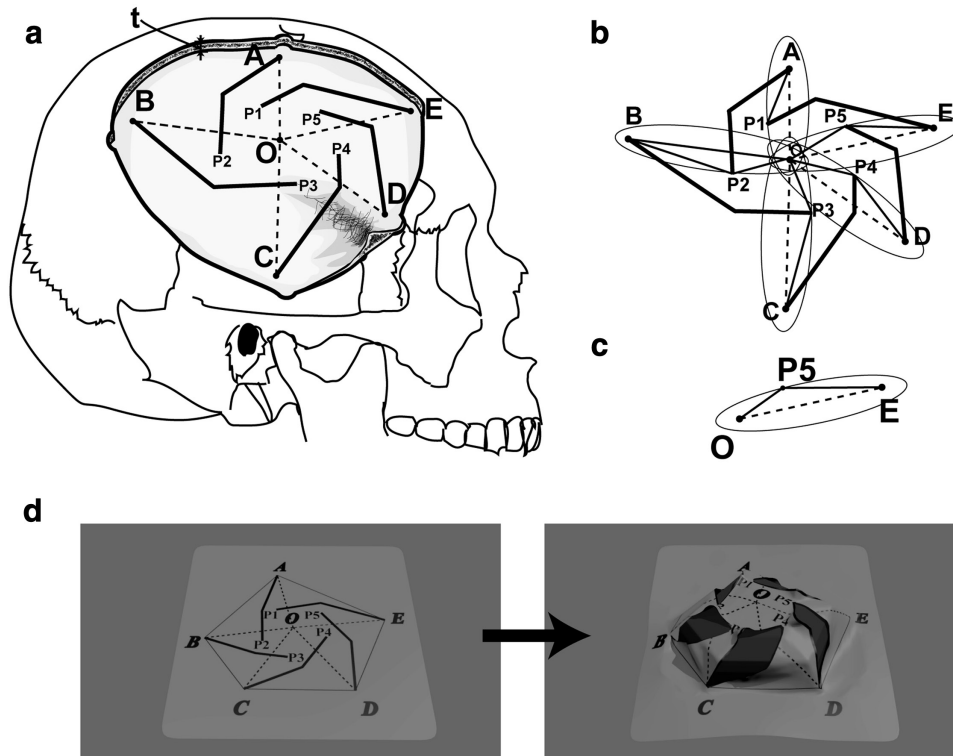


Fig. 2 Spiral incision design. A spiral incision on the dura mater is illustrated. (a) ABCDE are vertices of the pentagon that are meant to expand. O is around the center of the pentagon. The broken line indicates the line to extend. “t” indicates the thickness of the skull. The five curved lines indicate the incision lines. P1 to P5 are the end points of each incision line. (b) The incision design is illustrated with a thick solid line. P1–P5 are on the next ellipses in the counterclockwise direction, with OA, OB, OC, OD, and OE as the set of each foci. (c) According to the nature of an ellipse, the sum of each point on the ellipse to two foci (P5, O, E here; reflecting distance; curved solid line) should be 21 mm longer than the direct distance between these foci (broken line). (d) Expanding dura mater incised by the spiral incision design is simulated by a computed physics engine. Left: no pressure from beneath the dura. Right: The dura is compressed by bulging the brain from beneath it. The rotated center area of the dura, like a canopy, covers the projected part of the bulging brain while maintaining its continuity.

Japan) and fibrin glue with no suturing, as described elsewhere.⁷⁾

Construction of the design in practice

Refer to Fig. 3. Mark a pentagon counterclockwise ABCDE and point O at the center on the dura. Prepare a silk thread with two marks that are 21 mm apart from each other. Using the thread, determine P1 to P5 on the dura. Connect each vertex to P, and do not crossover the incision lines. The incision design drawn by this method is a spiral starting from each vertex to the center of the dura, and this method is thus called the “canopied spiral dural incision method.”

This design requires five repeated actions to make five independent rifts, but the process is easier than creating the incision design which consists of seven complicated rifts described in the previous report. This design is sufficiently simple to construct.

For a quadrilateral dural expansion, suppose a quadrilateral ABCD and O and then draw four radiations from O to each vertex ABCD. The incision design composed of four curved lines is determined in the same manner as setting P1–4 (Fig. 3h).

Efficacy of spiral dural incision method

We measured the operation times and inspected the avoidance of manual stuffing leading to stuffing risk in these cases. We validated the efficacy of the decompression by comparing the diameter of the dura at the maximally opened cranial window on the postoperative CT with the distances on the opposite side.

Case 1

We performed DC via the spiral dural incision method on a 71-year-old woman with severe brain edema due to a massive cerebral infarction to treat

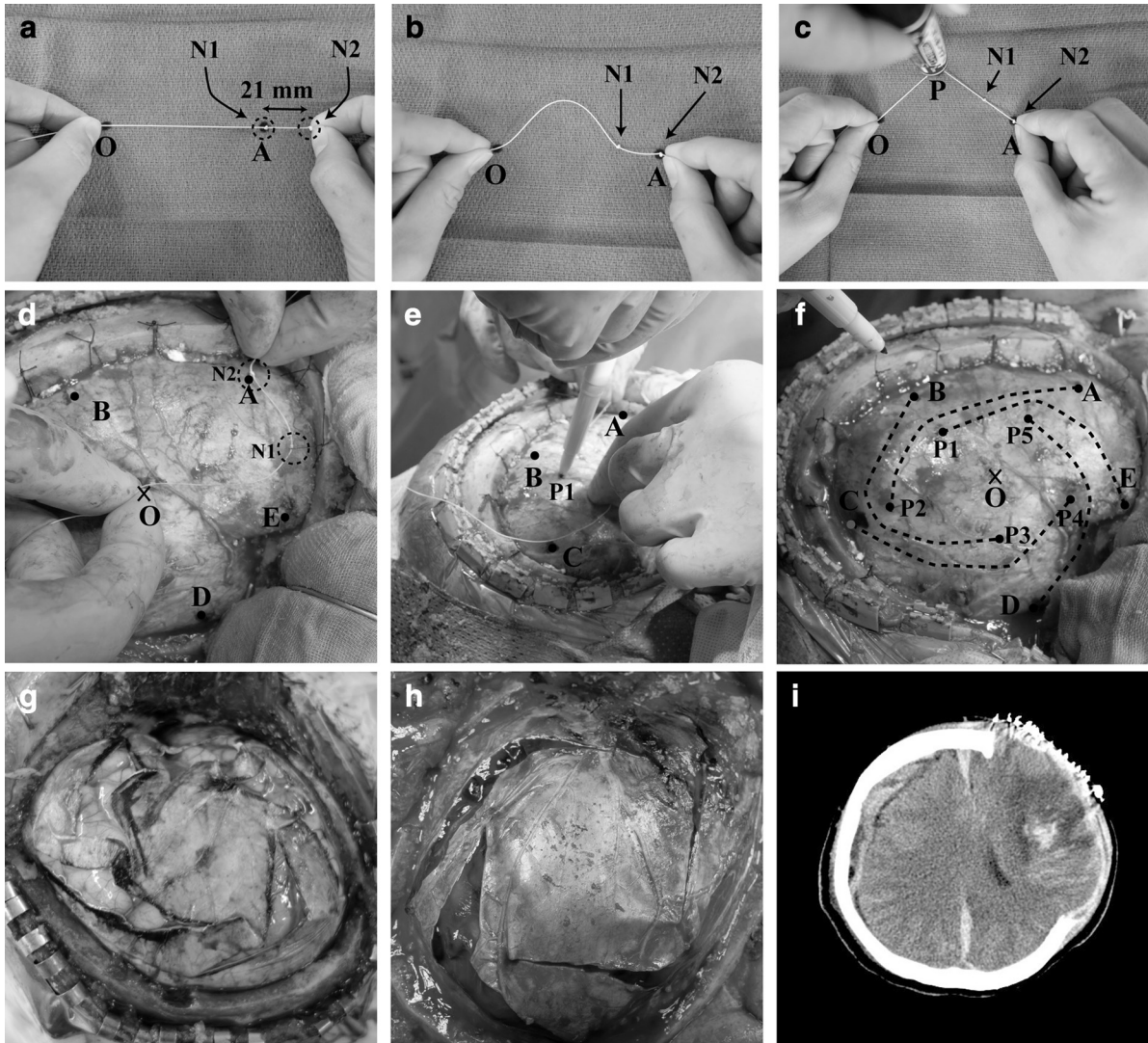


Fig. 3 Clinical practices. Imagine a pentagonal area to be decompressed and mark each vertex of the pentagon counterclockwise ABCDE and point O at the center on the dura. Determine each cutting end point P1–P5 to make incision lines A–P2, B–P3, C–P4, D–P5, E–P1. (a–c) Preparation of a silk thread used for the design construction and the way to determine a cutting ending point P are simulated. (A) Prepare a silk thread with two knot marks, named N1 and N2, which are 21 mm apart from each other. First, an assistant puts the tense thread on the plane simulating dura mater while holding N1 and a certain point of thread on vertex A and center point O. B: Second, he releases N1 and then reholds N2 on A while holding the point on O. (c) Third, the operator pulls the middle part of the thread with a marker to a counterclockwise direction and then marks a point at the reflecting point of the thread as P1. Thus, the cutting line starting from E ends at a point P1 on the ellipse with foci (O, A). (D–F) A description of how to construct a spiral incision design is provided. (d) The second step is demonstrated in practice. Vertices of the pentagon ABCDE (C is hidden) and center point O are marked on dura. N1 and N2 are indicated by broken circles. (e) The third step is demonstrated. P1, which is on the ellipse with foci (O, A), is determined and marked on the dura. (f) P2 to P5 are determined in the same manner. Connect A to P2 with a curved line while detouring outside P1 and do not crossover the incision lines. Connecting lines B–P3, C–P4, D–P5, and E–P1 are drawn in the same way. A set of five curved broken lines represents the incision design we have targeted. If a patient has a thick cranium, the length of the cut can be extended several millimeters while visually monitoring the decompression effect; if the cranium is thin, the length of the cut can be reduced slightly. (g) Transformation of the dura mater by cutting along with this design is shown. Five incision lines open to form spiral rifts. The central area of the dura-like canopy is rotated and covers the bulging brain. (h) A case that required quadrilateral duraplasty is shown. The incision design composed of four curved lines is determined in the same way as setting P1–4. The central part of the dura covers the bulging brain moderately. (i) CT at 4 days following the DC in the case of subarachnoid hemorrhage is shown. The swelling bulging brain is sufficiently decompressed by the transformed centroclinal dura.

a life-threatening brain herniation. The operative time was 52 minutes. Her brain was swelling and protruded out of the bone window, but the transformed centroclyndal dura covered it moderately well. We never stuffed the brain parenchyma during the surgery (Fig. 3g). The dura surface was enlarged, gaining a distance of 31.8 mm. Ten days later, her brain edema had ameliorated, and she had recovered from the crisis. No complications were noted. Modified Rankin scale score 30 days following surgery was 5.

Case 2

We performed the same method on a 65-year-old woman with acute brain swelling following clipping surgery on subarachnoid hemorrhage (Figs. 3h and 3i). The operative time was 52 minutes. The dura surface was enlarged, gaining a distance of 46 mm. The canopied dura covered the swallowing brain moderately. We never stuffed the brain parenchyma during the surgery. She died by brain herniation 14 days following DC, although no complications were observed.

Case 3

A 73-year-old woman with life-threatening intracranial hypertension due to a massive cerebral hemorrhagic infarction underwent DC with the method. The operative time was 53 minutes. The dura surface was enlarged, gaining a distance of 31.5 mm. We never stuffed the brain parenchyma during the surgery. No complications were noted. Modified Rankin scale score 30 days following surgery was 5.

Discussion

We herein present a new method, the “spiral dural incision method,” for DC. First, this method avoids manual stuffing of the brain, which can lead to an increased risk of iatrogenic brain injury. The new dural incision design is based on the principle of BIDE, which is composed of a combination of discontinuous multiple line segments. Placing a mutual plane among every incision line segment as a continuing plane of BIDE at the center of the dura generates an autologous canopy, which holds the bulging swollen brain sweepingly with uniform pressure and does not require manual stuffing.

Second, the canopied spiral dural incision method was easy to perform. This design allows for easier imagination and a more smoothly drawn spiral incision than the design we presented previously. Although the incision design seems complicated because it is based on geometrical logic, we can easily draw the design using silk thread in one step. In our practice, the operative times for this new

method were an hour or less and were preferable to those in previous reports.²⁻⁵⁾

In reviewing reports describing improvement of DC methods, a majority of them pursued a simple procedure leading short operative time. To reduce operating times, some authors have presented methods for DC with no dura suturing. Burger presented a shortened operative time when using a method consisting of three or four linear dural incisions with no duraplasty or suturing.³⁾ Bhat presented a multidural stab technique with no duraplasty combined with DC.¹⁾ The former author may not have performed the operations in emergency situations, and the latter author applied the method to acute subdural hematoma evacuation, but the methodology had the same concerns that the method cannot provide large subdural volume. Although these methods carry no stuffing risk since the designs provide too little dural windows for a massive brain to prolapse out, we propose that surgeons should provide a sufficient subdural volume by duraplasty using a dural substitute for patients in extreme emergency situations who are expected to have severe bulging of the brain parenchyma.

Güresir and Vieira shortened the operative time by omitting dural suturing.^{2,5)} They employed conventional incision design to open a wide dural window. Although they provided sufficient subdural volume for the bulging brain, there remained a concern for stuffing risk. Our thorough investigation is the first report describing an uncomplicated method to provide sufficient subdural volume while reducing stuffing risk.

An additional advantage of our new method is that it uses maximal autologous dura, and minimal dural substitutes are thus needed. Inserting less exogenous material during surgery is better for the patient in terms of risks of infection or rejection. With reduced material requirements, the total cost of the operation will be minimal. The biggest advantage of the new method is that it makes great use of the reduced pressure induced by craniectomy safely by dural incision with a simple spiral design. The canopied dura moderately covers the bulging brain with uniform pressure, which is a more natural action than stuffing the brain manually.

However, this new method has some disadvantages. The spiral incision should not be applied in cases involving large mass lesions, such as brain tumor removal from the brain parenchyma because the dural windows created are limited by the plane continuity of the design. However, this method could be sufficiently used for subdural hematoma removal through deformable rifts on the dura. Adhesion of cortical veins or brain structures to

the dura may also disturb the setting of the dural incision line.

We do not yet have enough data showing improved prognoses associated with the shortened operative time using this method. Nevertheless, the new incision design, which has been analyzed geometrically and used experienced in practice, will advance the method of DC. Numerous cases employing this method will be needed to discuss its complication rates and prognosis.

We developed a new method for duraplasty during DC by spiral dural incisions. This method averted stuffing risk because the canopied dura mater held a substantial amount of the brain. The spiral incision design was easy to define intraoperatively using silk thread. The method requires minimal dural substitute to patch the rifts because the incision design utilizes the entire autologous dura mater. This new method for DC will contribute to steady progress in the field.

Conflicts of Interest Disclosure

None of the authors has any conflict of interest.

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