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Japanese National Questionnaire Survey in 2018 on Complications Related to Cranial Implants in Neurosurgery

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Abstract

Cranial implants are commonly used throughout the world, yet the data on complications remain partly clarified. The aim of this study was to gather real data in 2018 on complications related to cranial implants in neurosurgery. The survey population consisted of 1103 institutes supplying neurosurgical treatment. The survey consisted of two-stage questionnaire. First the incidence of complications was investigated, then the secondary questionnaire was e-mailed to the respondents about the detailed of the complications. As the result, the annual incidence of complications related to cranial implants was 0.558% in Japan. Titanium plate and mesh were used predominantly in craniotomy and cranioplasty, respectively. The second survey collected data on 449 cases with complications (infection: 63%, implant exposure: 46%, multiple answer). Postoperative infection was associated with male sex, brain tumor, short interval between surgery and complication, usage of ceramics, hydroxyapatite, resin, and artificial dura, hyponutrition, multiple surgeries, dirty wound, and sinusitis as patient factors, and CSF leakage, ruptured sutures, and sinus maltreatment as surgery factors. Meanwhile, long hospital stay was associated with age, male sex, mRS 3–5 before complication, short interval between initial surgery and complication, large craniotomy, long operative time, usage of ceramics and artificial dura, multiple surgeries and dirty wound as patient factors, ruptured suture as a surgical factor, and bacterial infection, especially MRSA infection, as the complication and treatment consisting of removal as complication factors. In conclusion, this is the first Japanese national survey on complications related to cranial implants in neurosurgery. It is important to recall that complications may arise years after surgery and to be aware of the risk factors associated with complications.

Key words: artificial bone, cranioplasty, infection, re-operation, titanium plate

Introduction

Craniotomy and cranioplasty are standard procedures in neurosurgery, and various cranial implants are widely used for these procedures throughout the world. The titanium plate and screw system was invented and first used for neurosurgery in 1991[1)]; since then, various other fixation systems, artificial bones and artifacts have been developed and are now commonly used. In most cases, the clinical course after surgery is uneventful; in some cases, however, various complications related to cranial implants, including infections and skin troubles, can arise.[2)] Some cases require multiple surgeries or tissue reconstruction with vascularized tissue transplantation,[3,4)] severely burdening patients and their medical teams.

This study reports the results of our national questionnaire survey on complications related to cranial implants in neurosurgery, including the overall complication rate and risk factors for infection and long hospital stay.

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Methods

The survey consisted of a two-stage questionnaire on complications related to cranial implants in neurosurgery. The first-stage survey population consisted of 1103 institutes offering neurosurgical treatment. The first stage of the survey was mailed to all of these institutes in October 2018; the second stage was emailed to all institutes that had responded to the first stage with a due date in February 2019. This study was approved by the Institutional Review Board (IRB)/Ethics Committee of Okayama University Hospital, Japan (IRB No. 1808-043). Opt-out informed consent was obtained from patients.

Questionnaire

The questionnaire was in Japanese and consisted of multiple-choice (multiple answers allowed) or written response questions. The first stage collected institutional information on craniotomy and cranioplasty, namely, the number of annual craniotomies; the cranial implants used in craniotomy (titanium plate, titanium mesh, absorbable plate, and others); the cranial implants used in cranioplasty (titanium mesh, ceramics, hydroxyapatite, ultra-high-molecular-weight polyethylene, and others); and the number of cases with complications related to cranial implants.

The second stage collected detailed information on each case in which complications had occurred. Data collected included age at the initial surgery and at complication, neurological ability before complication (modified Rankin scale [mRS]), sex, reason for initial surgery (trauma, aneurysm, tumor, pediatric disease, and others), operative time of initial surgery (hours), craniotomy site (frontotemporal, bifrontal, parietal, occipital, posterior fossa, and others), craniotomy area (cm^2), implants used in craniotomy (titanium plate, titanium mesh, absorbable plate, and others) and in cranioplasty (titanium mesh, ceramics, hydroxyapatite, ultra-high-molecular-weight polyethylene, and others), other materials used (artificial dura, dural prosthetics, burr hole cap, bone cement, and others), institute performing the initial surgery (own and other), complications (infection, implant exposure, implant migration, skin depression, and others), infecting organism, cause of complication (Part A, patient factors: sinusitis, cancer, diabetes mellitus, previous irradiation, multiple surgeries, malcirculation, hyponutrition, thin skin, advanced age, dirty wound, others; Part B, surgical factors: ruptured sutures, skin ischemia, cerebrospinal fluid (CSF) leakage, sinus maltreatment, uncovered implant, implant malfixation, others; Part C, device factors: malsterilization, implant breakage, and others), outcome severity/response level (no treatment, non-surgical treatment, re-operation, aftereffect, and death), treatment method in surgery (system removal, suturing, implant covering, tissue transplantation, and others), involvement of plastic surgeons (plastic surgeons only, combination of plastic surgeons and neurosurgeons, and neurosurgeons only), and length of hospital stay.

Data analyses

Excel sheets were used to summarize the data. Continuous data are shown as mean ± standard deviation. Categorical data are shown as frequency and percentage. Statistical analyses were performed using JMP 13 software (SAS Institute Inc.). The univariate associations between each potential risk factor and the occurrence of infection and hospital stay longer than 30 days were assessed using Pearson's chi-square test or Fisher's exact test, as appropriate. In these assessments, the following rules were applied to identify the risk factors. Diseases were classified into vascular, tumor, traumatic brain injury (TBI) and others (epilepsy, pediatric disease, microvascular decompression, abscess, etc.). Craniotomy site was classified into fronto-temporal, bifrontal, occipital or posterior fossa, and Others (frontal, temporal, etc.). The cutoff points for each continuous variable (age at initial surgery, interval between initial surgery and complication, area of craniotomy, and duration of operation) were determined according to a previous study on analyzing risk factors. Then, we constructed multivariable logistic regression models to estimate the odds ratios (OR) and 95% confidence intervals (CI) of the variables for the development of infection and hospital stay longer than 30 days. We selected clinically relevant variables consistent with the previous reports (age, sex, ADL, types of disease, interval, area of craniotomy, duration of operation, location of craniotomy, devices, and artifacts). Results are presented as OR with 95% CIs. Significance was set at $p < 0.05$.

Results

A flow diagram shows how the cases with complication were included in this study by the two-stage questionnaire survey (Fig. 1).

The first survey

Incidence of complications related to cranial implants

Out of the 1103 institutes to which we sent our first survey, 337 institutes responded (30.6%). Among

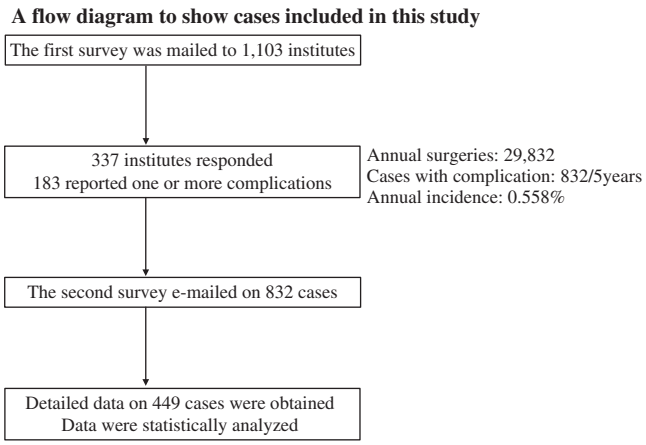

Fig. 1 A flow diagram to show cases with complication included in this study.

the responding institutes, 154 reported "no complication related to cranial implants" (45.7%) and 183 reported "or more complications" (54.3%). The total number of annual craniotomies at the responding institutes was 29832. The number of cases with complications related to cranial implants occurring within 5 years was 832. The calculated annual incidence of complications related to cranial implants was 0.558% per year.

Cranial implants used in Japan

For craniotomy, 92.6% of institutes used titanium plate (312/337), 35.9% used titanium mesh (121/337), and 18.4% used absorbable plate (62/337). For cranioplasty, 46.9% of institutes used titanium mesh (158/337), 36.2% used hydroxyapatite (122/337), 33.8% used ceramics (114/337), 25.8% used ultra-high-molecular-weight polyethylene (87/337), 3.3% used resin (11/337), and 2.7% used bone cement (9/337).

The second survey

Out of the 832 cases with complications reported by 183 institutes, details on 449 cases (54.0%) at 68 institutes (37.2%) were obtained in the second survey. These data are shown in Table 1. Age at initial surgery and age at complication were 52.1 ± 0.9 (0–86) and 57.3 ± 0.9 (0–86) years, respectively. The interval between initial surgery and complication was 63.7 ± 4.8 (0–576) months. Neurological ability before complication (mRS) was distributed as follows: mRS0: 123 cases (27.4%), mRS1: 103 cases (22.9%), mRS2: 45 cases (10.0%), mRS3: 52 cases (11.6%), mRS4: 69 cases (15.4%), mRS5: 49 cases (10.9%), and unknown/no response: 8 cases. The distribution of male/female sex was 195/252 (unknown/no response: 2). The reasons for the initial surgery were as follows: tumor: 157, aneurysm: 119, trauma: 84, intracerebral hemorrhage: 20, cerebral infarct: 18, moyamoya disease: 13, epilepsy: 9, pediatric neurosurgery: 7, arteriovenous malformation (AVM): 7, others: 12, and unknown/no response: 3. The operative time of initial surgery was 5.6 ± 0.2 (1–17) hours. Distribution of craniotomy sites was as follows: fronto-temporal: 227, bifrontal: 74, parietal: 44, frontal+parietal (+temporal): 36, posterior fossa: 27, occipital: 10, frontal: 9, temporal: 6, others: 14, and unknown/no response: 2. The craniotomy area was 83.3 ± 3.1 (4–900) cm^2. The implants used in craniotomy were as follows: titanium plate: 314, titanium mesh: 43, absorbable plate: 27, titanium clamp: 8, others: 3, and unknown/no response: 84. The implants used in cranioplasty were as follows: resin: 42, titanium mesh: 40, ceramics: 23, hydroxyapatite: 16, ultra-high-molecular-weight polyethylene: 8, wire: 5, others: 8 (cranioplasty: 139). Other materials used in combination were as follows: artificial dura: 98, bone cement: 23, burr hole cap: 12, shunt/Ommaya reservoir system: 7, dural prosthetics: 5, others: 2. In 392 cases, the initial surgery had been performed at the same institute where the complication was treated; in 54 cases, the initial surgery had been performed at another institute (unknown/no response: 3).

The types of complications were as follows: infection: 281, implant exposure: 205, skin depression: 7, implant migration: 6, others: 10. The infecting organisms were as follows: methicillin-sensitive *Staphylococcus aureus* (MSSA): 66, methicillin-resistant *Staphylococcus aureus* (MRSA): 64, Enterobacter: 14, methicillin-sensitive *Staphylococcus epidermidis*: 12, Streptococcus: 10, Corynebacterium: 9, *Pseudomonas aeruginosa*: 9, Propionibacterium: 7, others: 40, culture negative: 36, and unknown/no response: 12. The number of cases with concomitant infection was 15. The causes of complication were separately considered as Part A: patient factors, Part B: surgical factors, and Part C: device factors. The patient factors (Part A) were as follows: thin skin: 148, multiple surgeries: 132, advanced age: 57, previous irradiation: 55, cancer: 34, hyponutrition: 32, diabetes mellitus: 29, dirty wound: 27, malcirculation: 25, others: 85, unknown/no response: 80. The surgical factors (Part B) were as follows: uncovered implant: 147, ruptured suture: 31, CSF leakage: 23, sinus maltreatment: 17, skin ischemia: 12, implant malfixation: 9, others: 9, and unknown/no response: 221. Almost no respondents identified any device factors (Part C) (3/449 responses); the device factors that were reported were as follows: malsterilization: 2, implant breakage: 1. The outcome severity/response levels were as follows: re-operation: 439 (dead: 3,

Table 1 Data of patients with complications related to cranial implants

Factor	Evaluation	
Age at the initial surgery (y)	52.1 ± 0.9 (0–86)	
Age at complication (y)	57.3 ± 0.9 (0–86)	
Duration (months)	63.7 ± 4.8 (0–576)	
mRS	The number of cases	%
0	123	27.4
1	103	22.9
2	45	10.0
3	52	11.6
4	69	15.4
5	49	10.9
Male/Female	195/252	
Disease for the initial surgery	The number of cases	%
Tumor	157	35.0
Aneurysm	119	26.5
Trauma	84	18.7
Intracerebral hemorrhage	20	4.5
Cerebral infarct	18	4.0
Moyamoya disease	13	2.9
Epilepsy	9	2.0
Pediatric	7	1.6
AVM	7	1.6
Others	12	2.7
Operative time (hours)	5.6 ± 0.2 (1–17)	
Area of craniotomy (cm^2)	83.3 ± 3.1 (4–900)	
Craniotomy site	The number of cases	%
Fronto-temporal	227	50.6
Bifrontal	74	16.5
Parietal	44	9.8
Frontal+parietal (+T)	36	8.0
Posterior fossa	27	6.0
Occipital	10	2.2
Frontal	9	2.0
Temporal	6	1.3
Others	14	3.1
Implants used in craniotomy	The number of cases	
Titanium plate	314	
Titanium mesh	43	
Absorbable plate	27	
Titanium clamp	8	

Factor	Evaluation	
Implants used in cranioplasty	The number of cases	
Resin	42	
Titanium mesh	40	
Ceramics	23	
Hydroxyapatite	16	
Polyethylene	8	
Others	13	
Materials used in combination	The number of cases	
Artificial dura	98	
Bone cement	23	
Burr hole cap	12	
Shunt/reservoir system	7	
Dural prosthetics	5	
Others	2	
Institute of surgery performed	The number of cases	%
Own	392	87.3
Other	54	12.0
Kind of complications	The number of cases	
Infection	281	
Implant exposure	205	
Skin depression	7	
Implant migration	6	
Others	10	
Infecting organisms	The number of cases	
MSSA	66	
MRSA	64	
Enterobacter	14	
MSSE	12	
Streptococcus	10	
Corynebacterium	9	
Pseudomonas aeruginosa	9	
Others	40	
Cause of complications		
Part A: patient factor	The number of cases	
Thin skin	148	
Multiple surgeries	132	
Aged	57	

Table 1 (Continued)

Factor	Evaluation	
Previous irradiation	55	
Cancer	34	
Hyponutrition	32	
Diabetes mellitus	29	
Dirty wound	27	
Malcirculation	25	
Others	85	
Part B: surgical factor	The number of cases	
Uncovered implant	147	
Ruptured suture	31	
CSF leakage	23	
Sinus maltreatment	17	
Skin ischemia	12	
Implant malfixation	9	
Others	12	
Incident level	The number of cases	%
Re-operation	439	97.8
Medication	7	1.6
Treatment methods	The number of cases	%
Removal with suture	352	78.4
Transplantation	32	7.1
Removal with coverage	18	4.0
Others	40	8.9
Involvement of plastic surgeons	The number of cases	
Neurosurgeons only	339	75.5
N + P	94	20.9
Plastic surgeons only	14	3.1
Length of hospital stay (days)	36.9 ± 3.0 (0–910)	

AVM: arteriovenous malformation, MRSA: methicillin-resistant *Staphylococcus aureus*, mRS: modified Rankin scale, MSSA: methicillin-sensitive *Staphylococcus aureus*, MSSE: methicillin-sensitive *Staphylococcus epidermidis*. Frontal+parietal(+T): frontal+parietal with/without temporal, N+P: neurosurgeon+plastic surgeon.

aftereffect: 3, non-curative: 2), medication: 7, no treatment: 1, unknown/no response: 2. The surgical treatment methods for complications were as follows: removal with suturing: 352, transplantation: 32, removal with coverage: 18, suturing: 15, medication: 5, others: 20, unknown/no response: 8. The involvement of plastic surgeons was as follows: neurosurgeons only: 339, combination of neurosurgeons and plastic surgeons: 94, plastic surgeons only: 14, unknown/no response: 2. The mean length of hospital stay was 36.9 ± 3.0 days (0–910 days).

Risk factors for infection

The results of the univariate analyses of factors related to infection in comparison with other complications are summarized in Table 2. The univariate analyses revealed that male sex, tumor as initial disease, interval shorter than 1 month between initial surgery and complication, usage of ceramics, usage of hydroxyapatite, usage of resin, usage of artificial dura, hyponutrition, multiple surgeries, dirty wound, sinusitis, CSF leakage, ruptured suture, and sinus maltreatment were significantly associated with infection. In contrast, vascular disease, bifrontal craniotomy, usage of titanium mesh, usage of burr-hole cap, and thin skin were negatively associated with infection. The results of the multivariate analyses of factors related to infection as a complication are summarized in Table 3. The multivariate analyses revealed that male sex, tumor as initial disease, interval shorter than 1 month between initial surgery and complication, usage of resin, and usage of artificial dura were significantly associated with infection.

Risk factors for hospital stay longer than 30 days

The results of the univariate analyses of factors related to hospital stay longer than 30 days are summarized in Table 4. The univariate analyses revealed that age at initial disease, male sex, mRS, interval shorter than 1 month between initial surgery and complication, craniotomy area more than 100 cm^2, operative time over 10 hours, usage of ceramics, usage of artificial dura, multiple surgeries, dirty wound, ruptured suture, infection, presence of bacteria, presence of MRSA, and removal as treatment were associated with hospital stay longer than 30 days. The results of the multivariate analyses of factors related to hospital stay longer than 30 days are summarized in Table 5. The multivariate analyses revealed that age at initial disease, male sex, mRS, interval shorter than 1 month between initial surgery and complication, craniotomy area more than 100 cm^2, operative time over 10 hours, usage of titanium plate, usage of ceramics, and usage of artificial dura were associated with hospital stay longer than 30 days.

Discussion

Key findings

This is the first study revealing the current rates of and factors associated with complications related to cranial implants in neurosurgery in Japan. This

Table 2 Univariate analysis for factors associated with infection

Factors	Complications		Univariate	
	Infection	Other	Odds ratio of infection	p value
	n = 168	n = 281		
Patients' characteristics				
Age at the initial surgery ≤10 years (%)	5 (3.0)	12 (4.3)	1.45 (0.50–4.20)	0.49
Age at the initial surgery ≥70 years (%)	31 (18.5)	48 (17.1)	0.91 (0.55–1.50)	0.71
Male sex (%)	51 (30.4)	146 (52.3)	2.51 (1.68–3.77)	**<0.001**
mRS 3–5 (%)	58 (34.7)	111 (40.4)	1.27 (0.85–1.90)	0.24
Disease				
Vascular (%)	85 (51.2)	95 (33.8)	0.49 (0.33–0.72)	**<0.001**
TBI (%)	25 (15.1)	62 (22.1)	1.60 (0.96–2.66)	0.071
Tumor (%)	43 (25.9)	113 (40.2)	1.92 (1.26–2.93)	**0.0022**
Others (%)	13 (7.8)	11 (3.9)	0.48 (0.21–1.10)	0.076
Operation				
Interval ≤1month (%)	8 (4.8)	77 (27.4)	7.50 (3.52–15.99)	**<0.001**
Area of craniotomy ≥100 cm^2 (%)	41 (25.6)	93 (34.1)	1.50 (0.97–2.32)	0.067
Operative time ≥10 hours (%)	14 (11.4)	31 (13.4)	1.21 (0.62–2.37)	0.58
Location				
Fronto-temporal (%)	89 (53.0)	173 (61.8)	1.43 (0.97–2.11)	0.067
Bifrontal (%)	46 (27.4)	35 (12.5)	0.38 (0.23–0.62)	**<0.001**
Occipital or posterior fossa (%)	13 (7.7)	28 (10.0)	1.32 (0.67–2.63)	0.42
Others (%)	20 (11.9)	44 (15.7)	1.38 (0.78–2.43)	0.26
Devices				
Craniotomy				
Titanium plate (%)	131 (78.0)	197 (70.6)	0.68 (0.43–1.06)	0.088
Absorbable plate (%)	10 (6.0)	17 (6.1)	1.03 (0.46–2.29)	0.95
Cranioplasty				
Titanium mesh (%)*	41 (24.4)	44 (15.8)	0.58 (0.36–0.93)	**0.024**
Ceramics (%)	4 (2.4)	22 (7.9)	3.51 (1.19–10.37)	**0.016**
Hydroxyapatite (%)	2 (1.2)	16 (5.7)	5.05 (1.15–22.24)	**0.018**
Polyethylene (%)	2 (1.2)	6 (2.2)	1.82 (0.36–9.14)	0.72
Resin (%)	6 (3.6)	38 (13.6)	4.26 (1.76–10.30)	**<0.001**
Artifacts				
Artificial dura (%)	18 (10.7)	80 (28.5)	3.31 (1.91–5.77)	**<0.001**
Burr-hole cap (%)	9 (5.4)	3 (1.1)	0.19 (0.05–0.71)	**0.012**
Cement paste (%)	9 (5.4)	17 (6.0)	1.14 (0.50–2.61)	0.76
Factors associated with patients				
Aged (%)	25 (14.9)	35 (12.5)	0.81 (0.47–1.41)	0.46
Cancer (%)	11 (6.5)	25 (8.9)	1.39 (0.67–2.91)	0.38
DM (%)	8 (4.8)	21 (7.5)	1.62 (0.70–3.73)	0.26
Thin skin (%)	89 (53.0)	61 (21.7)	0.25 (0.16–0.37)	**<0.001**
Hyponutrition (%)	5 (3.0)	27 (9.6)	3.47 (1.31–9.18)	**0.0082**
Malcirculation (%)	13 (7.7)	12 (4.3)	0.53 (0.24–1.19)	0.12
Multiple surgeries (%)	35 (20.8)	94 (33.5)	1.91 (1.22–2.99)	**0.0042**

Table 2 (Continued)

Factors	Complications		Univariate	
	Infection	Other	Odds ratio of infection	p value
	n = 168	n = 281		
Dirty wound (%)	4 (2.4)	23 (8.2)	3.66 (1.24–10.76)	**0.012**
Previous irradiation (%)	15 (8.9)	42 (14.9)	1.79 (0.96–3.34)	0.064
Sinusitis (%)	2 (1.2)	19 (6.8)	6.02 (1.39–26.18)	**0.0068**
Factors associated with surgeries				
Uncovered implant (%)	64 (38.1)	83 (29.5)	0.68 (0.46–1.02)	0.062
CSF leakage (%)	4 (2.4)	19 (6.8)	2.97 (0.99–8.89)	**0.042**
Skin ischemia (%)	4 (2.4)	6 (2.1)	0.89 (0.25–3.22)	1
Implant malfixation (%)	6 (3.6)	3 (1.1)	0.29 (0.072–1.18)	0.067
Ruptured suture (%)	5 (3.0)	26 (9.3)	3.32 (1.25–8.83)	**0.011**
Sinus maltreatment (%)	2 (1.2)	15 (5.3)	4.68 (1.06–20.73)	**0.026**
Factors associated with devices				
Device failure (%)	0 (0.0)	3 (1.1)	–	0.3

*Titanium mesh was used both in *Craniotomy* and *Cranioplasty*. It is placed in *Cranioplasty* for certain reasons of data collection.
CSF: cerebrospinal fluid, DM: diabetes mellitus, mRS: modified Rankin scale, TBI: traumatic brain injury.

national questionnaire survey has revealed a record high number of cases with complications. The calculated annual incidence of complications related to cranial implants is 0.558% per year. For craniotomy and cranioplasty, titanium plate and mesh were mainly used, respectively. Among 832 cases with complications reported by 183 institutes that responded to the primary survey, detailed data on 449 cases (54.0%) at 68 institutes (37.2%) were obtained in the second survey. Our questionnaire results shed light on various complications and have allowed us to identify risk factors for infection, including male sex, tumor as the initial disease, and usage of resin, ceramics, hydroxyapatite, and artificial dura. Hyponutrition, multiple surgeries, dirty wound, and sinusitis were patient-derived risk factors. CSF leakage, ruptured suture, and sinus maltreatment were surgery-derived risk factors. The multivariate analyses showed that male sex, tumor as initial disease, interval shorter than 1 month between initial surgery and complication, and usage of resin and artificial dura were risk factors for infection. The risk factors for hospital stay longer than 30 days were age at initial disease, male sex, mRS, interval shorter than 1 month between initial surgery and complication, craniotomy area more than 100 cm^2, operative time over 10 hours, usage of ceramics and/or artificial dura, multiple surgeries, dirty wound, ruptured suture, infection, presence of bacteria, presence of MRSA, and removal as treatment. The multivariate analyses showed that age at initial disease, male sex, mRS, interval shorter than 1 month between initial surgery and complication, craniotomy area more than 100 cm^2, operative time over 10 hours, and usage of titanium plate, ceramics, and artificial dura were risk factors for hospital stay longer than 30 days.

Incidence and characteristics of complications related to cranial implants

The incidence of complications related to cranial implants has been explored in several studies. Several large neurosurgical centers in the United States have jointly released a report on complications related to craniotomy, in which, over 11 years from 1997 to 2007, surgery was required for postoperative infection in 0.5% of cases (82/16540 cranial surgeries).[5] In that study, brain tumor was the most frequent causative disease and MSSA was the most common offending organism. That study and ours have a great deal in common in terms of the incidence, causative disease, and offending organism.

In a study on 5361 prospectively evaluated neurosurgical procedures, the rate of subsequently culture-proven infection was 0.61%, although two-thirds of these procedures were spinal procedures.[6] In a single-institute retrospective investigation of the removal of titanium plates after craniotomy, over 3 years from 2014 to 2016, 1.6% (5/319) of patients who had undergone craniotomy later underwent removal of the plates because of pain and

Table 3 Multivariate analysis for factors associated with infection

Variables	Multivariate		
	Odds ratio	95% CI	p value
Patients' characteristics			
Age at the initial surgery ≥70 years	1.77	0.86–3.62	0.12
Male sex	2.5	1.38–4.52	**0.0024**
mRS 3–5	1.16	0.64–2.13	0.62
Disease			
Vascular	2.3	0.61–8.67	0.22
TBI	2.14	0.51–8.96	0.3
Tumor	3.99	1.10–14.52	**0.036**
Others	Ref	Ref	NA
Operation			
Interval ≤1month	15.2	5.27–43.8	**<0.001**
Area of craniotomy ≥100 cm^2	0.89	0.45–1.77	0.74
Operative time ≥10 hours	1.78	0.77–4.12	0.18
Location			
Fronto-temporal	1.13	0.44–2.90	0.79
Bifrontal	0.53	0.20–1.44	0.22
Occipital or posterior fossa	1.37	0.43–4.32	0.59
Others	Ref	Ref	NA
Devices			
Craniotomy			
Titanium plate	0.77	0.34–1.77	0.54
Cranioplasty			
Titanium mesh*	0.6	0.29–1.25	0.18
Ceramics	6.8	1.32–35.05	0.022
Hydroxyapatite	4.1	0.47–36.09	0.2
Resin	6.9	1.45–32.84	**0.015**
Artifacts			
Artificial dura	2.28	1.10–4.75	**0.027**
Burr-hole cap	0.019	0.0014–0.25	**0.0027**

*Titanium mesh was used both in *Craniotomy* and *Cranioplasty*. It is placed in *Cranioplasty* for certain reasons of data collection. mRS: modified Rankin scale, TBI: traumatic brain injury.

protrusion, although this might be a relatively high incidence.[7)]

Studies specifically addressing complications after cranioplasty offer additional detailed information. The incidence of complications related to titanium mesh was reported at the relatively high rate of 29% among 127 cranioplasties in Western Australia.[8)] Infection was the most frequent complication type with an incidence of 18%. Large titanium mesh was a significant risk factor for infection. Similar data have been reported in a study in England[9)] in which the rates of complication and titanium plate removal were 26.4% and 10.3%, respectively. In 69% of cases with system removal, removal was indicated due to infection. The risk factors associated with complications were trauma as the initial disease and large skull defect (larger than 100 cm^2).

In another study, 155 non-titanium cranioplasties performed between 2005 and 2016 at a single institute in Japan were retrospectively reviewed.[10)] The overall complication rate was 12.3%. Infection was the most frequent complication, occurring at a rate

Table 4 Univariate analysis factors associated with hospital stay longer than 30 days

Factors	Hospital stay longer than 30 days		Univariate	
	No	Yes	Odds ratio	p value
	n=287	n=154		
Patients' characteristics				
Age at the initial surgery ≤10 years (%)	11 (3.8)	6 (3.9)	1.02 (0.37–2.81)	1
Age at the initial surgery ≥70 years (%)	41 (14.3)	37 (24.0)	1.90 (1.16–3.12)	**0.011**
Male sex (%)	107 (37.5)	85 (55.2)	2.05 (1.38–3.05)	**<0.001**
mRS 3–5(%)	83 (29.3)	81 (53.6)	2.79 (1.85–4.20)	**<0.001**
Disease				
Vascular (%)	122 (42.5)	56 (36.8)	0.79 (0.53–1.18)	0.25
TBI (%)	49 (17.1)	35 (23.0)	1.45 (0.89–2.36)	0.13
Tumor (%)	100 (34.8)	53 (34.9)	1.00 (0.66–1.51)	1
Others (%)	16 (5.6)	8 (5.3)	0.94 (0.39–2.25)	0.89
Operation				
Interval ≤1month (%)	39 (13.6)	45 (29.2)	2.61 (1.61–4.24)	**<0.001**
Area of craniotomy ≥100 cm2 (%)	67 (24.3)	66 (44.0)	2.45 (1.60–3.74)	**<0.001**
Operative time ≥10 hours (%)	21 (9.9)	23 (17.0)	1.88 (0.99–3.55)	**0.0496**
Location				
Fronto-temporal (%)	158 (55.1)	100 (65.4)	1.54 (1.03–2.31)	**0.037**
Bifrontal (%)	58 (20.2)	22 (14.4)	0.66 (0.39–1.13)	0.13
Occipital or posterior fossa (%)	33 (11.5)	7 (4.6)	0.37 (0.16–0.86)	**0.016**
Others (%)	38 (13.2)	24 (15.7)	1.22 (0.70–2.12)	0.48
Devices				
Craniotomy				
Titanium plate (%)	216 (75.3)	108 (71.1)	0.81 (0.52–1.25)	0.34
Absorbable plate (%)	18 (6.3)	8 (5.3)	0.83 (0.35–1.96)	0.67
Cranioplasty				
Titanium mesh (%)*	61 (21.3)	22 (14.5)	0.63 (0.37–1.07)	0.084
Ceramics (%)	12 (4.2)	14 (9.2)	2.32 (1.05–5.16)	**0.034**
Hydroxyapatite (%)	12 (4.2)	6 (3.9)	0.94 (0.35–2.56)	0.91
Polyethylene (%)	5 (1.7)	2 (1.3)	0.75 (0.4–3.92)	1
Resin (%)	27 (9.4)	17 (11.2)	1.21 (0.64–2.30)	0.56
Artifacts				
Artificial dura (%)	41 (14.3)	56 (36.4)	3.43 (2.15–5.46)	**<0.001**
Burr-hole cap (%)	7 (2.4)	4 (2.6)	1.07 (0.31–3.70)	0.92
Cement paste (%)	15 (5.2)	11 (7.1)	1.39 (0.62–3.12)	0.42
Factors associated with patients (%)				
Aged (%)	38 (13.2)	21 (13.6)	1.03 (0.58–1.83)	0.91
Cancer (%)	20 (7.0)	16 (10.4)	1.55 (0.78–3.08)	0.21
DM (%)	18 (6.3)	11 (7.1)	1.15 (0.53–2.50)	0.73
Thin skin (%)	105 (36.6)	41 (26.6)	0.63 (0.41–0.97)	**0.034**

(*Continued*)

Table 4 (Continued)

Factors	Hospital stay longer than 30 days		Univariate	
	No	Yes	Odds ratio	p value
	n=287	n=154		
Hyponutrition (%)	15 (5.2)	15 (9.7)	1.96 (0.93–4.12)	0.073
Malcirculation (%)	15 (5.2)	10 (6.5)	1.26 (0.55–2.87)	0.58
Multiple surgeries (%)	68 (23.7)	59 (38.3)	2.00 (1.31–3.06)	**0.0012**
Dirty wound (%)	12 (4.2)	14 (9.1)	2.29 (1.03–5.09)	**0.037**
Previous irradiation (%)	36 (12.5)	21 (13.6)	1.10 (0.62–1.96)	0.74
Sinusitis (%)	11 (3.8)	10 (6.5)	1.74 (0.72–4.20)	0.21
Factors associated with operators				
Uncovered implant (%)	101 (35.2)	44 (28.6)	0.74 (0.48–1.13)	0.16
CSF leakage (%)	13 (4.5)	10 (6.5)	1.46 (0.63–3.42)	0.38
Skin ischemia (%)	5 (1.7)	5 (3.2)	1.89 (0.54–6.64)	0.31
implant malfixation (%)	9 (3.1)	0 (0.0)	–	0.03
Ruptured suture (%)	14 (4.9)	17 (11.0)	2.42 (1.16–5.05)	**0.016**
Sinus maltreatment (%)	9 (3.1)	7 (4.5)	1.47 (0.54–4.03)	0.45
Factors associated with devices				
Device failure (%)	2 (0.7)	1 (0.6)	0.93 (0.08–10.35)	1
Types of complications				
Exposure (%)	131 (45.6)	21 (13.6)	0.19 (0.11–0.31)	**<0.001**
Infection (%)	145 (50.5)	132 (85.7)	5.88 (3.54–9.76)	**<0.001**
Bacterium positive (%)	97 (66.4)	103 (78.0)	1.79 (1.05–3.07)	**0.032**
MRSA (%)	23 (15.8)	39 (29.5)	2.24 (1.25–4.01)	**0.0058**
Multi-bacterium (%)	9 (6.2)	4 (3.0)	0.48 (0.14–1.58)	0.22
Treatment				
Medication alone (%)	4 (1.4)	2 (1.3)	0.93 (0.17–5.16)	0.94
With plastic surgery (%)	56 (19.5)	42 (27.3)	1.55 (0.98–2.45)	0.062
Removal (%)	255 (89.2)	146 (95.4)	2.54 (1.09–5.90)	**0.026**
Transplantation (%)	17 (5.9)	15 (9.8)	1.72 (0.83–3.55)	0.14

*Titanium mesh was used both in *Craniotomy* and *Cranioplasty*. It is placed in *Cranioplasty* for certain reasons of data collection. CSF: cerebrospinal fluid, DM: diabetes mellitus, mRS: modified Rankin scale, TBI: traumatic brain injury.

of 8.4%, followed by postoperative epidural hemorrhage at 2.6% and ruptured suture at 1.3%. In that study, long operative time (over 98 minutes) was a significant risk factor for infection.

Several studies have reported on complication rates in pediatric cranioplasty. A multicenter retrospective study reported an infection rate of 10.5% in 359 pediatric patients.[11] In a study on pediatric cranial reconstruction for craniosynostosis with resorbable plate system, the incidence of unplanned re-operation was 5.4%.[12] The relatively low incidences of complications in this study might be explained by the usage of a resorbable plate system and a procedure that does not involve dura opening.

Risk factors for infection after neurosurgical procedure

In our study, cases with complications were analyzed and risk factors for infection were explored. Male sex, brain tumor as the initial disease, cranioplasty with resin, combined usage of several artifacts (artificial dura, burr hole cap, and bone cement), CSF leakage, ruptured suture, sinus maltreatment, hyponutrition, multiple surgeries, dirty wound, and

Table 5 Multivariate analysis for factors associated with hospital stay over 30 days

Variables	Multivariate		
	Odds ratio	95% CI	p value
Patients' characteristics			
Age at the initial surgery ≥70 years	2.01	1.02–3.99	**0.044**
Male sex	2.91	1.64–5.17	**<0.001**
mRS 3–5	2.06	1.17–3.63	**0.013**
Disease			
Vascular	0.99	0.29–3.41	0.99
TBI	0.49	0.13–1.81	0.28
Tumor	0.62	0.18–2.09	0.44
Others	Ref	Ref	NA
Operation			
Interval ≤1month	3.22	1.69–6.12	**<0.001**
Area of craniotomy ≥100 cm^2	1.94	1.03–3.64	**0.04**
Operative time ≥10 hours	7.21	3–17.30	**<0.001**
Location			
Fronto-temporal	0.53	0.22–1.26	0.15
Bifrontal	0.52	0.2–1.39	0.19
Occipital or posterior fossa	0.13	0.035–0.47	**0.0018**
Others	Ref	Ref	NA
Devices			
Craniotomy			
Titanium plate	1.26	0.64–2.50	**0.04**
Cranioplasty			
Titanium mesh*	1.19	0.59–2.40	0.63
Ceramics	4.05	1.32–12.47	**0.015**
Artifacts			
Artificial dura	2.8	1.47–5.34	**0.0017**

*Titanium mesh was used both in *Craniotomy* and *Cranioplasty*. It is placed in *Cranioplasty* for certain reasons of data collection. mRS: modified Rankin scale, TBI: traumatic brain injury.

sinusitis were the relevant risk factors. Cases with these risk factors should be handled with more cautions and steps should be taken to minimize the risks.

In several studies, large skull defect in cranioplasty was the risk factor for infection.[5,6] In our study, however, an area of craniotomy/cranioplasty over 100 cm^2 was not a significant risk factor. Similarly, long operative time was a significant risk factor in some studies,[7] although it was not significant in ours. The explanation for these discrepancies might lie in the fact that cases with craniotomy and cases with cranioplasty were analyzed together in our study. A retrospective study using data on 258 cranioplasties reported a complication rate of 10.9% (28/258 cases) and found that risk factors for infection were male sex, brain tumor, and surgery at the county hospital.[13] Similarly, in our study, male sex and brain tumor were considered the main risk factors for infection. Very recently, a multicenter retrospective study on autologous cranioplasty revealed that smoking and age less than 45 years were risk factors for complications requiring bone flap removal and that age less than 30 years was a risk factor for bone flap resorption.[14] In our study, we did not assess bone flap resorption because the aim was to assess complications related to cranial implants. As bone flap resorption does sometimes occur, however, its incidence and risk factors should be explored in the future.

Study limitations

This was a retrospective questionnaire-based study. The response rate in the primary survey was 30.6% (337/1103 institutes) and that in the second survey was 54.0% of cases with complications (449/832 patients). The response rates may be sufficiently high, yet the results of questionnaire surveys are not guaranteed to accurately represent all cases with complications.

Additionally, we reported the rates of complications related to cranial implants, including both craniotomy and cranioplasty. In our evaluation of the risk factors associated with infection, we only used the data on cases with complications. Our study therefore provides detailed information on cases with complications, but not cases without complications. This situation might limit the usefulness of risk factors for infection and long hospital stay. Although readers should consider these limitations, we believe that our data will be informative to neurosurgeons around the world.

Conclusions

Even after a long and uneventful postoperative period, complications related to cranial implants may arise after craniotomy/cranioplasty. The use of cranial implants is now common practice, but we still need to perform each neurosurgical procedure with care to minimize complications after surgery and keep the risk factors for complications in mind.

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Conflicts of Interest Disclosure

The authors have no COI to be declared related to this study.

References

1) Smith SC, Pelofsky S: Adaptation of rigid fixation to cranial flap replacement. *Neurosurgery* 29: 417–418, 1991
2) Yoshioka N, Tominaga S: Titanium mesh implant exposure due to pressure gradient fluctuation. *World Neurosurg* 119: e734–e739, 2018
3) Takumi I, Akimoto M: One-stage reconstruction using a vascularized calvarial flap for intractable scalp ulcers in relation with cranial implants without removing the whole prosthesis. *Neurosurg Rev* 32: 363–368, discussion 368, 2009
4) Takumi I, Akimoto M, Hironaka K, et al.: Pedicle galeo-pericranial flap augmentation in salvage frontotemporal cranioplasty: additional 'neurosurgeon-friendly' reconstruction technique of aesthetic neurosurgery in superficial temporal artery branch compromised host. *Neurol Med Chir (Tokyo)* 58: 350–355, 2018
5) Dashti SR, Baharvahdat H, Spetzler RF, et al.: Operative intracranial infection following craniotomy. *Neurosurg Focus* 24: E10, 2008
6) Theodosopoulos PV, Ringer AJ, McPherson CM, et al.: Measuring surgical outcomes in neurosurgery: implementation, analysis, and auditing a prospective series of more than 5000 procedures. *J Neurosurg* 117: 947–954, 2012
7) Gupta R, Adeeb N, Griessenauer CJ, et al.: Removal of symptomatic titanium fixation plates after craniotomy. *Acta Neurochir (Wien)* 158: 1845–1848, 2016
8) Wiggins A, Austerberry R, Morrison D, Ho KM, Honeybul S: Cranioplasty with custom-made titanium plates—14 years experience. *Neurosurgery* 72: 248–256, discussion 256, 2013
9) Mukherjee S, Thakur B, Haq I, Hettige S, Martin AJ: Complications of titanium cranioplasty—a retrospective analysis of 174 patients. *Acta Neurochir (Wien)* 156: 989–998, discussion 998, 2014
10) Shibahashi K, Hoda H, Takasu Y, Hanakawa K, Ide T, Hamabe Y: Cranioplasty outcomes and analysis of the factors influencing surgical site infection: a retrospective review of more than 10 years of institutional experience. *World Neurosurg* 101: 20–25, 2017
11) Rocque BG, Agee BS, Thompson EM, et al.: Complications following pediatric cranioplasty after decompressive craniectomy: a multicenter retrospective study. *J Neurosurg Pediatr* 22: 225–232, 2018
12) Branch LG, Crantford C, Cunningham T, et al.: Long-term outcomes of pediatric cranial reconstruction using resorbable plating systems for the treatment of craniosynostosis. *J Craniofac Surg* 28: 26–29, 2017
13) Klinger DR, Madden C, Beshay J, White J, Gambrell K, Rickert K: Autologous and acrylic cranioplasty: a review of 10 years and 258 cases. *World Neurosurg* 82: e525–530, 2014
14) Korhonen TK, Tetri S, Huttunen J, et al: Predictors of primary autograft cranioplasty survival and resorption after craniectomy. *J Neurosurg* 130: 1672–1679, 2019

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