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The Evolution of Modern Treatment for Depressed Skull Fractures

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Key words
- Compound skull fracture
- Depressed skull fracture
- Ping-pong skull fracture
- Skull fracture elevation

Abbreviations and Acronyms
CT: Computed tomography
DSF: Depressed skull fracture

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Surgery for depressed skull fractures has developed over centuries to attain the consensus approaches currently used. This review outlines the last 200 years of development of surgical approaches to closed and open depressed skull fractures, fractures involving dural venous sinuses and ping-pong fractures involving infants. Early reports often dealt with only closed and open depressed skull fractures. However, experience has shown that each fracture category merits its own management strategies. Accepted approaches are based on observation only; there is little to no scientific evidence to support treatment for any fracture type.

> Though many scalp wounds which appear serious prove to be trifling, more which appear trifling prove to be serious.
>
> Harvey Cushing

INTRODUCTION

Treatment of depressed skull fracture (DSF) has been discussed in some of the oldest recorded medical literature, and there is even evidence of surgery for DSF in prehistoric times.[1,2] Approaches to DSFs from ancient times until 1800 were reviewed recently by Ganz and Arndt.[3] This purpose of this publication is to update their review to include modern surgical strategies.

METHODS

A search of PubMed and EMBASE was performed in July 2018, using the search terms "Skull Fracture, Depressed" as a medical subject heading; "Skull Fractures" as a subject heading with "Depressed" in the title and the combination of "Depressed," "Skull" and "Fracture" as title terms. Additional references were obtained from the bibliographies of neurosurgical and neurotrauma textbooks and from older (pre-MEDLINE) articles.

RESULTS

The literature search yielded 380 publications, and an additional 143 articles from various bibliographies. Case reports were excluded unless they introduced novel therapies. Also excluded were laboratory studies, editorials, or letters without original data and articles containing duplicated data. The 124 articles remaining constitute the basis for this review.

Nineteenth Century

Enthusiasm for aggressive surgical intervention in cases of DSF, so common in the eighteenth century, was tempered by the frighteningly high rate of fatal infection.[4] Several authorities questioned the effectiveness and safety of surgery.[5-7] In a review of surgical practice in the 1800s, Gamgee[8] concluded that trephination had nearly been abandoned on the European continent and was still being practiced primarily in Great Britain and the United States. Open DSFs were commonly packed and allowed to heal by secondary intention. Despite the contributions of Pasteur and Lister, surgeons often attributed infections to "bad air" in their hospitals.[9] It was not until the late nineteenth century, with the introduction of aseptic surgical techniques and antiseptics, that trephination for DSF became popular once more.[4] There were several case reports of successful elevations of closed and even open DSFs. Victor Horsley[10] recommended routine elevation of bone fragments to relieve local signs and prevent epilepsy. For open fractures, MacEwen[11] suggested soaking the wound and bone fragments in antiseptic and replacing the fragments immediately, whereas Phelps[12] recommended discarding them.

Early Twentieth Century

At the turn of the century and for many years thereafter, head injury literature focused on the location and type of skull fracture. Perhaps this focus was because DSFs were so obvious on physical examination and so prominent on newly introduced roentgenography. Harvey Cushing[13] pointedly reminded surgeons that it was the intracranial injury that mattered more than the fracture itself. He soon abandoned his early practice of enlarging the scalp laceration associated with open DSFs in a radial fashion, because of poor wound healing.[14] There was little agreement over the indications for elevating closed DSFs,[15] for using antiseptics in open fractures,[16] for removing contaminated bone fragments,[17] for repairing dural tears,[18] or for replacing bone fragments,[15] performing an immediate cranioplasty,[18] or leaving a bony defect.[19] A case of an adult with spontaneous elevation was reported as evidence that immediate elevation is unnecessary.[20]

When Cushing reported his World War I experience with fractures, he recommended elevating all closed DSFs with the aid of a trephine at the fracture periphery. He also justified inspecting the dura and repairing tears to reduce the risk of epilepsy. He advocated immediate surgery for open DSFs to prevent infection, aggressive skin debridement, discarding all bone fragments, and tight skin closure. Roberts and Kelly[21] were among the first to recommend replacement of bone fragments in open DSF, but only if the scalp wound was clean and the dura intact. Throughout the 1920s and 1930s, there was no standardized approach to DSF; several investigators suggested delayed or no elevation of open injuries. This strategy included applying antiseptic to the wound and draining, covering, or closing the scalp.[22-25]

Dealing with World War II injuries taught surgeons the value of immediate debridement, careful cleaning of the wound, and dural closure for open DSFs.[26] Although some authorities[27] simply removed the bone fragments and performed cranioplasty at a later date, others performed immediate cranioplasty with adjacent outer table of the skull[28] or acrylic.[29] Although in short supply, penicillin was recommended as prophylaxis against infection.[29] Once penicillin became more widely available, prophylaxis was recommended, and elevated bone fragments could be replaced immediately.[30,31] Although there were no agreed guidelines for elevating closed DSFs, elevation usually involved a marginal burr hole, dissection of individual bone fragments, and replacement to cover the bony defect.[32] For deep depressions, Rogers[33] recommended craniotomy around the fracture and reversing and replacing it.

Modern Literature

Since 1960, there has been a burgeoning literature about treatment of DSFs (**Figure 1**). The diagnosis of DSF, usually suspected on physical examination, is readily confirmed by skull radiography. Cranial computed tomography (CT) scans are usually adequate both to diagnose DSF and to rule out intracranial hemorrhage or injury.[34] Tangential radiographic views are useful in fractures of the vertex, a site where CT scans lack maximal resolution.[35] Sometimes three-dimensional reconstruction of the CT scan (**Figure 2**) helps to understand the injury mechanism or to plan surgery.[36,37] In the modern period, the uniqueness of the individual fracture categories and the treatments for them became apparent. Although outcome is more dependent on brain damage than on the fracture itself,[38] the following sections are organized by fracture category to simplify discussion.

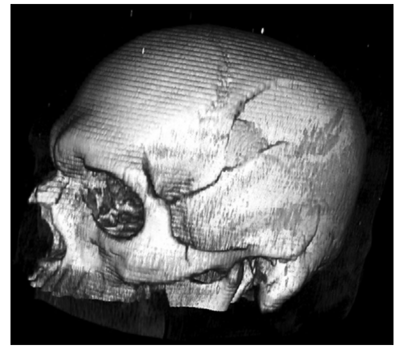

Figure 2. Three-dimensional cranial computed tomography scan of large left parietal depressed skull fracture. Also pictured is a linear fracture running obliquely upward and communicating with the depressed fracture.

Closed DSF. Reported indications to elevate closed DSFs run the spectrum from routine elevation[39-42] to operating only on those with intracranial complications[43-46] or cosmetic deformity.[47] Most authorities are somewhere in between.[48-54] A list of consensus indications for fracture elevation is shown in **Table 1**. Typically, 1 cm is chosen as the minimum depth to

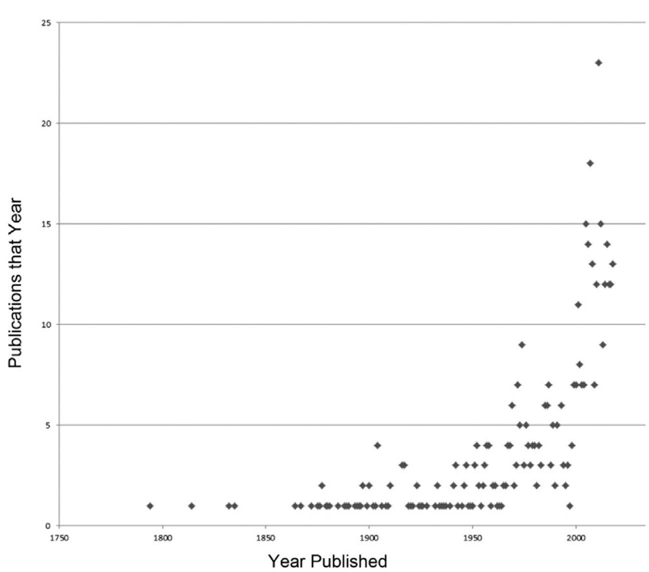

Figure 1. Number of publications per year found on PubMed search, plotted against year of publication.

Table 1. Indications for Surgery to Elevate Depressed Skull Fractures

Closed	Open (Compound) Same as Closed, Plus:
Mass effect	Depression >1 cm deep
Intracranial hematoma or large contusion, requiring surgery	Evidence of dural penetration (e.g., intracranial air, cerebrospinal fluid, or brain visible)
Severe bone depression	Grossly contaminated wound
Focal neurologic deficit	Infected wound
Other evidence of dural laceration	Large, complex, ragged scalp laceration
Unacceptable cosmetic deformity	
Frontal sinus involvement	

Table 2. Case Series—Open Depressed Skull Fracture

Reference	Number of Cases	Dural Laceration (%)	Dural Coverage	Prophylactic Antibiotics (%)	Infection Rate (%)
AbdelFatah, 2016[75]	76	28	Bone fragments	100	0
Adeloye and Shokunbi, 1993[76]	12	58	Bone fragments	100	0
Ahmad et al., 2018[77]	70	57	Bone fragments	100	6
Akram et al., 2007[78]	51	NR	Bone fragments	NR	6
Al-Haddad and Kirollos, 2002[79]	73	49	Bone fragments	100	8
Ali et al., 2011[80]	75	NR	Bone fragments	NR	8
Blankenship et al., 1990[81]	31	48	Bone fragments	100	0
Braakman, 1972[49]	152	63	Bone fragments	100	7
Carrington et al., 1960[82]	20	70	Bone fragments	NR	25
Coulon, 1983[83]	57	NR	Bone fragments	NR	4
Curry and Frim, 1999[84]	7	43	Bone fragments	100	0
Ersahin et al., 1996[52]	350	30	Bone fragments	100	2
Heary et al., 1993[85]	28	NR	Bone fragments	100	0
Heary et al., 1993[85]	26	81	No elevation	100	0
Heiskanen et al., 1973[39]	166	56	Delayed cranioplasty	NR	4
Jamieson and Yelland, 1972[41]	240	62	Bone fragments	0	8
Jennett and Miller, 1972[73]	359	52	Bone fragments	100	11
Kaptigau et al., 2007[86]	23	NR	Bone fragments	NR	9
Katikar et al., 2014[87]	30	NR	No elevation	100	7
Katikar et al., 2014[87]	30	NR	Bone fragments	100	7
Knoringer, 1979[63]	101	NR	Immediate cranioplasty	NR	7
Kriss et al., 1969[88]	79	NR	Bone fragments	100	3
Kumar et al., 2010[89]	26	100	Bone fragments	NR	15
Marbacher et al., 2008[90]	5	NR	Immediate cranioplasty	NR	0
Mendelow et al., 1983[91]	176	51	Delayed cranioplasty	89	6
Miller and Jennett, 1968[74]	486	50	NR	NR	8
Mukherjee et al., 2015[92]	183	26	No elevation	0	4
Mukherjee et al., 2015[92]	49	51	Bone fragments	0	18
Nadell and Kline, 1974[72]	85	56	Bone fragments	100	40
Nnadi et al., 2014[93]	14	NR	Delayed cranioplasty	100	29
Plese and Humphreys, 1981[94]	60	57	50% bone fragments	50	0
Prakash et al., 2018[95]	401	65	Bone fragments	NR	17
Rehman et al., 2007[96]	56	41	Bone fragments	100	5
Rolekar, 2014[43]	18	17	Bone fragments	NR	17
Sande et al., 1980[97]	216	NR	Nr	NR	4
Sande et al., 1980[97]	359	NR	Nr	NR	11
Satardey et al., 2018[38]	32	44	Bone fragments	NR	22
Subczynski, 1977[98]	25	40	Immediate cranioplasty	NR	4
van den Heever and van der Merwe, 1989[99]	143	NR	No elevation	100	3
van den Heever and van der Merwe, 1989[99]	125	NR	Bone fragments	100	8
Wylen et al., 1999[100]	32	69	Bone fragments	100	0

NR, not reported.

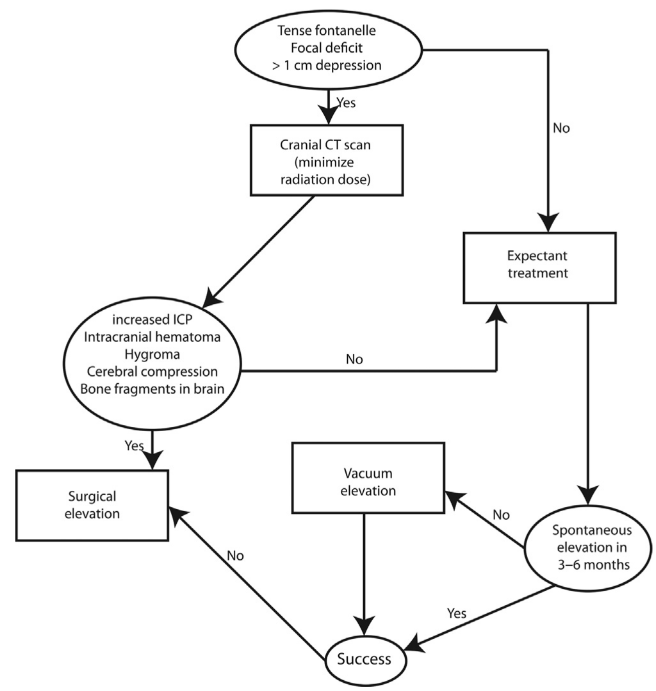

Figure 3. Suggested algorithm for dealing with ping-pong depressed skull fractures in newborns. CT, computed tomography; ICP, intracranial pressure.

require DSF elevation, perhaps because of the greater likelihoods of dural tear and cerebral compression. Without evidence that another depth is a more precise indicator, 1 cm is accepted by most authorities. If there is cosmetic deformity, particularly at or near the hairline, elevation may be needed, even for a smaller depression. There is no evidence that immediate elevation of bone fragments relieves focal deficit,[48] but the hope persists that it improves local blood flow.[51] Both dural tears and late-onset epilepsy are common with closed DSF,[55,56] the incidence of dural laceration being highly correlated with the depth of fracture depression.[57] Cushing[58] hypothesized that dural tears predispose to epilepsy and that dural repair is protective. However, there is no evidence to support this practice,[48,50,54] nor have prophylactic antiepileptics been shown to be protective.[59] As suggested by Chiarelli et al.,[51] epilepsy after DSF is the result of cortical damage at impact, and its development is independent of whether the dura is closed or left open.

Although most often fracture elevation is performed soon after injury, emergency surgery is rarely indicated.[60] If another surgical procedure is not indicated, waiting until the patient can tolerate anesthesia safely is preferable to emergency fracture elevation.[51] Most often, the bony fragments are elevated piecemeal or with the aid of a peripheral burr hole. A high-speed drill may facilitate mobilization of bone fragments.[61] Although healing usually occurs satisfactorily after the fragments are replaced, obtaining ideal bony contour may require cranioplasty,[62-64] titanium clamps,[45,65,66] or miniplates.[67,68]

Dural Sinus Involvement. Midline or occipital DSFs have the potential to compress or lacerate the superior sagittal or (rarely) the transverse sinus. Cases treated surgically have been reported as far back as the 1800s.[69] The sinus may become stenotic or occluded secondary to direct compression or thrombosis. Because of the risks associated with massive sinus hemorrhage, fracture elevation should be performed only if indicated and if the surgical team is prepared for sinus repair or reconstruction. CT venography should be performed if a DSF overlies the sinus, especially if there is neuroimaging evidence of venous infarction or if the patient develops delayed signs of intracranial hypertension. In the event of sinus compression, careful surgical elevation should be considered.[70] Chiarelli et al.[51] have summarized approaches to dealing with a lacerated sinus. Open DSFs over a sinus should also be elevated, although surgical complications are common.[71] Nadel and Kline[72] had success soaking bone fragments in Betadine and replacing them.

Open (Compound) DSF. Open fracture carries a higher incidence of infection, epilepsy, and death than does closed.[73,74] For that reason, many have recommended prompt and aggressive surgery. Table 2 summarizes the results of 37 modern series, including 4547 cases. Four series compared patients with fracture elevation with those with only scalp debridement, although only one can be considered a controlled trial.[87] Pooled average values from the case series were calculated using inverse-variance random-effects meta-analysis for observational data. The mean incidence of dural tears was 52.4% (±13.8%) in open DSF, and an infection occurred in 8.6% (±5.2%) of cases. The pooled mean infection rate was 7.1% (±5.8%) in patients who received prophylactic antibiotics and 9.9% (±3.4%) in those who did not. A t test shows no significant advantage ($P = 0.432$) to taking prophylactic antibiotics to prevent infection. Although prophylactic antibiotics are commonly used[51,74,91,101] and recommended in the most recent traumatic brain injury guidelines,[50] there is little evidence that they prevent postoperative infection in open DSFs.[48,102]

Operative repair traditionally involves generous irrigation and meticulous scalp debridement, removal of all free bone fragments, dural inspection, and repair as needed. Immediate replacement of bone fragments seems safe[49,55,81,88] and is recommended.[50] Salia et al.[103] have created a sensitive algorithm that predicts dural laceration using the presence (or absence) of pneumocephus or cerebral contusion and the depth of the fracture. As mentioned earlier, the significance of a dural tear and the benefits of repair are uncertain in open DSFs[92,95] as well as in closed.

Several have questioned the need for bony removal in all cases of open DSF. In cases in which the fracture is shallow and the wound is small and clean, washout, scalp debridement, and closure, in the operating room or at the bedside, do not increase the risk of infection or other complications.[60,85,86,92,99,104] A list of indications for more extensive surgery, including elevation of bony fragments, is shown in **Table 1**.

Ping-Pong Fracture. Ping-pong fracture, also called greenstick, pond, celluloid-ball, and derby hat fracture, usually occurs at the time of delivery. It is usually obvious on inspection, and skull radiographs usually show incomplete fracturing. When no cortical fracture accompanies the depression, the condition is termed faulty fetal packing.[105] Although plain or three-dimensional CT scans have been promoted as providing more information than plain radiographs,[106,107] radiation risks are unacceptable for all but the largest, deepest, and most complex cases.[108]

Traditionally, all such fractures were treated with urgent or semi-elective elevation,[33,109-113] originally by inserting a periosteal elevator through a burr hole at the margins of the fracture and levering the depressed bone fragments up. Other surgical approaches have included inserting the elevator through the coronal or lambdoidal sutures,[114] inserting a sharp hook or percutaneous screw through the fracture apex and pulling,[110,115] cutting a circumferential trench around the fracture with a high-speed drill or scissors,[116] excising, remolding, and reinserting the fracture.[33] Several investigators have reported successful fracture elevations after the application of suction.[117-120] Instruments used have included vacuum extractors, breast pumps, and even a neonatal face mask attached to a 50-mL syringe. Digital pressure at the margins of the fracture has sometimes resulted in elevation without need for further intervention.[121,122]

The observation that some ping-pong DSFs resolved spontaneously prompted longer periods of observation.[113] It is now generally accepted that most fractures elevate on their own over time.[51,106] One potential concern is cortical compression by deep fracture; the threshold has been hypothesized to be 0.5–1 cm.[118,120,123] Several indications for intervention have been suggested, the most practical being by Strong et al.[124] **Figure 3** has been modified from their algorithm.

Widely accepted approaches to each category of DSF are based entirely on observation and application of conventional surgical principles. Compelling scientific evidence is lacking to justify any of the measures currently used to deal with DSF. It can only be hoped that well-designed randomized controlled trials will serve as the bases for DSF treatment in the future.

CONCLUSIONS

Over the centuries, there have been many different approaches to DSF. Management strategies have evolved, based on observation and clinical judgement. Only in modern times have we recognized that treatment should be tailored to the clinical needs of each specific type of fracture. Nevertheless, there is a lack of scientific evidence to support present consensus treatments.

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