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The Mayfield Skull Clamp: A Literature Review of Its Complications and Technical Nuances for Application

Dieter Thijs and Tomas Menovsky

■ BACKGROUND: **The Mayfield skull clamp is the most commonly used 3-pin head immobilization device. It is routinely used in cranial neurosurgical procedures and selected cervical procedures. Despite its role in some serious complications, guidelines and nuances on the correct application of the Mayfield clamp are lacking. The goal of this article was to present an overview of the complications associated with the Mayfield skull clamp. We also present a conceptual framework of the correct use—in our opinion—of the Mayfield clamp in several standard approaches to avoid the most common complications.**

■ METHODS: **PubMed was searched for original articles published between 1980 and 2020 with the search terms "Mayfield skull clamp" and "Mayfield head clamp." Eligibility criteria were availability of English abstract and complications clearly attributed to the Mayfield skull clamp. Both authors assessed all search results for eligibility. Additional articles were found with cross-references.**

■ RESULTS: **The most common complications associated with Mayfield clamp application were due to vascular injury inflicted by the pins or skull fractures. Complications related to use of the Mayfield clamp were rare but often serious and avoidable. A conceptual framework was presented on how to avoid these complications.**

■ CONCLUSIONS: **Attention to detail, anatomy, and the *primum non nocere* principle are imperative in every step of the neurosurgical pathway, including placement of the Mayfield skull clamp. Thoughtful application, taking into consideration several nuances, is recommended to avoid inadvertent patient harm.**

INTRODUCTION

The Mayfield skull clamp is the most commonly used 3-pin head immobilization device (HID). It is routinely used in cranial neurosurgical procedures and in selected cervical procedures. Guidelines on the correct application of the skull clamp are lacking. Complications related to the use of the Mayfield clamp are rare but often avoidable. In this article, we discuss the nuances on how to avoid these complications and propose a checklist for safe Mayfield clamp application based on the literature, experience, and common sense.

MATERIALS AND METHODS

PubMed was searched for original articles published between 1980 and 2020 with the search terms "Mayfield skull clamp" and "Mayfield head clamp." Eligibility criteria were availability of English abstract and complications clearly attributed to the Mayfield skull clamp. Both authors assessed all search results for eligibility. Additional articles were found with cross-references. A summary of all reported complications is provided. Institutional review board approval was not sought as this study was an analysis of existing data.

RESULTS AND DISCUSSION

Complications Associated with Mayfield Clamp Placement

Several complications attributable to the use of the Mayfield skull clamp have been reported. **Table 1** summarizes these complications with their probable causes and consequences for the patient.[1-28] Some complications were lethal, most of them being related to vascular injury. Taking into account the fact that the Mayfield clamp is so widely used, the frequency of reported complications is low. This is presumably because they are not recognized as such and lack novelty in reporting.[29] Alarming signs that require immediate clamp revision and diagnostic interventions are 1) a cracking sound on application of the HID, 2) plunging of the pin deeper than expected, 3) an

Key words
- Complications
- Head immobilization device
- Mayfield
- Skull clamp

Abbreviations and Acronyms
HID: Head immobilization device

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Table 1. Review of Reported Complications Related to Use of 3-Pin Skull Clamp and Probable Causes and Consequences

Complication	Reference	Probable Cause	Consequence
Arteriovenous fistula	Inagawa et al., 1984[1]	Penetration of MMA	Dural arteriovenous fistula requiring surgical ligation
Asystole	Miyoshi et al., 2015[2]	Trigeminocardiac reflex after pin placement; brainstem herniation due to skull compression (in Chiari type I malformation)	Immediate removal of skull clamp; atropine administration
Clamp breakage	Chovanes, 1992[3]; Taira and Tanikawa, 1992[4]; Lee et al., 2009[5]	Unclear; maybe fatigue fracture	No patient harm
CSF rhinorrhea	Moumoulidis and Fernandes, 2008[6]	Frontal sinus fracture	Managed with external lumbar drainage
Skull fracture with/without associated epidural hematoma	Baerts et al., 1984[7]	Thinned skull in hydrocephalus	Craniotomy for evacuation of EDH
	Erbayraktar et al., 2001[8]	Excessive pin force due to defect spring	Craniotomy for evacuation of EDH
	Lee et al., 1994[9]	Unclear; pediatric patients, some with hydrocephalus	4 of 5 patients underwent craniotomy for elevation of the depressed fracture; 3 patients had a dural laceration
	Lee and Lin, 2010[10]	Very thin temporal bone (skull clamp used during posterior cervical surgery)	Craniotomy for evacuation of EDH and elevation of depressed skull fracture
	Martinez-Lage et al., 2011[11]	Pediatric patient with thinned skull, hydrocephalus, and posterior fossa tumor	Conservative management
	Matouk et al., 2012[12]	Fragile skull in patient with chronic kidney failure and long-term antiepileptic drug use	Conservative management; control CT scan for evolution of EDH
	Medina et al., 1997[13]	Pediatric patient with supratentorial tumor	Craniotomy for evacuation of EDH
	Mohcine and Brahim, 2015[14]	Unclear; posterior fossa tumor	Unclear
	Moutaoukil et al., 2016[15]	Pediatric patient with thinned skull, hydrocephalus, and posterior fossa tumor	Conservative management
	Naik et al., 2011[16]	Penetration of inner cortex leading to bilateral EDH	Bilateral craniotomy for evacuation of EDH
	Sade and Mohr, 2005[17]	Thinned skull due to long-standing hydrocephalus	Craniotomy for evacuation of EDH
	Vitali and Steinbok, 2008[18]	Pediatric patients (age 2—6 years) with posterior fossa tumors and thinned skulls (2—4 mm)	Craniotomy for evacuation of EDH in 3 patients; conservative management in 2 patients
	Yan, 2007[19]	Pediatric patient with posterior fossa tumor; pin site near coronal suture	Craniotomy for evacuation of EDH
	Zaazoue et al., 2018[20]	Pediatric patients (age 1.6—10.3 years) with posterior fossa tumors and hydrocephalus; MRI-compatible skull clamp	Craniotomy for evacuation of EDH in 6 of 7 patients; 4 of 6 patients had permanent neurological deficits
Traumatic superficial temporal artery aneurysm	Fernandez-Portales et al., 1999[21]	Pin in superficial temporal artery	Ligation and excision of aneurysm
Tension pneumocephalus	Anegawa et al., 1986[22]	CSF leak through pin site and postoperative air aspiration	Cerebral ischemia and death
Venous air embolism	Cabezudo et al., 1981[23]	Penetration of noncollapsible venous channel (emissary veins, diploic veins, venous lakes); surgery in the sitting position; air aspiration at the end of surgery when removing skull clamp	Precordial Doppler sound changes; air aspiration through central venous line; finger pressure on pin site; supine positioning; suturing pin site wound
	De Lange et al., 1984[24]	Penetration of a noncollapsible venous channel (emissary veins, diploic veins, venous lakes); surgery in the sitting position	Pin site wound closure
	Grinberg et al. 1995[25]	Penetration of a non-collapsible venous channel (emissary veins, diploic veins, venous lakes)	Cardiorespiratory resuscitation
	Prabhakar et al. 2004[26]	Penetration of a non-collapsible venous channel (emissary veins, diploic veins, venous lakes)	Bone wax application to pin site and wound closure; air aspiration through central venous line

Continues

Table 1. Continued

Complication	Reference	Probable Cause	Consequence
	Khandelwal et al., 2018[27]	Penetration of a noncollapsible venous channel (emissary veins, diploic veins, venous lakes); skull clamp was repositioned and initial pin site was oozing	Trendelenburg and wound closure; air aspiration through central venous line
	Pang, 1982[28]	Penetration of noncollapsible venous channel (emissary veins, diploic veins, venous lakes); second surgery within few days, as pin placement too close to previous pinning site causing displaced skull fracture and dural tear	Wound closure

MMA, middle meningeal artery; CSF, cerebrospinal fluid; EDH, epidural hematoma; CT, computed tomography; MRI, magnetic resonance imaging.

unexpectedly low reading on the torque screw (owing to insufficient counterpressure), 4) wobbling of the head after proper installation, and 5) cerebrospinal fluid leaking at a pin site. In the event of unexpected intraoperative brain swelling, the team should consider a pin site epidural hematoma.

Basic Mayfield Clamp Concepts

The skull clamp should secure the head in such a way that it is rigidly fixed to the operating table. There should be no play or recoil between the skull and the clamp or between the clamp and the operating table. The clamp should support the head while leaving enough working space for the hands of the surgeon and the assistant, intraoperative navigation, and operating microscope and allow for skin retraction, skin flaps, and/or eventual extensions of the incision.

Application of the Mayfield Clamp

Soccer Ball Concept. The pins should hold the head in an efficient manner, minimizing the risk of slippage. Comparable to holding a soccer ball with bare hands, it is easier and safer to support a sphere from below than to hold it with both hands from above (**Figure 1**). In the latter instance, the risk of slippage is higher. The action forces that need to be exerted to stabilize the skull will be bigger if there is no direct antigravitational force from the pins to directly counteract the weight of the head.[20] We suggest that the skull rests on the 2 pins whenever possible for maximum safety. This rule can be disregarded if the patient is placed in a lateral position with the head turned toward the floor: in this case, a single pin on the forehead can be chosen for cosmetic reasons. In a bifrontal or occipital approach, the 2 pins cannot be placed on the underside because the single pin would then interfere with the operative field. Under ideal circumstances, the bisector of the skull clamp projects below the skull's equator.

Pin Application. The skull clamp should be inspected before each use. Cracks or fractures should be actively sought, as they can be the cause of clamp breakage during surgery (**Table 1**).

The latitude line corresponding with the upper part of the linea temporalis is a good guide for pin placement (**Figure 2**). Main trunks of superficial neurovascular structures, the thin temporal squama, and the temporalis muscle belly are avoided when placing the pins near this line. Pin placement in this zone minimizes the risk of slippage toward the vertex.

Usually the 2 pins are applied first. The single pin should extend sufficiently far beyond the socket; otherwise the socket might cause a pressure sore on the skin or get stuck on the patient's head when swiveling the arm (**Figure 3**). An antiseptic gel is applied on all the pins to act as an air sealant. This can prevent aspiration and resulting venous air embolism should a venous structure be penetrated. Pinning perpendicular to the skull vault is mandatory for safe fixation. If the pins are placed obliquely, this promotes skiving and prevents skull penetration, possibly creating an unstable construct (**Figure 4**). In adult patients, the torque screw of the Mayfield clamp should be tightened until the single-pin marker indicates 3. This corresponds to 60 lb (27 kg) of force (**Figure 5**). A higher force is usually not required for safe skull immobilization. The fourth marker, corresponding to 80 lb (36 kg), should not be surpassed, as this only increases the risk of complications (skull fractures and dural lacerations) without adding significant stability. Depending on the skin type of the patient, the skin around the single pin may rotate with it.

Figure 1. Illustration of the soccer ball concept. Holding the ball from above, with the hands higher than the equator, requires a lot of energy (i.e., force) and has a higher risk of slippage unless undue compression forces are exhibited. It requires less force to steadily support a sphere when one area of support is underneath it. This configuration is also safer should any intraoperative misadventure occur, as the skull will be supported at all times.

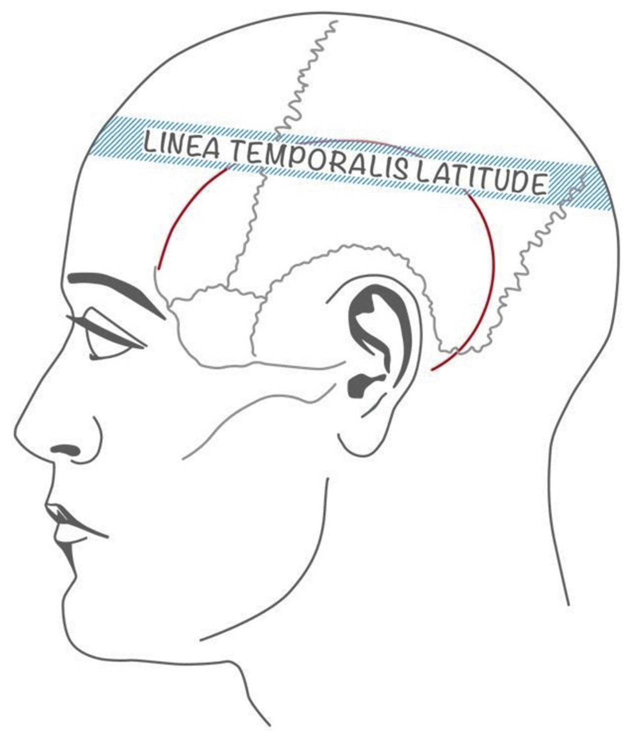

Figure 2. The latitude line that corresponds with the linea temporalis is a good guide for safe pin placement. When applying pins in this region, the most important neurovascular structures and the temporalis muscle belly can be avoided.

To avoid undue torsion on the skin during surgery, the torque screw is rotated a couple of degrees counterclockwise until the skin has regained its normal configuration.

Before tightening the starbursts (the saw-toothed interlocking gears), the head is gently rocked back and forth in the anteroposterior and lateral directions to ensure whether the head and neck are sufficiently relaxed and not at the end of their range of motion. The starbursts are then fastened top down and a final rocking movement is executed to confirm the stability of the entire system.

When removing the Mayfield clamp, the patient's head can be firmly pressed against the 2 pins while the single pin is released. This maneuver stabilizes the head so that a skin laceration inflicted by accidental scratching of the single pin can be avoided. Once the single pin is removed, the head is taken off the 2 pins. Massaging of the scalp can help reduce residual skin impression. If the forehead pin site bleeds, pressure can often stop this. If this proves insufficient, the skin is pulled taut from left to right and a single staple is placed craniocaudally to create a cosmetically acceptable transverse scar. The staple can be removed after 3–5 days.

Critical Areas to Avoid with Pin Application

The pins are meant to be anchored in the external table of the skull. They should not be inserted in regions where the skull is thin or weakened in any way or where proper skull penetration is difficult (Figure 6).

Temporal Squama. The temporal squama is the thinnest part of the calvaria (sometimes <2 mm) and overlies the middle meningeal artery. Most of HID-inflicted skull fractures occur in this region and often result in an epidural hematoma necessitating emergent craniotomy (Table 1).

Frontal Sinus. Evaluation of the extension of the frontal sinus on preoperative imaging is useful to avoid inadvertent entry. A frontal sinus fracture can result in infectious complications and cerebrospinal fluid rhinorrhea when the posterior wall and dura mater are penetrated. This risk is presumably bigger at the superior edge of the sinus where the anterior and posterior walls are closer to each other.

Mastoid Bone. Penetration of the mastoid air cells has to be avoided because there is a risk of infection and they provide less pin stability than the normal trabecular bone. Penetration of the diploic and emissary veins overlying the transverse and sigmoid sinuses can be the cause of air embolisms. This risk of air embolism can potentially be minimized by application of an air sealant (e.g., antiseptic gel) on the pins. Should an air embolism

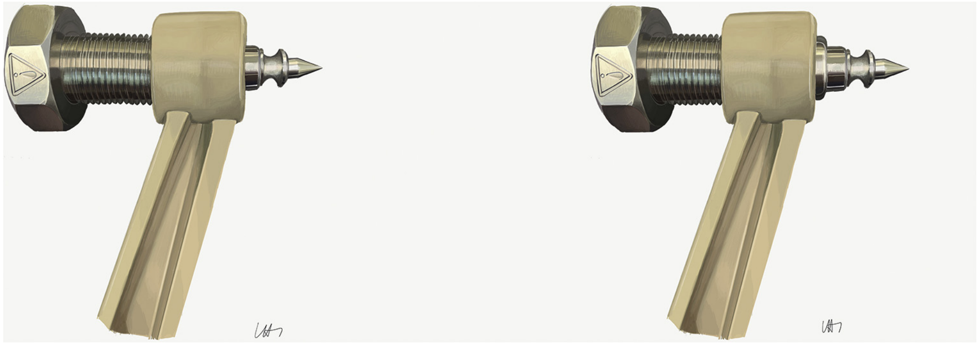

Figure 3. The single pin should be extending far enough beyond the socket before application. If the pin extends too little, the socket could come in touch with the skin, causing pressure sores, and swiveling the arm can be inhibited by a more prominent part of the skull.

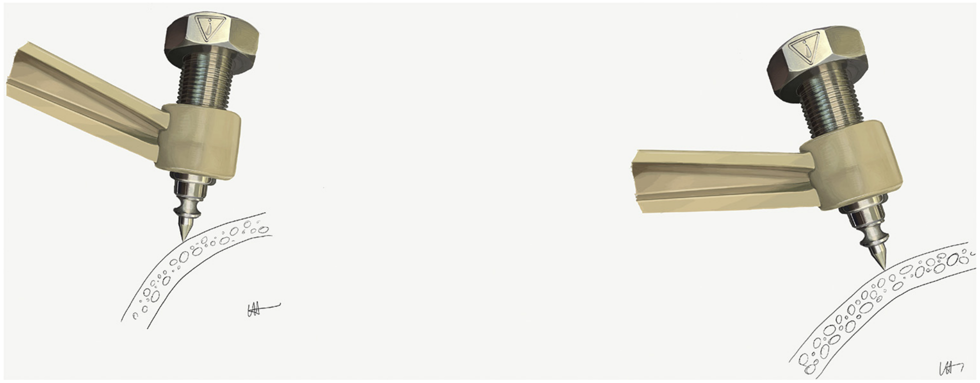

Figure 4. Pin placement perpendicular to the skull is necessary for safe fixation. If the pin is placed obliquely, it will not penetrate the skull vault as it should. Obliquely placed pins have an increased risk of slippage.

occur when the pins are removed, finger pressure on all pin sites, Trendelenburg position, and closure of the culprit scalp wound are advised.

Sutures, Meningoceles, and Other Congenital Defects. Attention should be paid to the unfused sutures, especially in younger patients. They should be identified clinically and on imaging and avoided for pin placement if pins are used in this patient group. Meningoceles can usually be appreciated on preoperative imaging, but we encourage routine palpation of the intended pin site to ensure safe pin placement.

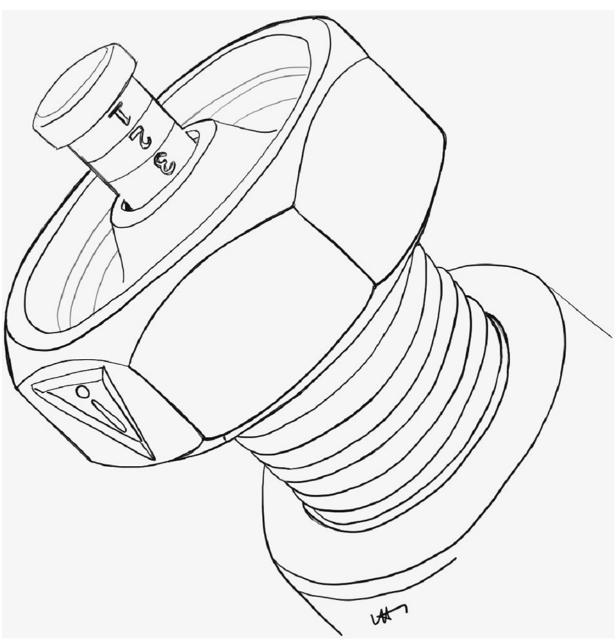

Figure 5. The Mayfield skull clamp has markers that each correspond to 20 lb or 9 kg of force. The force applied to stabilize an adult skull should be about 60 lb and not exceed 80 lb or 36 kg of force.

Skull Fractures. In trauma patients it is important to assess the integrity of the skull with a computed tomography scan. The pins should not be placed in or in the vicinity of skull fractures to avoid inadvertent penetration of the skull, displacement of a fractured

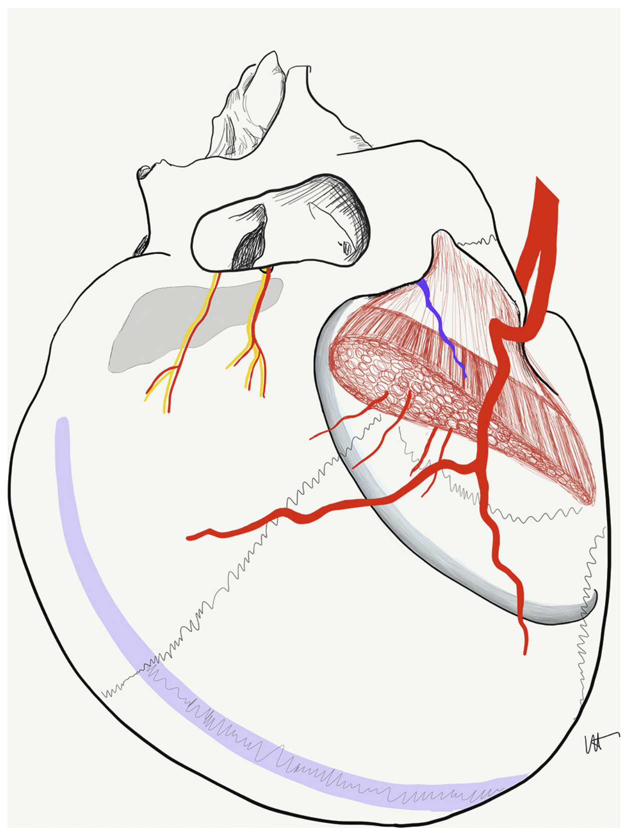

Figure 6. Illustration of several areas to avoid for pinning: the frontal sinus, the main trunks of the supraorbital and supratrochlear nerves, the temporalis muscle belly, the superficial temporal artery, and the bone overlying the major dural venous sinuses. See text for details.

fragment, or creation of a new fracture line. Placing the pin in these areas will lead to insufficient stabilization.

Prior Surgical Defects and Materials. Prior burr holes or craniotomy defects should be identified and avoided. Cranial plates can prevent the pins from anchoring in the skull. The presence of a ventricular shunt should be noted, and the area around the valve and tubing should not be chosen for pinning to avoid destruction or infection of the shunt. Here again, palpation can guide the surgeon. The same holds true for other implants like deep brain stimulation electrodes or bone anchored hearing aids.

Temporalis Muscle. The temporalis muscle belly is well vascularized and innervated. Pin insertion in this muscle can lead to a postoperative hematoma and pain. Moreover, the bulk of the muscle belly can prevent the pins from thoroughly penetrating the external table of the skull. To avoid unstable pin fixation or excessive pressure that might lead to skin or muscle necrosis, the pins should be placed near the linea temporalis where the muscle is flattened.

Superficial Arteries. The location of the main trunks of the superficial temporal and occipital arteries should be known (and checked by palpation) when pins are placed in this region. Brisk bleeding can occur when the pins are removed. Significant postoperative bleeding can occur if a previously tamponaded vessel reopens when blood pressure increases. A deep suture is preferred over stapling to control this. A traumatic pseudoaneurysm caused by pinning has been reported (**Table 1**).[21] Attention to these vessels is important, as injury renders them unsuitable for future bypass surgery.

Superficial Nerves. Pinning the main trunks of the supratrochlear and supraorbital nerves can cause loss of sensation on the forehead. Pinning a distal branch would likely cause sensational loss in a smaller skin area. The frontal or temporal branch of the facial nerve is usually not at risk because the temporal squama is avoided for pin placement. The occipital nerves usually divide into smaller branches below the occipital protuberance, so pins should not be placed caudal to it near the midline.

Dural Venous Sinuses. The bone directly overlying the dural venous sinuses is avoided for pinning. Pinning here can be a cause of air embolism during and even after surgery (e.g. when the pins are removed with the patient still in the sitting position). To detect a possible venous sinus puncture and prevent air embolism, the HID should be removed only when the patient is supine (and with positive end-expiratory pressure provided by the anesthesiologist). To prevent air entering through a non-collapsible diploic vein during surgery, an antiseptic ointment is abundantly applied on the pins to serve as an air sealant. Suspicion of an air embolism without an obvious embolism source in the operative field warrants inspection of all pin sites. When hemodynamic instability occurs after removal of the HID, finger pressure should be put on all pin holes and the patient should be put in the Trendelenburg position to detect any bleeding pin sites and prevent further air aspiration. A checklist to guide safe pin

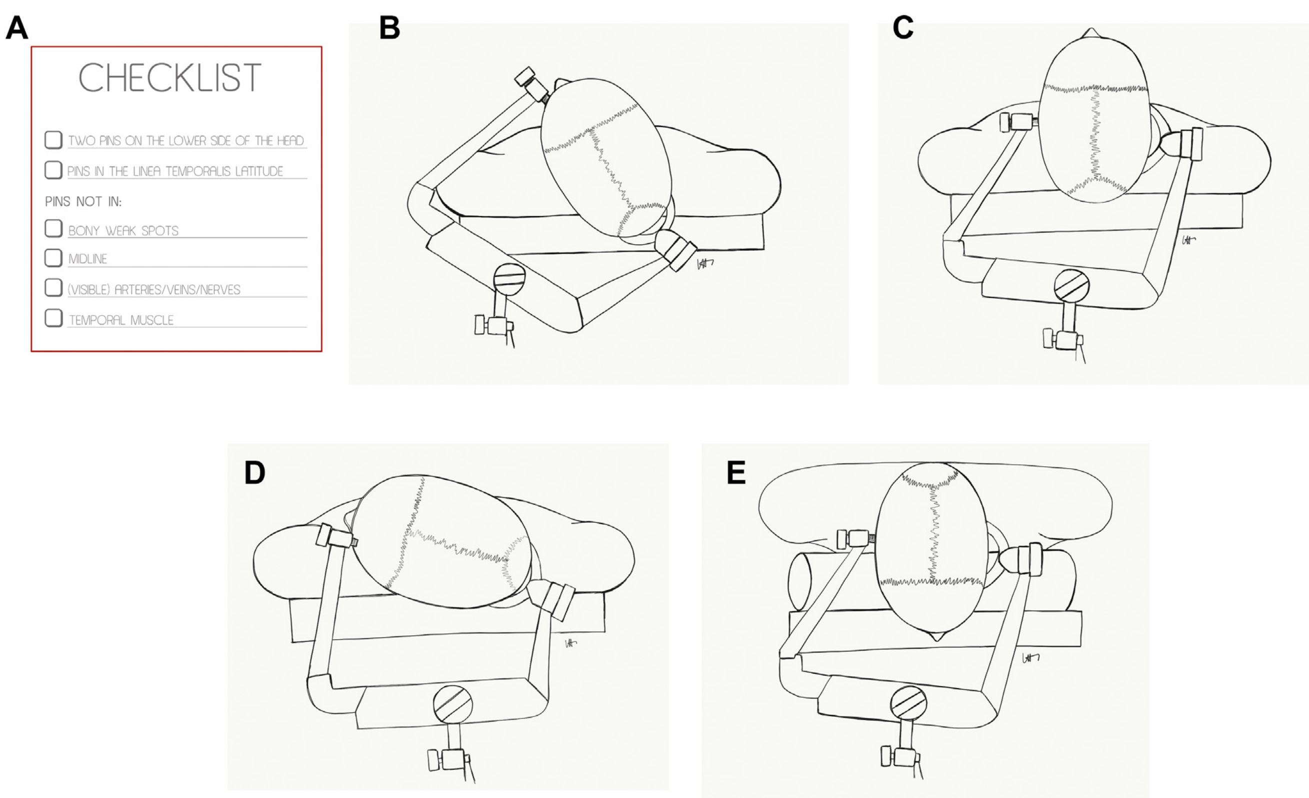

Figure 7. (**A**) Checklist for safe pin application. (**B–E**) Schematic illustration for adequate pin positioning for a pterional, frontal, temporal, and occipital approach. The pins are placed in the linea temporalis latitude, the midline is avoided, and the bisector of the pins is not above the skull's equator.

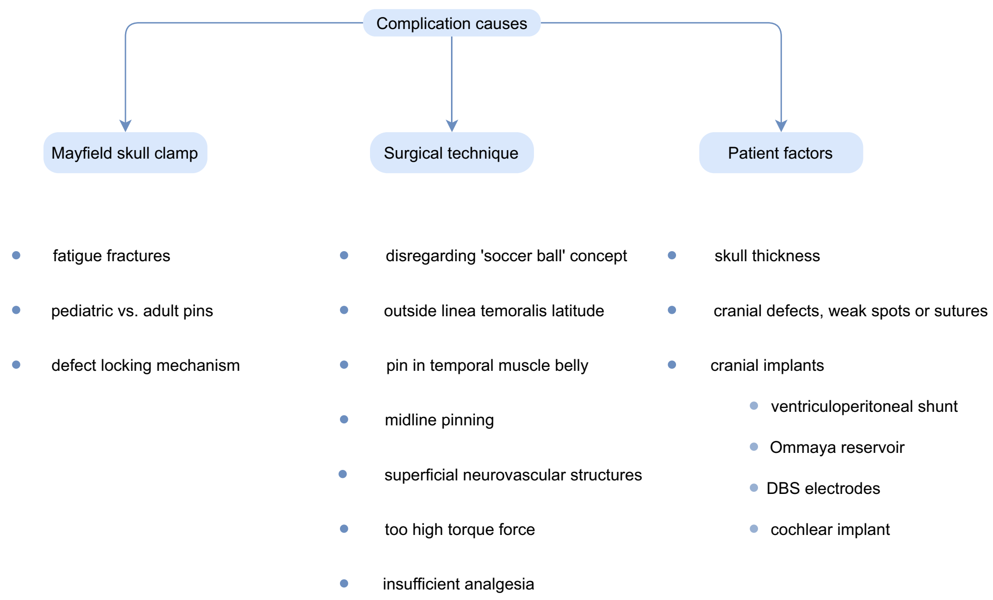

Figure 8. Root cause diagram showing the 3 major complication factors that have to be checked with every case: the Mayfield skull clamp itself, the surgical technique of application, and patient-specific factors. DBS, deep brain stimulation.

application and schematic illustrations for skull clamp positioning is provided in **Figure 7**.

Anesthetic Aspects

The application of the HID causes an intense pain stimulus and can elicit a strong adrenergic response. The HID should not be applied without timely notification of the anesthesiologist to administer a bolus of analgesics.[30] Infiltration of the pin sites with local anesthetics is optional to maximally blunt the hemodynamic response to pin placement, which is especially important in cerebrovascular surgery.[31-33]

The rigid head and neck fixation prevents rapid airway intervention in case of accidental extubation, especially in the prone position. The ventilator tubing should be securely attached to the patient or operating table (never coursing on the ground), and in case of an inadvertent extubation, the Mayfield arm is simply disengaged from the base so the patient can be turned while the skull clamp is kept in place. Then the 2-pin rocker is unlocked so the clamp can be tilted away from the anesthesiologist's working zone.

Considerations in Pediatric Patients

Because the pediatric skull is thinner and patients often present with chronic hydrocephalus that causes even more thinning of the skull (copper beaten skull), pediatric pins are advised in patients <3 years of age. The skull thickness should always be checked on preoperative imaging in older children. In children <6 years of age, the skull can be as thin as 1.1 mm.[34] The pediatric pins have a more obtuse angle and penetrate the skull's outer cortex to a lesser extent. The necessity of skull clamp fixation should be seriously considered, and another type of head fixation or rest should be used whenever feasible. An alternative is to use a head rest and then apply the HID to fix the position. This ultimately requires less pin force to stabilize the head. In a survey of 164 pediatric neurosurgeons, the majority used 10–40 lb of pressure for patients 2–5 years old and 30–40 lb of pressure for patients >5 years old. Skull clamp–related complications were reported by 89 of the pediatric neurosurgeons.[29] An adaptation to an older technique was recently described in which the pins are fitted with a rubber stopper. Deep penetration is prevented, and the force is distributed along the surface area of the rubber.[35] Mounting the pins with acrylic discs and felt is a similar conceptual idea.[36] Monitoring for pressure ulcers is advised. An absolute rule when applying a skull clamp in pediatric patients is to never forcefully clamp the skull, but rather to gently torque it to the desired pressure. This allows the skull to benefit from its intrinsic elasticity and prevents abrupt deformational forces that lead to fractures.

CONCLUSIONS

The Mayfield skull clamp is the most widely used HID worldwide. Mayfield clamp application can rarely result in lethal complications. Most complications are skull fractures with accompanying epidural hematomas. A conceptual framework on how to avoid all known complications and how to safely apply the Mayfield skull clamp is important, and the most important factors are illustrated in **Figure 8**. This article demonstrates that skull clamp application requires proper attention to several details and ideally supervision of an experienced neurosurgeon. Practicing application of the Mayfield clamp on synthetic or cadaver skulls is a very easy and efficient way to learn proper pinning for different cranial approaches. We encourage all who use the Mayfield skull clamp, especially trainees, to use this training model for a better understanding and execution of pinning. The most important approach to avoid complications from pin fixation is to be recognizant of them and look for an alternative way to stabilize the skull.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Dieter Thijs: Conceptualization, Methodology, Investigation, Writing - original draft. **Tomas Menovsky:** Conceptualization, Writing - review & editing.

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