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Nursing Care of Pediatric Cranioplasty Patients after Traumatic Brain Injury: Monitoring Benefits and Complications

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Purpose: To explore the benefits and complications of cranioplasty in pediatric patients and implications for nursing care and monitoring.
Design: A review of current literature on cranioplasty benefits and complications was conducted using Ovid, Scopus, and PubMed, with the search terms cranioplasty, craniectomy, traumatic brain injury, complications, benefits, and pediatrics. Inclusion criteria included original research published on cranioplasty complications and benefits within the past 20 years. Due to the paucity of research on pediatric cranioplasty patients, adult studies were included. Seventeen out of 105 peer-reviewed journal articles from 2002-2016 met criteria and include retrospective reviews and case reports. One article was added per expert recommendation.
Methods: Common benefits and complications of cranioplasty were compared and summarized.
Conclusions: Literature indicates there are clear benefits to cranioplasty. Repairing the skull protects the brain and improves the cosmetic appearance and neurological status of patients. Cranioplasty has a high rate of post-surgical complications, including bone flap resorption, surgical site infection, seizures, hematomas, and hydrocephalus. The pediatric population experiences different complications compared to adult patients.
Practice Implications: Nurses are integral members of the team who monitor cranioplasty patients. Increasing awareness of pediatric cranioplasty benefits and complications among nurses will assist them in providing expert care and improving outcomes.

Key Words: Traumatic brain injury, cranioplasty, craniectomy, pediatric, complications, nursing care.

Traumatic brain injury (TBI) is a public health problem in the United States that has significant long-term consequences for patients and families. TBI is the result of a blow or force to the head that causes a change in the normal functioning of the brain. In extreme cases, swelling can occur in the brain that cannot be relieved by medications or other clinical interventions. In some cases, a neurosurgical procedure called craniectomy is needed to relieve this swelling. A piece of the skull is surgically removed to allow more room for the brain to expand. A skin flap is sutured over the craniectomy site so that brain tissue is not left exposed. Patients who survive a craniectomy will undergo a second surgery at a later time called a cranioplasty to repair the skull. Pediatric patients require special considerations in cranioplasty compared to the adult population. Nurses care for children before and after cranioplasty in many different settings. Understanding the pathophysiology of brain injury and cranioplasty can help nurses to effectively monitor patients for improvements and complications.

Background

In 2015, the Centers for Disease Control and Prevention (CDC) reported to Congress that an estimated 2.5 million people were treated for TBI in 2010, and 2% subsequently died from complications of their injuries. Table 1 presents demographic data for children hospitalized for TBI in the United States. From 2002-2006, the CDC reported that 473,946 children ages 0 to 14 years were treated in the emergency department because of TBI, 35,136 were hospitalized, and 2,174 died (Faul, Xu, Wald, & Coronado, 2010). Due to the magnitude of this problem, the CDC (2015) has called for more comprehensive reporting on the incidence of TBI, mechanism of injury, and outcomes.

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Pathophysiology

TBI is the result of an impact to the head. Common causes of injury are falls, motor vehicle accidents, and assault. The initial injury can cause bleeding, edema, and accumulation of cerebral spinal fluid within the skull. Increased intracranial pressure can cause a secondary injury to the brain and fatal brain stem herniation. Medical management of TBI is aimed at preventing further injury to the brain by reducing intracranial pressure (Barthélemy, Melis, Gordon, Ullman, & Germano, 2016).

Several interventions can be attempted to minimize secondary brain injury, including elevating the

Table 1.
Percent Distributions of Traumatic Brain Injury-Related Hospitalizations by Age Group and Injury Mechanism – United States 2006-2010

Age Range	Total Number	Motor Vehicle Traffic	Falls	Assault	Struck by/ Against	All Other Causes	Unknown
0 to 4 years	13,383	8.3%	46.2%	7.8%	4.4%	9.9%	23.3%
5 to 14 years	13,475	17.1%	22.8%	0.8%	8.2%	21.4%	29.5%
15 to 24 years	40,674	32.6%	6.4%	10.2%	3%	14.6%	33.2%

Note: Percentages are rounded to the nearest tenth. Only pediatric age groups included in this table.
Source: Adapted from Centers for Disease Control and Prevention (CDC), 2016.

head of the bed to promote drainage of cerebral spinal fluid, intravenous hypertonic saline or manitol to shift fluid from the intracranial space into the intravascular space, sedation to decrease the oxygen demands of the brain, and diversion of cerebral spinal fluid with ventricular shunts. When these interventions fail, decompressive craniectomy can be attempted to relieve intracranial pressure (Stocchetti & Maas, 2014).

Decompressive craniectomy involves removing a piece of the skull to allow space for the swelling brain tissue to expand and to decrease intracranial pressure. After a period of recovery, the skull defect can be repaired with autologous bone or synthetic material in a surgical procedure called cranioplasty. When using autologous bone, the original piece of skull that was removed is used to repair the defect. Autologous graft is the preferred method in children for repair, though other materials may be used in severe skull fracture or open injury with the potential of bone infection (Grant et al., 2004).

Cranioplasty is an important treatment that has several benefits. Repairing the skull protects the brain from further injury, improves the cosmetic appearance of the patient, and has been shown to have positive neurological effects (Agner, Dujovny, & Gaviria, 2002; Isago, Nozaki, Kikuchi, Honda, & Nakazawa, 2004; Jelcic et al., 2013). Despite the benefits, there is a high incidence of post-surgical complications that can occur in the days immediately following the procedure, as well as months and even years later (Honeybul & Ho, 2016; Zanaty et al., 2015). The most common post-cranioplasty complications are bone flap resorption, surgical site infection, hydrocephalus, hematomas, and seizures (Zanaty et al., 2015).

The pediatric population requires special considerations when undergoing a cranioplasty. Unique complications can occur for pediatric patients because their skulls are continuing to expand and grow. A 2013 systematic review of cranioplasty outcomes for pediatric patients indicated there was a paucity of studies on this procedure in children (Rocque, Amancherla, Lew, & Lam, 2013). The authors identified the need for a greater number of large retrospective and prospective studies in this population.

Cranioplasty is not a new procedure. Archeological findings indicate that items such as precious metals, shells, and gourds were used to repair cranial defects by ancient Incans as early as 3000 BC (Feroze et al., 2015). Modern advances have been made in cranioplasty, and research for the future is focused on how to predict and minimize complications. Variables such as timing from craniectomy to cranioplasty and the use of autologous bone versus a synthetic material are the focus of current studies in this field (Feroze et al., 2015; Kolias, Kirkpatrick, & Hutchinson, 2013; Servadei & Iaccarino, 2015).

Benefits of Cranioplasty

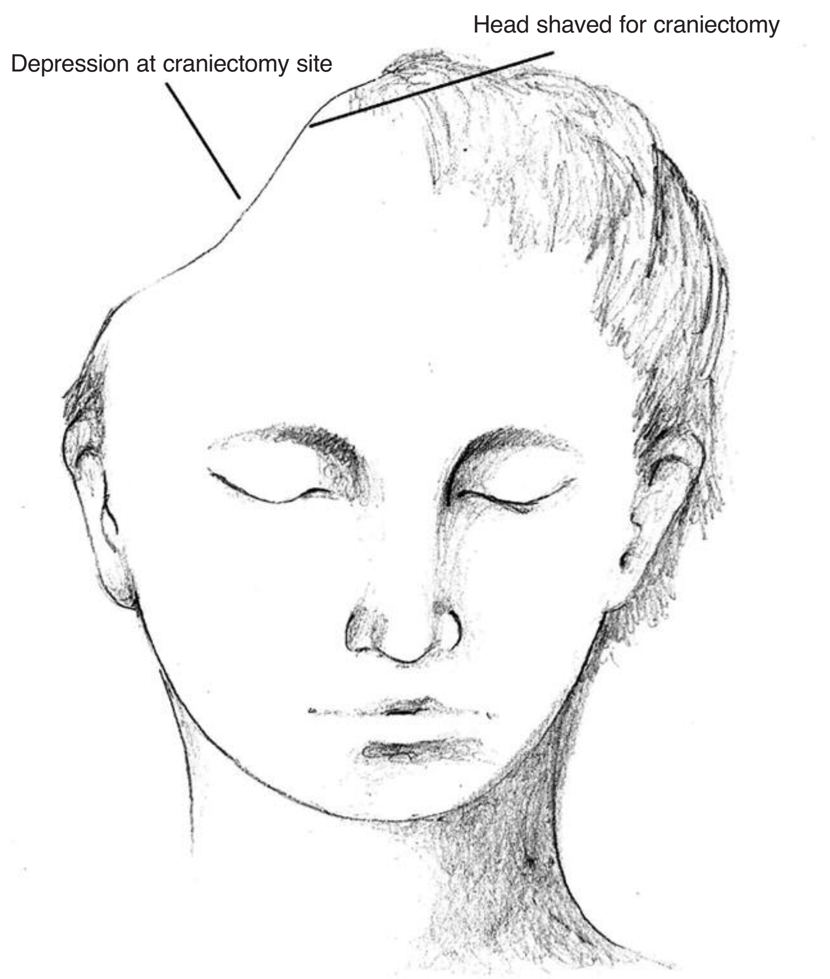
The obvious benefits of cranioplasty are protection of the brain and cosmetic appearance. Patients who have undergone a decompressive craniectomy will appear to have a sunken, soft spot on their skull where the bone was removed (see Figure 1). In a study of pediatric cranioplasty patients in Pakistan, 72.2% of patients reported they were satisfied with the cosmetic outcome of their cranioplasty procedure (Waqas et al., 2016). Prior to cranial repair, craniectomy patients lack the important protection the skull offers the brain. Patients who can ambulate need to be assisted and wear a helmet for protection until their defect is successfully repaired with cranioplasty because falling can cause further harm (Honeybul, 2008).

Neurological improvement is another important benefit of cranioplasty. The improvement that some patients experience can be better explained when looking at a complication of craniectomy called syndrome of trephined that is often referred to as sunken skin flap syndrome. As swelling of the brain tissue subsides following the removal of a piece of skull, atmospheric pressure will cause the scalp to sink and cause pressure on the cerebellar (brain) tissue. Refer to Figure 1 for an illustration of a patient with sunken skin flap. Blood flow to this part of the brain will be diminished, and in turn, will decrease cerebral metabolism (Ashayeri, Jackson, Huang, Brem, & Gordon, 2016). Symptoms often include headache, dizziness, depression, and neurological deficits. Patients who suddenly stop improving may decline rapidly. In a systematic review of syndrome of trephined, all patients who presented with symptoms of sunken skin flap showed rapid neurological improvement after cranioplasty (Ashayeri et al., 2016). Repairing the skull defect restores circulation to the area of the brain that had been compressed by atmospheric pressure.

Complications Of Cranioplasty

Although cranioplasty is an important procedure for patients who have survived craniectomy, complications may occur, and careful monitoring is required. Common complications include bone flap resorption, bone flap infection, hydrocephalus, seizures, and surgical site hematomas. Table 2 compares the incidence of common cranioplasty complications in several recent studies. Adults experienced all compli-

Figure 1.
Sunken Skin Flap Illustration: Post Craniectomy



Source: Original artwork by R. McCormick.

cations while pediatric studies did not report seizures or hematomas. Bone flap resorption occurred more frequently in the pediatric than adult population and had the highest reported incidence (Bowers, Riva-Cambrin, Hertzler, & Walker, 2013; Martin et al., 2014; Piedra, Thompson, Selden, Ragel, & Guillaume, 2012; Schuss et al., 2013).

Bone Flap Resorption

Bone flap resorption is the destruction of the autologous bone that is used to fix the skull defect. When the bone flap fails, it can become thin, soft, and even necrotic from osteolysis. Bone flap resorption may necessitate replacement by a synthetic material in a second cranioplasty procedure. The patient can be at risk for infection, lack of protection for the brain, and unsatisfactory cosmetic appearance (Grant et al., 2004).

Resorption of the bone is thought to happen more frequently in pediatric patients because they are growing more rapidly than adults and experience higher turnover of bone cells (Rocque et al., 2013). One study found that children less than 2.5 years of age had the greatest risk of bone flap resorption (Bowers et al., 2013). These authors suggest the high metabolic demand during this period of rapid skull growth may exceed the ability to create a fusion with the bone flap (especially if it is a large defect). Older children whose skulls are growing at a slower rate, and thus, have less metabolic demands can more successfully fuse the bone flap to the existing skull (Bowers et al., 2013).

In a study by Martin and colleagues (2014), pediatric patients were divided into age groups of less than 15 years and 15 to 18 years. Bone flap resorption occurred in 66.7% of those in those less than 15 years old and not at all in children aged 15 to 18 years. Another study found a 50% incidence of bone flap resorption in their study population (Grant et al., 2004). Each of those children required subsequent surgery for revision with new materials, thus exposing them to further physical and emotional hardship (Grant et al., 2014). In a mixed adult and pediatric retrospective study, four out of five of pediatric patients experienced bone flap resorption (Brommeland, Rydning, Pripp, & Helseth, 2015). In those aged 18 years and younger, early wound healing disturbance, such as abscess, and the presence of multiple fractures were risk factors for bone flap resorption (Schuss et al., 2013).

The use of synthetic materials has been identified as a potential solution to this problem, and research continues toward developing the optimal product. Autologous bone is still preferred in initial cranioplasty because synthetic materials do not always conform well to the growing pediatric skull and may require future revision. Research has also focused on defining an optimal timing for cranioplasty; however, results have been mixed. A study of 61 children found that only 14% experienced bone flap resorption when cranioplasty was done within six weeks of the original decompressive craniectomy (Piedra et al., 2012). This was compared to a 42% prevalence of resorption for children who had cranioplasty more than six weeks following craniectomy, suggesting that early repair may improve outcomes. Early cranioplasty did not affect the rate of other complications in this study such as infection, hematoma, and hydrocephalus (Piedra et al., 2012). A mixed adult and pediatric study found 11.1% of patients who had early cranioplasty (2 months or less from craniectomy) suffered from bone flap resorption, while only 2% had bone flap resorption with later cranioplasty (greater than 2 months from craniectomy) (Schuss et al., 2013). It is difficult to draw conclusions about the pediatric population from a mixed adult and pediatric study, but more research is needed to guide practice in timing cranioplasty.

Table 2.
Comparison of Common Complications Following Cranioplasty

Study Authors	Adult or Pediatric	Bone Flap Resorption	Bone Flap Infection	Hydrocephalus	Seizures	Surgical site Hematoma
Grant et al., 2004	Pediatric (4 months to 19 years)	50%	10%	22.5%	—	—
Peidra et al., 2012	Pediatric (<18 years)	29.5%	6.56%	3.28%	—	0%
Bowers et al., 2013	Pediatric (< 18 years)	50%	16.7%	—	—	—
Martin et al., 2014	Pediatric (age < 15 years)	66.7%	—	11.1%	—	—
Martin et al., 2014	Pediatric (age 15 to 18 years)	—	22.2%	—	—	—
Waqas et al., 2016	Pediatric (< 18 years)	—	8.3%	—	—	—
Schuss et al., 2013	Mixed pediatric and adult	17.4% (≤ 18 years) 2.7% (> 18 years)	—	—	—	—
Gooch et al., 2009	Adult	6.5%	11.3%	1.6%	1.6%	3.2%
Zanaty et al., 2015	Adult	—	26.43%	13.51%	14.37%	6.9%
Honeybul & Ho, 2016	Adult	20.9%	8.2%	—	23.6%	12.3%

Bone Flap Infection

Infection of the bone flap is the second most common complication in pediatric cranioplasty patients. Infection can range from superficial to deep. Table 2 shows over-all prevalence of infection without differentiating between different types. Superficial infections can be treated with antibiotics, while deeper infection may require the removal of the bone flap and replacement with a synthetic material (Honeybul & Ho, 2016). Infection rates for cranioplasty are high compared to other neurosurgical procedures. Audits in Western Australia consistently showed a 1% to 2% general infection rate for neurosurgical procedures (Honeybul, 2010). Rates for cranioplasty procedures displayed in Table 2 range from 6.56% to 26.43%. Possible explanations for this difference are skin colonization while hospitalized and immunocompromise of patients following trauma and surgery. One recommendation to decrease post-surgical infections rates in cranioplasty is to have a single, senior neurosurgeon perform the procedure with strict adherence to aseptic technique (Honeybul & Ho, 2016).

Table 3.
Cranioplasty Complications and Nursing Interventions

Complication	Early/Late	Nursing Intervention/Monitoring
Bone flap resorption	Late	Monitor for signs and symptoms: postural headaches, vertigo and hearing noises similar to water movement when position is changed. Patients can be asymptomatic when bone flap resorption is present or may only present with a sunken, soft or depressed area of the skull.
Bone flap infection	Early/Late	Monitor site for drainage, discoloration, and edema. Symptoms include headache, fever, and soft-tissue swelling.
Hydrocephalus	Early	Monitor mental status, cranial nerves; CT scan can guide further interventions.
Seizures	Early	Implement seizure precautions: may include placing pads along the bedrails for patient protection, having oxygen and wall suction readily available, and implementing continuous monitoring.
Surgical site hematoma	Early	Monitor site for color changes and drainage; monitor mental status, cranial nerves; CT scan can guide further interventions.

Notes: Early complications are less than or equal to 30 days post-cranioplasty. Late complications are greater than 30 days post-cranioplasty.

Hydrocepahlus

Hydrocephalus is common following TBI. Patients may have a shunt placed to aid in the drainage of fluid before or after cranioplasty surgery. One study demonstrated that four out of 18 children less than 15 years old and one out of nine adolescent patients had cerebral spinal fluid shunts placed prior to or during cranioplasty to help control persistent hydrocephalus (Martin et al., 2014). Shunt infection or malfunction can further complicate recovery and may require revision or removal in some patients. Additionally, bone flap resorption rates were higher in patients with permanent cerebral spinal fluid shunts (Bowers et al., 2013; Martin et al., 2014).

Other Complications

Seizures and surgical site hematomas were not reported in the reviewed pediatric studies; however, monitoring for these complications remains important because they have been observed in adult patients. Seizures following cranioplasty are a predictor for mortality in adult patients (Zanaty et al., 2015). Several variables were associated with high risk for seizure, such as male sex, age greater than 60 years, and cranioplasty graft infection. Patients who had seizure episodes prior to cranioplasty were not included in these data. The authors postulated there could be several causes for seizures, including the original trauma, the original decompressive craniectomy surgery, or cranioplasty. Surgery can produce free radicals, shift ionic balance, and manipulate cerebral tissue, all of which could potentially cause seizure activity (Zanaty et al., 2015).

Hematomas following cranioplasty are caused by persistent scalp bleeding that collects in the epidural, subdural, or intraparenchymal space (Zanaty et al., 2015). Patients may require another surgery for evacuation of the hematoma, thus exposing them to further complications and longer hospital stay. These patients had a higher mortality rate (Zanaty et al., 2015). A 2009 study found that two out of 62 patients experienced hematoma as a post-cranioplasty complication, and both required re-operation for evacuation of blood (Gooch, Gin, Kenning, & German, 2009). Seizures and surgical site hematomas are post-cranioplasty complications that impact patient recovery. The incidence of these complications in the adult population suggests a need to be vigilant in pediatric patients as well.

Implications for Nursing Practice

Monitoring Benefits

Nurses have many methods to monitor the benefits of cranioplasty. Assessing neurological status can be done through physical assessment and documentation of improvements. A thorough neurological exam will assess cranial nerves, sensation and strength in extremities, fine and gross motor skills, balance, and proprioception. Documenting baseline abilities of patients before cranioplasty will allow for accurate assessment of improvements. Intensive physical and occupational therapy can help patients make progress in their fine and gross motor skills, and ability to perform activities of daily living, and speech and articulation. Nurses in rehabilitation settings can participate in interdisciplinary team meetings and encourage patients in their progress.

Agner and colleagues (2002) illustrated the value of tracking neurocognitive changes in an adult patient before and after cranioplasty using a comprehensive cognitive test, such as the Neurobehavioral Cognitive Status Examination (Cognistat), and a rapid bedside exam, called The Executive Interview (EXIT). Likewise, pediatric psychologists can administer cognitive testing appropriate for the pediatric population. A full assessment will test general cognitive ability, attention, memory, language functioning, and visual motor skills (Campbell, Brown, Cavanaugh, Vess, & Segall, 2008). An example of a validated, comprehensive pediatric tool that tests all five domains is the Developmental Neuropsychological Assessment (NEPSY) (Korkman, Kirk, & Kemp 1998). Testing can be repeated to track outcomes. It is important for nurses to be aware of the results of previous testing to detect changes in patient cognitive status.

A 2004 adult case study highlighted the remarkable recovery of a 28-year-old female following cranioplasty (Isago et al., 2004). She had been bedridden, unable to speak, and paralyzed in all four extremities prior to surgery. Within months, she had improvements in depression, memory, ability to concentrate, and coordinated movements of the upper extremities. She could repeat words, laugh, and sing. Additionally, her dysphagia resolved after two months, and she was able to feed herself. The authors of this study evaluated the cerebral blood flow of this patient to determine that she had suffered from syndrome of trephined. Blood flow to the brain was increased following cranioplasty and was consistent with her clinical improvements (Isago et al., 2004).

Monitoring Complications

Complications can arise immediately in the post-operative period and can also arise months after surgery. Extrapolating from adult literature, complications may even develop many years after cranioplasty. One case study described a patient who had a cranioplasty in 1946 at age 6 years that required repair 67 years later when drainage was noted from the site (Kahn, Calayag, Patel, & Pilitsis, 2014). Changes in the appearance of a healed cranioplasty site or drainage must be evaluated by a neurosurgeon no matter how many years have passed since the original operation.

Understanding which complications typically arise early post-operatively versus later can help nurses to be vigilant for common problems. Early complications are considered less than or equal to 30 days post-operative and late complications are greater than 30 days. Pediatric studies indicate that bone flap resorption is a late complication (Bowers et al., 2013; Martin et al., 2014; Schuss et al., 2013). Hydrocephalus is an early complication, and surgical site infection can be seen in the early and late post-operative period (Martin et al., 2014). These results are consistent with an adult study, which adds that seizures and hematomas are also early complications (Gooch et al., 2009).

Signs and symptoms of bone flap resorption include postural headaches, vertigo, and hearing noises similar to water movement when position is changed (Honeybul, 2010). Patients can be asymptomatic when bone flap resorption is present or may only present with a sunken, soft, or depressed area of the skull. Surgical site infection can present with headache, fever, and soft-tissue swelling. Patients and fami-

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Nursing Care of Pediatric Cranioplasty Patients After Traumatic Brain Injury: Monitoring Benefits and Complications

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Learning Outcome

After completing this continuing nursing education activity, the learner will be able to discuss the benefits and complications of cranioplasty in pediatric patients, and implications for nursing care and monitoring.

Learning Engagement Activity

1. Identify the benefits of cranioplasty after craniectomy in the pediatric patient with traumatic brain injury.
2. Review Table 2: The Comparison of Common Complications Following Cranioplasty to be able to monitor pediatric patients post-cranioplasty for early detection of complications.

Fees — *Subscriber:* FREE *Regular:* $20

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lies must be educated on the care of the cranioplasty site and instructed to closely follow the instructions provided by their neurosurgeon. (Honeybul, 2010).

Hydrocephalus and hematoma formation are early complications that can occur following cranioplasty. Noting changes in the neurological status of patients is an important nursing intervention for these potential problems. Imaging such as a computerize tomography (CT) scan may be used to diagnose these complications and guide management (Honeybul, 2010).

Seizures are a complication that occurred in the adult population of the review of literature. Nonetheless, the occurrence of seizures should be closely monitored in children as well. Seizure precautions may be followed in the early period following cranioplasty according to the protocol of the institution. Precautions may include placing pads along the bedrails for patient protection, having oxygen and wall suction readily available, and implementing continuous monitoring or surveillance of the patient (Buelow, Privitera, Levisohn, & Barkley, 2009).

Conclusion

TBI is a national health concern with significant morbidity and mortality for children in the United States. Some children who experience TBI will undergo emergency decompressive craniectomy and subsequent cranioplasty. Reporting on the incidence of TBI that requires decompressive craniectomy and cranioplasty in the United States is lacking. Comprehensive data on cranioplasty procedures and outcomes can help guide future research. Additionally, there is a scarcity of research published on pediatric cranioplasty benefits and complications that may limit the conclusions and recommendations made in this review.

Cranioplasty is an important procedure that can benefit craniectomy patients, but there is a high rate of complication in cranioplasty compared to other neurosurgical procedures. Neurosurgical literature on cranioplasty has focused on finding the optimal timing and materials to decrease complication rates. Nursing research can add to the literature by focusing on monitoring post-cranioplasty patients for early detection of complications. Such research may provide insight into improving outcomes. Nurses are highly skilled in monitoring benefits and complications in children recovering from cranioplasty in acute care hospitals, rehabilitation settings and outpatient clinics, and are essential members of the interdisciplinary team.

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