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Methodological Article & Framework

Implementing Spring-Assisted Posterior Vault Expansion in Emerging Craniofacial Units: A Practical Framework for Centres New to the Technique

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Abstract

Spring-assisted posterior vault expansion (SA-PVE) has emerged over the past two decades as an effective and less invasive alternative to traditional open posterior vault remodeling for children with multisuture or syndromic craniosynostosis. The technique provides reliable intracranial volume expansion, favourable scar and morbidity profiles, and is particularly advantageous for infants and children with raised intracranial pressure. However, despite its established efficacy in high-volume craniofacial units, SA-PVE remains unavailable in many countries due to limited specialised expertise, lack of structured training, and uncertainty regarding safe implementation. There is therefore a need for a practical, clinically oriented framework to guide new centres through the early adoption of this technique.

Methods. This article synthesises the operative, perioperative, and programme-level considerations necessary for the safe introduction of SA-PVE in emerging craniofacial units. Drawing on experience from a high-volume paediatric neurosurgical and craniofacial centre, we describe essential components including patient selection, multidisciplinary preoperative assessment, operative workflow of the classic SA-PVE technique, postoperative management, and long-term follow-up pathways. We outline a structured three-stage training and partnership model for capacity building and provide guidance on outcome monitoring, data collection, and programme auditing. The manuscript integrates published evidence and practical experience to produce a coherent implementation framework applicable across varying resource settings.

Results. SA-PVE was identified as a reproducible and adaptable technique suitable for both aesthetic and functional indications. Key determinants of successful adoption include accurate diagnosis of craniosynostosis subtype, confirmation of raised intracranial pressure where relevant, and careful radiological, ophthalmological, and genetic assessment. The operative technique—as refined through large single-centre series—is characterised by limited dissection, low blood loss, short operative time, and tension-free closure. Early postoperative recovery is typically rapid, with short hospitalisation and low complication rates. Long-term follow-up requires structured ophthalmological review, interval imaging, three-dimensional photography, and multidisciplinary surveillance extending into adolescence. For centres new to the technique, robust auditing of operative metrics, spring characteristics, radiological

outcomes, and postoperative morbidity provides essential feedback for progressive refinement and ensures alignment with international standards. A staged mentorship model—comprising observational learning, supervised local cases, and remote collaboration—supports safe and sustainable transfer of expertise.
Conclusion: SA-PVE is a safe, efficient, and physiologically favourable intervention for children with complex craniosynostosis. Its introduction into new healthcare environments is feasible when supported by structured training, multidisciplinary planning, and rigorous postoperative surveillance. By outlining practical steps for implementation—from patient selection to long-term follow-up—this framework provides a roadmap for centres aiming to establish SA-PVE programmes for the first time. Adoption of these principles can help ensure high standards of care, reduce perioperative risks, and expand global access to modern craniofacial surgery.

Keywords: spring-assisted posterior vault expansion, craniosynostosis, intracranial pressure, paediatric craniofacial surgery, operative implementation, multisuture synostosis.

1. Introduction

Craniosynostosis involving multiple sutures or syndromic diagnoses presents one of the most complex challenges in paediatric craniofacial surgery [1]. In these patients, premature fusion of the cranial sutures disrupts skull growth, frequently leading to raised intracranial pressure (ICP), impaired brain development, visual deterioration, and progressive cranial deformity [2]. Posterior vault expansion is a central component of modern management, as it provides substantial increases in intracranial volume (ICV) and effectively addresses the functional consequences of restricted posterior cranial fossa growth [2,3]. Over the past two decades, spring-assisted posterior vault expansion (SA-PVE) has emerged as a safe, less invasive, and highly effective alternative to traditional open posterior vault remodeling [4]. By using internal springs to generate controlled distraction forces over several months, SA-PVE achieves gradual calvarial expansion with reduced operative trauma, shorter hospitalisation, and a favourable complication profile reported across high-volume centres [4–6].

Despite its demonstrated benefits, the availability of SA-PVE remains uneven worldwide. Many countries, particularly those without established craniofacial units, continue to rely exclusively on extensive open cranial vault procedures. These approaches, while effective, are associated with greater operative blood loss, higher physiological stress, and longer recovery, making them less suitable for infants or children with syndromic comorbidities [7,8]. In parallel, the adoption of distraction-based posterior vault techniques has been limited by technological barriers, lack of specialised training, and uncertainty regarding how such procedures should be safely introduced into new healthcare environments.

As global surgical collaborations expand, there is increasing recognition of the need for structured, ethically robust frameworks to support the introduction of specialised surgical techniques in countries where they have not previously been available. Successful implementation requires more than transferring an operative method; it depends on coordinated training, infrastructure development, perioperative pathway design, and the establishment of local audit mechanisms. Experience from other surgical fields, including epilepsy surgery and advanced laparoscopic programmes [9,10] demonstrates that new procedures can be adopted safely when introduced through staged partnerships, supervised early cases, and context-specific clinical guidelines. However, no such roadmap currently exists for the implementation of SA-PVE in emerging craniofacial units.

The purpose of this article is to provide a comprehensive and practical framework for introducing SA-PVE in countries where the technique has not yet been established. Drawing on the experience of a high-volume craniofacial and paediatric neurosurgical centre, we outline the key components required for safe and sustainable adoption: patient selection, operative workflow, perioperative management, expected outcomes, and programme-level considerations such as training, mentorship, regulatory requirements, and long-term follow-up. Rather than reporting a single institution's results, this manuscript aims to serve as a guide for surgeons, hospitals, and health systems seeking to incorporate SA-PVE into their craniosynostosis practice and to ensure that its introduction occurs with the same rigour, safety, and multidisciplinary collaboration that characterise established centres.

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Context and rationale for introducing SA-PVE in new countries

Craniosynostosis care varies widely across the world, with substantial disparities in access to specialised surgical techniques. While high-income countries with established craniofacial units routinely employ a spectrum of advanced interventions, including posterior vault distraction [11], endoscopic techniques [12], and spring-assisted expansion [4,12], many nations continue to rely exclusively on traditional open cranial vault remodeling [4,12,13]. These procedures, although effective, are associated with increased operative blood loss, greater physiological stress, higher transfusion requirements, and longer hospitalisation compared with less invasive methods [7]. For infants with syndromic or multisuture craniosynostosis, particularly those with raised intracranial pressure or medical comorbidities, these physiological demands can significantly increase perioperative risk. As a result, some children may undergo delayed or staged interventions, or in some instances may not receive timely expansion at all.

SA-PVE offers a compelling alternative for centres seeking to modernise their craniosynostosis care. Over two decades of experience from specialised units in Europe and internationally have demonstrated that SA-PVE provides substantial and durable increases in intracranial volume, effective control of raised ICP, and meaningful improvement in cranial shape [4,14,15]. These outcomes are achieved through small incisions, limited osteotomies, and gradual controlled distraction forces, resulting in reduced operative trauma, lower transfusion rates, and shorter recovery compared with extensive open remodeling [16]. Importantly, SA-PVE is well-suited to syndromic and multisuture cases, groups in whom early, reliable volume expansion is essential and where open techniques often carry the highest physiological burden.

Despite these advantages, the global uptake of SA-PVE remains uneven. Barriers to adoption frequently include limited local expertise, absence of spring manufacturing pathways, uncertainty regarding indications and follow-up protocols, and lack of structured training programmes. In many countries without dedicated craniofacial units, multidisciplinary collaboration between neurosurgery, plastic surgery, anaesthesia, and paediatric intensive care is still developing, and introducing a novel technique requires coordinated institutional commitment. Furthermore, without a clear implementation roadmap, early cases may expose both teams and patients to avoidable challenges, undermining confidence in the technique before its benefits can be realised.

International surgical partnerships provide an effective mechanism to bridge these gaps. Collaborative models, mirroring those successfully used to introduce epilepsy surgery [16], advanced laparoscopy [10], and microsurgical training programmes in low- and middle-income settings [17], have shown that complex procedures can be implemented safely when supported by structured mentorship, shared protocols, and progressive transfer of responsibility. A similar approach for SA-PVE allows emerging centres to benefit from the accumulated clinical experience of high-volume units, enabling safe case selection, standardised perioperative pathways, and consistent early outcomes.

2. Materials and methods

Training and Partnership Model

Introducing SA-PVE into a country where the technique has never been performed requires more than technical instruction; it demands a structured, durable partnership between the initiating centre and an experienced, high-volume craniofacial unit. Evidence from other complex surgical fields consistently demonstrates that sustained collaboration, progressive skills transfer, and clearly defined mentorship are essential for successful adoption. This model ensures that the first procedures are performed safely, that local teams develop confidence and autonomy in a controlled manner, and that early outcomes align with international standards.

A partnership-based approach begins with an initial needs assessment and stakeholder alignment, during which the hosting institution evaluates its case volume, perioperative infrastructure, anaesthetic capabilities, and multidisciplinary support. In parallel, the experienced centre reviews local resources and identifies potential areas requiring adaptation of technique or workflow. This preliminary stage establishes realistic expectations and ensures that SA-PVE is introduced only where appropriate clinical support systems are already in place or can be developed.

Formal training typically progresses through a three-stage model [17–19]. The first stage involves observational learning, during which members of the host team visit the experienced centre to observe SA-PVE procedures, participate in preoperative planning sessions, and gain exposure to postoperative pathways, complication management, and spring removal technique. These visits foster a shared understanding of operative philosophy and create a common language between teams, which is critical during the initial cases.

The second stage consists of on-site mentorship, during which the visiting surgical team performs the first SA-PVE cases jointly with the local surgeons. In early operations, the experienced team may act as primary operators while the host surgeons assist, allowing real-time guidance through patient positioning, osteotomies, spring selection and placement, and intraoperative decision-making. Subsequent cases progressively shift responsibility to the local surgeons, who take the lead while being supported by mentors. This deliberate transition mirrors models used successfully in neurosurgical programme development, where gradual transfer of operative responsibility has been key to building sustainable local expertise.

The third stage involves remote supervision and ongoing case collaboration, supported through regular virtual case discussions, review of imaging, and perioperative troubleshooting. This continuous contact allows the local team to maintain momentum while ensuring alignment with best practices. As experience accumulates, external mentorship becomes consultative rather than directive, enabling the host centre to achieve fully autonomous practice while retaining access to expert guidance for complex or atypical cases.

Throughout all stages, emphasis is placed on multidisciplinary training, including anaesthesia, paediatrics, nursing, and ICU staff, as SA-PVE requires coordinated perioperative management to optimise safety. Simulation of workflow, rehearsals of instrument setup, and shared review of postoperative monitoring protocols build institutional familiarity and reduce uncertainty during early cases. A structured mechanism for data collection, outcome auditing, and morbidity review is established from the outset, aligning the new programme with international quality standards and ensuring that early cases inform continuous refinement.

By framing SA-PVE implementation around a sustained partnership rather than isolated outreach, this training model promotes skill acquisition, institutional learning, and long-term programme stability. It ensures that the introduction of SA-PVE is not a singular event but the beginning of a reproducible, self-sustaining craniofacial service capable of delivering safe, high-quality care to children with complex craniosynostosis.

Preoperative assessment

A comprehensive preoperative assessment is essential to ensure safe patient selection and optimal surgical planning for SA-PVE. Evaluation is conducted jointly by the neurosurgery and plastic surgery teams, with input from ophthalmology, radiology, genetics, anaesthesia, and, when required, respiratory and developmental specialists. This multidisciplinary approach allows identification of the underlying aetiology, assessment of functional impairment, and definition of the objectives of surgery, whether aesthetic or related to raised intracranial pressure.

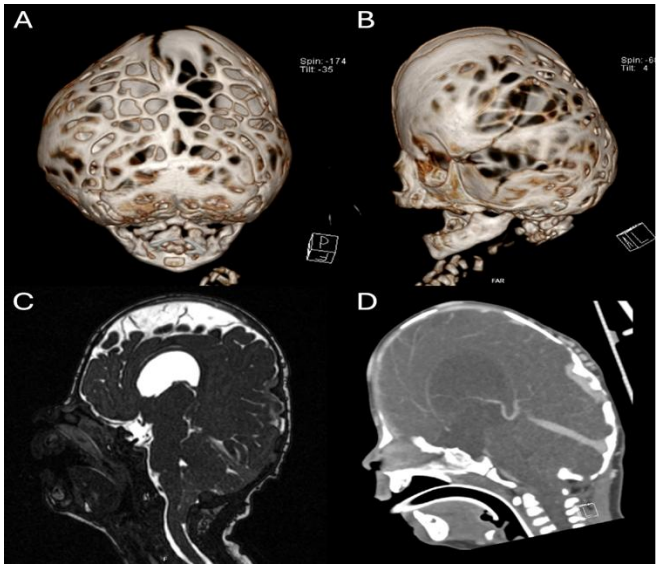

Figure 1 - Preoperative assessment of patients with complex craniosynostosis. A) Computer tomography (CT) posterior view with clear signs of altered ossification and pathologic venous drainage. B) CT lateral view showing multiple bone gaps. C) Magnetic resonance T2 sagittal view showing extensive tonsilar descent and small posterior fossa. D) Venous CT showing pathologic venous drainage and bone gaps over the superior sagittal sinus

All patients undergo a baseline clinical review that includes a detailed examination of head shape, neurological status, developmental history, and scalp condition. Radiological assessment begins with a low-

dose CT scan, which provides essential information regarding suture fusion, calvarial morphology, intracranial volume, venous sinus anatomy, and posterior fossa dimensions (Figure 1A-B). When the CT scan suggests complex features such as Chiari malformation, syringomyelia, venous anomalies, or atypical skull base development, MRI is obtained to clarify posterior fossa crowding and cerebrospinal fluid dynamics (Figure 1C). CT venogram is recommended is suspicion of complex venous drainage (Figure 1D). These imaging studies are used not only for diagnostic accuracy but also for operative planning, including the design and placement of osteotomies and springs.

Ophthalmological evaluation is performed in all cases and includes fundoscopy and visual evoked potentials. These assessments are central to the diagnosis of raised intracranial pressure, particularly in young children for whom clinical symptoms may be subtle or non-specific. When children present with symptoms that may suggest raised intracranial pressure—such as irritability, sleep disturbance, headache, or changes in behaviour—but their ophthalmological examination is normal, continuous intracranial pressure monitoring with a 48-hour ICP bolt is undertaken. This provides an objective measure of ICP dynamics and guides the decision to proceed with SA-PVE for functional indications.

Genetic testing is routinely performed to determine the presence of pathogenic variants associated with craniosynostosis syndromes. The results inform risk stratification, anticipated growth patterns, timing of surgery, and long-term follow-up pathways. Three-dimensional cranial photography is obtained as part of the preoperative assessment to record baseline morphology and to provide a standardised reference for postoperative comparison.

In syndromic craniosynostosis, additional assessments are often necessary. Respiratory evaluation, including sleep studies when obstructive symptoms are present, helps identify airway compromise that may affect anaesthetic planning or the timing of surgery. Developmental and psychological assessments are incorporated into the baseline craniofacial review to document preoperative status and to support longitudinal monitoring. Anaesthetic preassessment is performed in all cases to evaluate comorbidities, airway management considerations, and transfusion risk.

Finally, all cases are discussed in a multidisciplinary craniofacial team meeting, where imaging, clinical findings, and operative plans are jointly reviewed. This ensures consensus regarding the indications, timing, and technical details of SA-PVE and provides families with a coordinated and comprehensive treatment pathway.

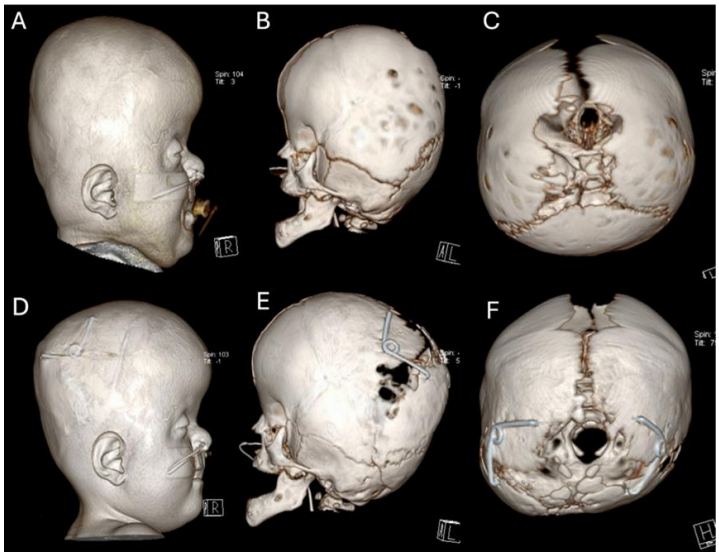

Figure 2 -Preoperative assessment of patients with complex craniosynostosis. A) Computer tomography (CT) posterior view with clear signs of altered ossification and pathologic venous drainage. B) CT lateral view showing multiple bone gaps. C) Magnetic resonance T2 sagittal view showing extensive tonsilar descent and small posterior fossa. D) Venous CT showing pathologic venous drainage and bone gaps over the superior sagittal sinus

Patient selection

SA-PVE may be undertaken for two principal indications: aesthetic cranial reshaping and functional decompression in the setting of raised intracranial pressure. Although the operative technique is similar, the criteria for patient selection, optimal timing, and expected outcomes differ substantially between these groups.

Aesthetic indication

Aesthetic indications most commonly involve children with bicoronal craniosynostosis and, less frequently, selected cases of biparietal synostosis. In our centre, children with isolated sagittal synostosis are typically treated early with either endoscopic strip craniectomy or sagittal springs before six months of age. In addition, SA-PVE is generally not preferred for aesthetic correction of sagittal synostosis because these children usually present with a scaphocephalic head shape, and additional posterior expansion may accentuate the anteroposterior elongation. By contrast, SA-PVE is particularly effective in bicoronal synostosis, where the cranial shape is characteristically brachycephalic. Controlled posterior expansion restores the anteroposterior dimension and produces a smooth, rounded occipital contour, often resulting in a balanced and harmonious cranial profile (Figure 2A-F).

For aesthetic indications, SA-PVE is usually performed at approximately nine months of age, although the procedure may be undertaken slightly earlier or later depending on clinical circumstances. Before spring removal, each child undergoes evaluation to determine whether a fronto-orbital remodeling is required to optimise frontal contour and orbital symmetry. Many children achieve adequate global cranial improvement with SA-PVE alone. However, in cases where frontal protrusion or temporal narrowing persists, a subsequent fronto-orbital remodeling may be beneficial. When indicated, this procedure is ideally performed at around two years of age, timed to coincide with spring removal to avoid additional anaesthetic exposure. In children who do not require fronto-orbital remodeling, the springs may be electively removed after a minimum of three months, once adequate distraction and consolidation have been achieved.

Functional indication

Functional indications for SA-PVE arise when posterior vault expansion is required to treat raised intracranial pressure. At our institution, raised intracranial pressure is diagnosed on the basis of objective signs rather than symptoms alone. Children are considered to have confirmed raised pressure when ophthalmological examination demonstrates papilledema or other pressure-related changes, when visual evoked potentials show abnormalities consistent with pressure effects, or when continuous intracranial monitoring with a 48-hour ICP bolt recording demonstrates elevated pressure. If a child presents with symptoms suggestive of raised intracranial pressure or with indirect radiographic features on MRI or CT but has normal ophthalmological findings, intracranial monitoring is routinely undertaken before surgery is considered.

Once raised intracranial pressure is objectively confirmed, SA-PVE is an effective and well-tolerated option in appropriately selected patients. Functional indications commonly include multisuture craniosynostosis, syndromic craniosynostosis, and craniosynostosis associated with Chiari malformation or syringomyelia, particularly when posterior fossa crowding contributes to the clinical presentation. SA-PVE is most often performed in children younger than two years, when cranial bone malleability allows efficient distraction and rapid intracranial volume expansion. Nevertheless, the procedure has been successfully carried out in selected children between two and four years of age when bone quality and suture biology remain favourable.

In functional cases, SA-PVE offers several advantages over more extensive posterior vault remodeling procedures. The operation is relatively rapid, involves limited dissection, results in low blood loss, and permits simultaneous posterior fossa decompression. These characteristics make SA-PVE particularly suitable for children with complex syndromic diagnoses, significant comorbidities, or reduced physiological reserve, in whom minimising operative stress is essential.

Technical requirements and operative workflow

Successful adoption of SA-PVE requires a clear understanding of its technical foundations, operative sequence, and perioperative resource needs. The classic technique has been well described in large single-centre series and forms a reproducible and adaptable framework for centres introducing the procedure. These detailed operative descriptions, together with outcome data from more than two hundred cases, provide a robust reference standard for implementation.

SA-PVE is performed in a paediatric operating theatre equipped for prone positioning and supported by a multidisciplinary team experienced in craniofacial and neurosurgical anaesthesia. After induction, the child is positioned prone with careful head and airway protection. A bicoronal incision is made, and the scalp is elevated in a subgaleal plane, taking care to preserve a broad pericranial layer. The pericranium is then raised as a composite flap to ensure adequate coverage of the springs during closure and to minimise the risk of exposure.

SA-PVE relies on a posterior bucket-handle osteotomy that spans the parietal and occipital bones. Burr holes are placed strategically to avoid the transverse and sigmoid sinuses, and the osteotomy is then completed with a combination of craniotome cuts and controlled bone spreading.

When performing the inferior osteotomies, it is essential to extend the cuts across both lambdoid sutures (Figure 3). If either suture is left intact, it can act as a mechanical hinge and significantly restrict the posterior distraction achieved by the springs, thereby limiting the overall effectiveness of the expansion. The epidural space is generally not widely exposed, and the limited dissection contributes to the reduced operative blood loss consistently reported across institutional series.

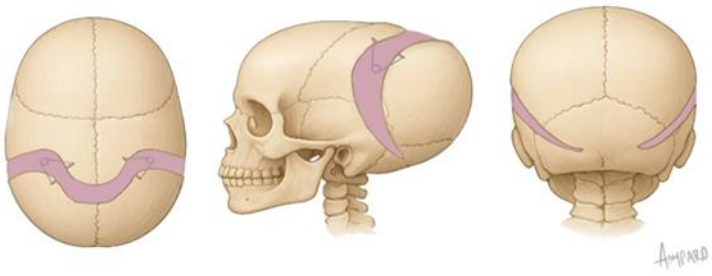

Figure 3 - Superior, lateral and posterior skull iluutrations showing the osteotomies and spring position

Once the osteotomy is mobilised, stainless steel springs are selected according to patient age, skull thickness, and the degree of desired distraction. The technique uses pairs of pre-bent springs that apply outward force across the osteotomy, gradually expanding the posterior vault over several months. Precise placement is critical: the spring feet are secured to the bone edges, and the springs are activated intraoperatively to achieve the correct initial distraction vector. As described in the operative atlas and case series, the surgeon must ensure symmetrical placement and appropriate seating of the spring feet, as uneven activation can lead to asymmetric expansion or early mechanical complications. Once the springs are positioned, the distance between the spring feet should be measured and documented in the operative record, providing a reference for postoperative assessment and longitudinal analysis. Following spring insertion, the pericranium is advanced and closed over the implants to provide an additional protective layer. The scalp is then closed in standard fashion using absorbable sutures. An important advantage of this technique over other distraction-based approaches is that it permits tension-free skin closure, which reduces the risk of wound-related complications and is associated with more favourable scar outcomes. A wound drain is placed in the subgaleal space at the end of the procedure. On the first postoperative day, a full blood count is obtained to assess overall status, with particular attention to haemoglobin and haematocrit levels to determine whether transfusion is required. In our practice, transfusion is considered when the haemoglobin level is below 70 g/L or when the child is clinically symptomatic. If the full blood count is satisfactory and no further intervention is needed, the drain can be removed on the ward without sedation.

Operative times for classic SA-PVE are relatively short, reflecting the limited dissection and efficiency of the technique. In the large single-centre experience, the mean duration of surgery was just over two hours, with characteristically low blood loss and minimal need for transfusion in appropriately selected children. Postoperative care is straightforward, and most children are monitored overnight in a high-dependency setting before returning to the ward. Prior to discharge, frontal and lateral skull radiographs are obtained to confirm the appropriate spring position (Figure 4A-B). The reduced physiological stress of the operation, together with the absence of extensive calvarial remodeling, contributes to consistently short hospital stays, typically around three to four days.

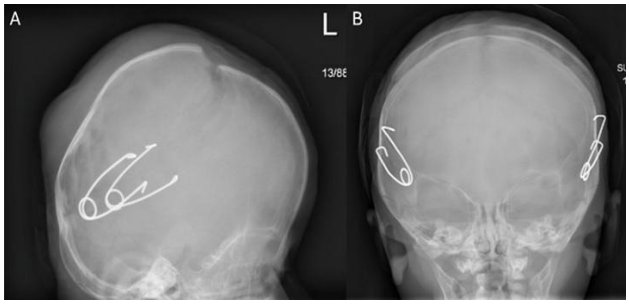

Figure 4 – Postoperative skull XR. A) Lateral view. B) Antero-posterior view

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Spring removal is performed once adequate distraction and consolidation have been achieved. The procedure is undertaken under general anaesthesia, and at the time of removal the distance between the spring feet is measured again and documented to facilitate comparison with intraoperative values and assessment of overall expansion. In aesthetic indications, removal usually occurs after three to six months, and when a planned fronto-orbital remodeling is required, removal is combined with the second operation to avoid additional anaesthetic exposure. In functional cases, the timing of spring removal is determined by clinical progress and serial imaging. When raised intracranial pressure has been diagnosed on the basis of ophthalmological findings, we typically wait until two consecutive ophthalmology examinations have returned to normal before proceeding with removal. In our cohort, the mean interval between spring insertion and removal for functional indications is approximately nine months. It is important to note, however, that most of the distraction occurs early: the springs achieve the majority of their effect within the first month, with additional but diminishing expansion over the following two months. Beyond this period, further volumetric gain is minimal, and the springs could technically be removed earlier. In practice, the timing is usually dictated by the reassessment of intracranial pressure rather than by the mechanical contribution of the springs alone.

3. Results

Postoperative Follow-up and Long-Term Surveillance

Long-term follow-up is an essential component of safe and effective implementation of SA-PVE. Because children undergoing SA-PVE frequently present with multisuture or syndromic forms of craniosynostosis, postoperative surveillance must extend beyond the immediate operative period to include repeated clinical, ophthalmological, developmental, and radiological assessments throughout childhood. The follow-up protocols used in our centre are structured according to the underlying diagnosis, the presence of functional indications such as raised intracranial pressure, and the risk of interval suture fusion or late intracranial hypertension. These pathways guide the frequency and content of review from infancy into adolescence.

Children with confirmed multisuture craniosynostosis are allocated to either a high-risk or low-risk pathway depending on the underlying syndrome, severity of suture involvement, and risk of functional impairment. Both pathways share a common principle of early and repeated multidisciplinary assessment. In the high-risk pathway, which includes patients with conditions such as Apert, Crouzon, and Pfeiffer syndromes, clinical reviews occur frequently during early childhood, including assessments at one, one and a half, two, two and a half, three, four, five, and six years of age. Ophthalmology, three-dimensional photography, and CT or MRI are incorporated at key time points to evaluate postoperative volume, cranial shape, ventricular size, venous outflow, and the status of the posterior fossa. From seven years of age onwards, children are reviewed in craniofacial multidisciplinary transition (CRANF-T) clinics until transfer to adult services. The high frequency of review reflects the elevated risk of delayed intracranial hypertension, progressive midface hypoplasia, and other syndrome-specific complications.

The low-risk multisuture pathway applies to children with milder syndromes or genetically confirmed conditions such as Muenke, Saethre-Chotzen, ERF, or TCF-12-related craniosynostosis. Although these children also require structured longitudinal monitoring, the intervals between clinical reviews are modestly longer than in the high-risk group. Follow-up includes a baseline craniofacial assessment and regular clinical reviews throughout early childhood, with additional multidisciplinary imaging-based assessments at three, seven, and ten years. These visits evaluate intracranial volume, posterior vault development, orbital morphology, respiratory parameters, speech and language development, and neurocognitive outcomes. The low-risk pathway continues through adolescence with transition to the CRANF-T programme at ten years, followed by further review at twelve, fifteen, and seventeen years of age before final discharge.

Non-syndromic multisuture craniosynostosis follows a similar surveillance structure, with the same emphasis on ophthalmological monitoring, repeated three-dimensional imaging, and periodic CT scans to assess postoperative volume and shape. Early reviews at eighteen months, three years, five years, and seven years allow systematic assessment of cranial morphology, developmental progress, ocular health, and the need for further intervention. A ten-year review serves as a key landmark for evaluating long-term aesthetics and for planning any further corrective procedures where required. These patients also transfer to transition clinics during adolescence to ensure uninterrupted multidisciplinary care.

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Across all pathways, ophthalmology plays a central role, particularly during the early years following SA-PVE. Infants and young children undergo six-monthly ophthalmological examinations until at least eight years of age. For children who initially presented with raised intracranial pressure, these examinations continue more frequently until sustained resolution of papilloedema or visual pathway compromise has been demonstrated. Repeat three-dimensional cranial photography is obtained at major review points to assess shape progression, whilst imaging studies—usually low-dose CT—are strategically timed to coincide with key developmental ages in order to minimise cumulative radiation exposure.

This structured follow-up framework ensures that children undergoing SA-PVE receive consistent, comprehensive, and developmentally appropriate surveillance. It allows early identification of recurrent intracranial hypertension, interval suture fusion, Chiari progression, midface growth disturbances, and neurodevelopmental concerns, while also guiding planning for subsequent procedures such as fronto-orbital remodeling or midface advancement when required. For centres adopting SA-PVE for the first time, establishing a similar longitudinal follow-up system is fundamental to ensuring patient safety, optimising outcomes, and maintaining high standards of multidisciplinary craniofacial care.

Suggested outcome and audit metrics for new centres

For centres newly adopting SA-PVE, establishing a structured system for outcome monitoring and audit is essential to ensure safety, guide refinement of technique, and maintain comparability with established international standards. Early implementation should therefore include a prospective registry in which operative data, perioperative parameters, and longitudinal clinical outcomes are systematically recorded. Operative metrics such as duration of surgery, intraoperative blood loss, transfusion requirements, and length of hospital stay provide important markers of procedural efficiency and physiological impact, and can be compared over time as local experience grows. Documentation of spring characteristics, including number, force, and intraoperative foot-to-foot distance, allows correlation of mechanical expansion parameters with postoperative outcomes.

Postoperative morbidity must be carefully audited, including wound complications, spring exposure, infection, dural breach, CSF leak, or need for unplanned reoperation. Many of these events are uncommon but may be influenced by operative technique, patient selection, or perioperative protocols, making early identification critical for improving practice. Radiological metrics, such as intracranial volume changes and posterior vault morphology on interval CT or MRI scans, provide objective measures of expansion and can be used to assess reproducibility across cases. For functional indications, longitudinal data on intracranial pressure, whether assessed through resolution of papilloedema, normalisation of visual evoked potentials, or improvement of symptoms, serve as key indicators of success. In aesthetic cases, three-dimensional photography offers a standardised means of evaluating changes in cranial shape, symmetry, and contour over time.

4. Conclusion

SA-PVE represents a well-established, efficient, and physiologically favourable technique for treating both functional and aesthetic indications in children with complex craniosynostosis. Its limited dissection, predictable expansion profile, and favourable morbidity make it particularly suitable for infants and young children, including those with multisuture or syndromic diagnoses for whom minimising operative risk is essential. For countries and centres where the technique has not previously been available, successful implementation requires far more than technical transfer. It depends on a structured programme encompassing careful patient selection, comprehensive preoperative assessment, detailed operative planning, postoperative surveillance, and long-term multidisciplinary follow-up.

Through partnership with experienced centres, staged mentorship, and adherence to standardised protocols, new surgical units can adopt SA-PVE with high levels of safety and reproducibility. Establishing robust outcome monitoring and audit systems from the outset ensures that early experience informs continuous improvement and aligns new programmes with international best practice. By providing a clear framework for training, implementation, and evaluation, this manuscript aims to support emerging craniofacial teams in delivering the benefits of SA-PVE to their patient populations, thereby expanding global access to modern, effective care for complex craniosynostosis.

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Declaration of AI and AI-assisted technologies in the writing process. The authors confirm that no AI or AI-assisted technologies were used in the generation of any part of this manuscript, including data analysis, image preparation, or the writing and editing process. The entire work was produced solely by the human authors.

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Бассүйек-бет хирургиясымен айналысатын орталықтарды дамытуда серіппе көмегімен артқы бассүйек күмбезін кеңейтуді енгізу: Аталған әдісті қолданатын орталықтың тәжірибелік негізі

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Түйіндеме

Соңғы екі онжылдықта серіппелі артқы бассүйек күмбезін кеңейту (SA-PVE) көп тігісті немесе синдромалдық краниосиностозы бар балаларда дәстүрлі ашық артқы бассүйек күмбезін қайта құруға тиімді және аз инвазивті балама әдіс ретінде пайда болды. Аталмыш әдіс бассүйекішілік көлемнің сенімді кеңеюін, отадан кейінгі аурушаңдық пен тыртық дамуының қолайлы профилін қамтамасыз етеді. Әсіресе бассүйекішілік қысымы жоғары нәрестелер мен жас балалар үшін пайдалы болып саналады. Дегенмен, SA-PVE әдіс бірқатар бассүйек-бет орталықтарында қолдану барысында дәлелденген тиімділігіне қарамастан, көптеген елдерде мамандардың шектеулі қолжетімділігіне, мамандарды құрылымдық оқытудың болмауына және қауіпсіз енгізуге қатысты жұмыстардың реттелмеуіне байланысты қолжетімсіз болып қала беруде. Сондықтан, жаңа орталықтарға осы әдісті ерте енгізуде басшылық ететін тәжірибелік, клиникалық бағытталған құрылым қажет.

Әдістері. Бұл мақалада бассүйек-бет орталықтарын дамытуда SA-PVE қауіпсіз енгізу үшін қажетті операциялық, периоперациялық және бағдарламалық мәселелер қорытындыланған. Ірі педиатриялық нейрохирургиялық және бассүйек-бет орталығының тәжірибесіне сүйене отырып, біз науқас іріктеу, ота алдындағы көпсалалы бағалау, классикалық SA-PVE техникасының ота үстіндегі процесі, отадан кейінгі басқару және ұзақ мерзімді бақылау сияқты негізгі компоненттерді сипаттаймыз. Біз әлеуетті арттыру үшін құрылымдалған 3 фазалы оқыту және серіктестік моделін сипаттаймыз. Сондай-ақ, нәтижелерді бақылау, деректерді жинау және бағдарлама аудиті бойынша ұсыныстар береміз. Қолжазба әртүрлі ресурстарға қолданылатын бірізді енгізу негізін жасау үшін жарияланған деректер мен тәжірибені біріктіреді.

Нәтижелері. SA-PVE эстетикалық және функционалдық көрсеткіштерге сәйкес келетін қайталанатын және бейімделетін әдіс ретінде анықталды. Табысты енгізудің негізгі факторларына краниосиностоз кіші түрін дәл диагностикалау, қажет болған жағдайда бассүйекішілік қысымның жоғарылауын растау және мұқият радиологиялық, офтальмологиялық және генетикалық бағалау жатады. Ірі, бір орталықты зерттеулер арқылы жетілдірілген бұл хирургиялық әдіс тіндердің шектеулі диссекциясымен, қан жоғалтудың аздығымен, ота жасауға кеткен уақытының қысқалығымен және жараның кернеусіз жабылуымен сипатталады. Отадан кейінгі ерте қалпына келу әдетте жылдамырақ, ауруханада жату мерзімінің қысқаруымен және асқынулардың кездесу жиілігінің төмендігімен жүреді. Ұзақ мерзімді бақылау үшін құрылымдық офтальмологиялық тексерулер, мерзімді бейнелеу, 3D рентгенге түсіру және жасөспірімдік кезеңге дейін салааралық бақылау жүргізу қажет. Бұл әдісті қолданатын орталықтар үшін хирургиялық өнімділіктің,

серіппе сипаттамаларының, радиографиялық нәтижелердің және отадан кейінгі аурушаңдықтың мұқият аудиті біртіндеп жақсарту үшін қажетті кері байланысты және халықаралық стандарттарға сәйкестікті қамтамасыз етеді. Оқыту мен клиникалық жағдайларды бақылауда ұстау, сондай-ақ қашықтықтан ынтымақтастықты қамтитын әрі кезеңмен жүзеге асатын тәлімгерлік моделі тұрақтылық пен қауіпсіздікті қамтамасыз ету арқылы тәжірибе бөлісуді жеңілдетеді. қауіпсіз және тұрақты түрде беруді жеңілдетеді.

Қорытынды. SA-PVE - күрделі краниосиностозы бар балалар үшін қауіпсіз, тиімді және физиологиялық тұрғыдан пайдалы шешім. Оны жаңа медициналық мекемелерде енгізу құрылымдық оқытуды, пәнаралық жоспарлауды және отадан кейінгі мұқият бақылауды қолдау арқылы мүмкін болмақ. Әдісті енгізудің тиімді тәжірибеге қадамдарын, яғни науқастарды дұрыс іріктеуден бастап ұзақ мерзімді бақылауға дейінгі қадамдарды белгілеу арқылы ұсынылған әдістеме SA-PVE бағдарламаларын алғаш рет құружы жоспарлаған орталықтар үшін жол картасын ұсынады. Сипатталған қағидаттарды қабылдау күтімнің жоғары стандарттарын қамтамасыз етуге, периоперациялық тәуекелдерді азайтуға және озық краниофациальды хирургияға жаһандық қолжетімділікті кеңейтуге көмектеседі.

Түйін сөздер: серіппе көмегімен артқы бассүйек күмбезінің кеңеюі, SA-PVE, краниосиностоз, бассүйекішілік қысым, балалар бассүйек-бет хирургиясы, хирургиялық араласу, көп тігісті синостоз.

Внедрение пружинной задней экспансии свода черепа в развивающихся черепно-лицевых отделениях: Практическая основа для центров, впервые применяющих указанную методику

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Резюме

Пружинная задняя экспансия свода черепа (SA-PVE) за последние два десятилетия стала эффективной и менее инвазивной альтернативой традиционному открытому ремоделированию заднего свода черепа у детей с многошовным или синдромальным краниосиностозом. Данная методика обеспечивает надежное увеличение внутричерепного объема, благоприятный профиль рубцовой ткани и заболеваемости, и особенно полезна для младенцев и детей с повышенным внутричерепным давлением. Однако, несмотря на доказанную эффективность в крупных центрах, занимающихся черепно-лицевой хирургией, SA-PVE остается недоступной во многих странах из-за ограниченного числа специалистов, отсутствия структурированного обучения и неопределенности в отношении безопасного внедрения. Поэтому существует необходимость в практической, клинически ориентированной структуре, которая бы направляла новые центры в процессе раннего внедрения этой методики.

Методы. В данной статье обобщены оперативные, периоперационные и программные аспекты, необходимые для безопасного внедрения SA-PVE в развивающихся черепно-лицевых центрах. Опираясь на опыт крупного детского нейрохирургического и черепно-лицевого центра, мы описываем основные компоненты, включая отбор пациентов, междисциплинарную предоперационную оценку, оперативный рабочий процесс классической методики SA-PVE, послеоперационное ведение и долгосрочное наблюдение. Мы описываем структурированную трехэтапную модель обучения и партнерства для наращивания потенциала и предоставляем рекомендации по мониторингу результатов, сбору данных и аудиту программы. В рукописи интегрированы опубликованные данные и практический опыт для создания согласованной структуры внедрения, применимой в различных условиях ресурсов.

Результаты. SA-PVE была определена как воспроизводимая и адаптируемая методика, подходящая как для эстетических, так и для функциональных показаний. Ключевыми факторами успешного внедрения являются точная диагностика подтипа краниосиностоза, подтверждение повышенного внутричерепного

давления, где это уместно, и тщательная радиологическая, офтальмологическая и генетическая оценка. Оперативная методика, усовершенствованная в ходе крупных исследований в одном центре, характеризуется ограниченным рассечением тканей, низкой кровопотерей, коротким временем операции и закрытием раны без натяжения. Раннее послеоперационное восстановление, как правило, происходит быстро, с коротким сроком госпитализации и низким уровнем осложнений. Долгосрочное наблюдение требует структурированного офтальмологического осмотра, периодической визуализации, трехмерной фотографии и междисциплинарного наблюдения, продолжающегося до подросткового возраста. Для центров, впервые внедряющих эту методику, тщательный аудит оперативных показателей, характеристик пружин, рентгенологических результатов и послеоперационной заболеваемости обеспечивает необходимую обратную связь для постепенного совершенствования и гарантирует соответствие международным стандартам. Поэтапная модель наставничества, включающая обучение на основе наблюдения, контролируемые локальные случаи и удаленное сотрудничество, способствует безопасной и устойчивой передаче опыта.

Выводы. SA-PVE — это безопасное, эффективное и физиологически благоприятное вмешательство для детей со сложным краниосиностозом. Его внедрение в новые медицинские учреждения возможно при поддержке структурированного обучения, междисциплинарного планирования и тщательного послеоперационного наблюдения. Описывая практические шаги по внедрению — от отбора пациентов до долгосрочного наблюдения — эта структура предоставляет дорожную карту для центров, стремящихся впервые создать программы SA-PVE. Принятие этих принципов может помочь обеспечить высокие стандарты оказания медицинской помощи, снизить периоперационные риски и расширить глобальный доступ к современной черепно-лицевой хирургии.

Ключевые слова: пружинная задняя экспансия свода черепа, SA-PVE, краниосиностоз, внутричерепное давление, детская черепно-лицевая хирургия, оперативное вмешательство, многошовный синостоз.