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The removal of cranial springs used in the treatment of scaphocephaly: A minimal access approach

Michael Alexander Rtshiladze [a, *], Andee-Anne Roy [b], David Goltsman [a], Jeremy Hunt [a], Rajesh Reddy [a, c, d, e], Mark Peter Gianoutsos [f]

[a] Department of Craniofacial Surgery, Sydney Children's Hospital, Randwick, NSW, Australia
[b] Department of Plastic and Reconstructive Surgery, University of Montreal, Canada
[c] Department Head, Department of Neurosurgery, Prince of Wales Hospital, NSW, Australia
[d] Prince of Wales Private Hospital, Australia
[e] University of New South Wales, Australia
[f] Department Head, Department of Craniofacial Surgery, Sydney Children's Hospital, Randwick, NSW, Australia

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ABSTRACT

The treatment of non-syndromic scaphocephaly with spring-activated cranioplasty offers acceptable outcomes with the potential for reduced surgical morbidity when compared with cranial vault remodelling procedures. A disadvantage of this technique is the need for a second operative intervention to remove the implanted devices. There are many descriptions of the surgical technique for performing spring-activated cranioplasty available in the literature; however, little is documented regarding the procedures used for device removal. The published accounts of spring removal demonstrate a wide range of approaches, from the reopening and dissection of the entire previous surgical field, to attempts to limit the incisions and dissection. In this study we describe our technique for the minimally invasive removal of cranial springs used in the treatment of scaphocephaly. Our technique focuses on minimal soft tissue disruption and uses a Kirschner wire cutter to divide the spring at its mid-point so as to relieve any residual internal forces acting on the footplates.

1. Introduction

The use of metallic implantable springs for the treatment of craniofacial conditions was first performed at Sahlgrenska University Hospital, Sweden in 1997 (Lauritzen et al., 2008). Since that time, spring-activated cranioplasty (SAC) for the management of craniosynostosis has increased in popularity and spread across the world (Rodgers et al., 2017; Mackenzie et al., 2009; Pyle et al., 2009; David et al., 2010). Compared with cranial vault remodelling, SAC has the advantages of less scarring, shorter periods of hospitalisation, and lower rates of blood transfusion (Zakhary et al., 2014; Taylor and Maugans, 2011; Rodgers et al., 2017).

A major disadvantage of SAC is the need for a second operation to remove the springs several months after the initial surgery. There are many published accounts of the surgical technique for SAC, however, the authors of these articles rarely include details of the removal procedure. The limited documentation available about the removal of cranial springs suggests a wide range of approaches, from re-opening the entire surgical scar and performing a wide soft tissue dissection, to more minimal approaches using multiple smaller incisions over the footplates and midpoint of the springs (Table 1). Furthermore a review of the available literature pertaining to SAC highlights a great variety in the design and construction of the springs used by different surgeons across the world (Lauritzen et al., 1998, 2008; Mackenzie et al., 2009; Pyle et al., 2009; David et al., 2004, 2010; Doumit et al., 2014; Proctor, 2012; Le et al., 2014; Gerety et al., 2015; de Jong et al., 2013; van Veelen and Mathijssen, 2012; Maltese et al., 2007; Sanger et al., 2007; Guimaraes-Ferreira et al., 2003; Lauritzen and Tarnow, 2003; Davis and Lauritzen, 2008; Windh et al., 2008; Davis et al., 2009; Tovetjarn et al., 2012; Tuncbilek et al., 2012; Arko et al., 2015; Costa et al., 2015; Shen et al., 2015). Correspondingly, techniques for spring placement and removal will

* Corresponding author. Department of Craniofacial Surgery, Sydney Children's Hospital, Randwick High Street, Randwick, NSW, 2031, Australia.
E-mail address: mradmin@melanoma.org.au (M.A. Rtshiladze).

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Table 1
Cranial spring removal techniques and spring types.

Study (location)	Craniofacial conditions treated with springs	*n*	Interval between spring placement and removal (average months)	Spring shape	Description of spring removal procedure
Lauritzen et al., 1998 (Sweden)	coronal, metopic and multi-sutural	2	3	Safety pin style spring	Removal of the springs was uneventful
Guimaraes-Ferreira et al., 2003 (Portugal, US, Sweden)	sagittal	10	Not stated	Omega style spring with hooked footplates	A simple operation, necessitating admission for only a single day To date no transfusion has been required
Lauritzen and Tarnow, 2003 (Sweden)	Sagittal, bicoronal and metopic pansynostosis	0	6	Omega style spring with bayonet-shaped footplates	Laboratory research directed at developing springs that do not need to be removed
David et al., 2004 (USA)	Nonsyndromic scaphocephaly	15	4	Omega style spring with hooked footplates	Springs were removed when the calverial defect between the footplates had reossified The procedure was a minimal one and similar to distractor removal
Maltese et al., 2007 (Italy and Sweden)	Metopic synostosis	23	Not stated	Omega style spring with bayonet-shaped footplates	Timing of removal depended on the clinical effect of the spring and the cephalograms Removal under general anesthesia 1 cm incision beyond the hairline; spring loop exposed and cut Arms of the spring pulled out separately
Sanger et al., 2007 (USA)	Experimental animal study on swine	0	–	Omega style spring with resorbable footplates	Five separate, small, stab incisions were made in the scalp — one over each of the four ends of the springs that wrap around the bone and one over the junction of the two springs
Davis and Lauritzen, 2008 (New Zealand and Sweden)	Ventricular shunt induced scaphocephaly	4	13	Omega style spring with bayonet shaped footplates	Nil
Lauritzen et al., 2008 (Sweden)	Sagittal, metopic, bicoronal, multiple synostoses, and midface surgery	100	7	Omega style spring with bayonet-shaped footplates	Operation performed under general anesthesia Same-day surgery entailing a small cut in the skin and a few minutes of manipulation
Windh et al., 2008 (Sweden, New Zealand, and USA)	Sagittal	20	6	Omega style	–
Davis et al., 2009 (New Zealand)	Non-synostotic scaphocephaly	7	7.25	Omega style spring with bayonet-shaped footplates	–
Mackenzie et al., 2009 (New Zealand)	Nonsyndromic scaphocephaly	9	Not stated	Omega style spring with bayonet-shaped footplates	–
Pyle et al., 2009 (USA)	Nonsyndromic scaphocephaly	90	Not stated	Omega style spring with hooked footplates	Springs were removed when there was radiographic and clinical evidence of reossification between the springs
David et al., 2010 (USA)	Nonsyndromic scaphocephaly	75	Not stated	Omega style with hooked footplates	A brief outpatient surgery with discharge from the recovery room
Taylor and Maugans, 2011 (USA)	Nonsyndromic scaphocephaly	7	Not stated	Not stated	–
Tovetjarn et al., 2012 (Sweden)	Bicoronal	18	6	Omega style spring	Spring removal was a minor surgery The average age for this surgery was 11 months The mean duration was 17 min Blood loss was estimated at a mean of 5 ml Mean hospital stay was 1.1 days No intracranial complications were observed
Tuncbilek et al., 2012 (Turkey)	Multiple suture and cloverleaf	3	5.7	Omega style spring with hooked footplates	Reossification between the footplates needed both clinically and radiologically prior to spring removal
van Veelen and Mathijssen, 2012 (Netherlands)	Nonsyndromic scaphocephaly	41	2–3	Safety pin style spring with hooked footplates	Initial incisions were reopened Springs were each cut twice, as close to the lateral ends as possible The lateral ends containing the hooked footplates were grasped with needle holders and rotated out of position

(*continued on next page*)

Table 1 (*continued*)

Study (location)	Craniofacial conditions treated with springs	*n*	Interval between spring placement and removal (average months)	Spring shape	Description of spring removal procedure
de Jong et al., 2013 (Netherlands)	Multi-suture synostoses requiring posterior vault expansion	15	2.5	Safety pin style spring with hooked footplates	Initial incisions were reopened Soft tissue covering removed Springs were cut halfway, which allowed removal of springs with a rotating movement
Arko et al., 2015 (USA)	Nonsyndromic scaphocephaly	22	4	Omega style spring with hooked footplates	An outpatient procedure Average duration of procedure 44.9 min Average estimated blood loss of 20 ml Mean postoperative hospital stay of 0.9 days
Costa et al., 2015 (USA)	Multi-suture synostoses	1	2	Omega style spring with hooked footplates	–
Shen et al., 2015 (China)	Six sagittal synostoses Three coronal synostoses Three metopic synostoses	12	12 months for implanted hook	External 'U' springs Omega style spring interacting with an implanted titanium hook	Removal of the externally located spring was carried out in the outpatient clinic The technique for removal of the implanted titanium hook was not described
Swanson et al., 2016 (USA)	Nonsyndromic scaphocephaly	26	4	Omega style spring with hooked footplates	Removal was an outpatient procedure with or without overnight observation
Tenhagen et al., 2016 (UK)	Nonsyndromic scaphocephaly	12	Not stated	Safety pin style spring	–
Borghi et al., 2017 (UK)	Nonsyndromic scaphocephaly	60	3.5	Safety pin style spring	–
Ou Yang et al., 2017 (Australia)	Nonsyndromic scaphocephaly	16	3	Omega style spring with bayonet-shaped footplates	Delay in removal may result in springs being embedded, making removal much more difficult

vary with spring type. At the Sydney Children's Hospital, Randwick, SAC is performed using an omega spring design with bayonet-shaped footplates in keeping with the type popularized by Laurirzen (Lauritzen et al., 1998, 2008).

2. Surgical technique

In our institution SAC is performed for non-syndromic scaphocephaly between the ages of 3 and 6 months. The surgery is undertaken with the patient in the prone position. A midline lazy S incision is made and a subgaleal dissection is performed. Following the placement of multiple burrholes, the fused sagittal suture is resected with a strip of bone 1–1.5 cm wide. Our implantable springs are constructed by the Medical Physics and Bioengineering Department at Christchurch Hospital, Christchurch, New Zealand. The springs are made of 304 grade stainless steel. They are pre-bent with a distraction force of 14 N when the tips are 12 mm apart. The footplates are constructed in a bayonet style. Following placement of two springs (one anterior and one posterior) the scalp is closed in two layers. A suction drain is placed.

The procedure of spring removal is performed approximately 3 months after SAC. The procedure is booked following clinical assessment confirming maximal expansion of the springs and the formation of bone across the midline defect. Again patients are positioned prone. The orientation and location of the underlying devices is determined by palpation. A small incision is made in the midline at the point where the existing scar intersects with each spring's mid-section. Each incision is limited to 1–1.5 cm in length. A combination of sharp and blunt dissection is performed down to the palpable metallic spring (Fig. 1). Dissection in the midline, over the sagittal sinus, proceeds with caution. For this reason, monopolar cautery is avoided.

Once the metallic spring is identified a periosteal elevator is used to raise the central portion of the spring off the recently consolidated interpositional bone. The periosteal elevator is used to both raise the spring and protect any soft areas of interpositional bone while further soft tissue is dissected off the spring. A Kirschner wire cutter is then used to divide the spring in two halves (Fig. 2). This releases any residual intrinsic tension in the spring that may still be exerting force on the footplates. The two spring halves are now able to be manipulated with little resistance (Fig. 3). The two halves are then removed in turn by firm and

Fig. 1. Dissection to reveal the midpoint of the cranial spring.

constant inline traction with a heavy needle driver (Fig. 4). The small incisions are closed in two layers with resorbable sutures. The only dressing is a light covering of antibiotic ointment. Patients are observed in the day surgery ward and are discharged home on the same day.

The described approach to limited-access spring removal was adopted at Sydney Children's Hospital in January 2015. Prior to this, incisions were made directly over each spring foot plate and, on occasion, a portion of the original incision was also reopened. Between January 2015 and January 2018 there were 20 cases of spring removal at our institution (Table 2). 19 cases were performed as an independent procedure. One case was performed as a combined procedure with excision of an interhemispheric lipoma and frontal remodelling. This case took a total of 214 min to complete and so was excluded from our analysis of our procedures. The average operative time for the 19 cases was 47 min. In 15 cases (79%) the surgery was completed with no need to extend the incision or dissection beyond the technique described above. In four cases (21%), the majority of the original incision was reopened to remove the spring. The decision to reopen the entire wound was based on a combination of difficulty in palpating the exact spring location through the scalp, difficulty in safely dissecting the spring free from underlying structures in the midline, and surgeon preference. We experienced no complications in the 20 cases of spring removal. No blood transfusions were required in any of the cases. All procedures were performed as day surgery.

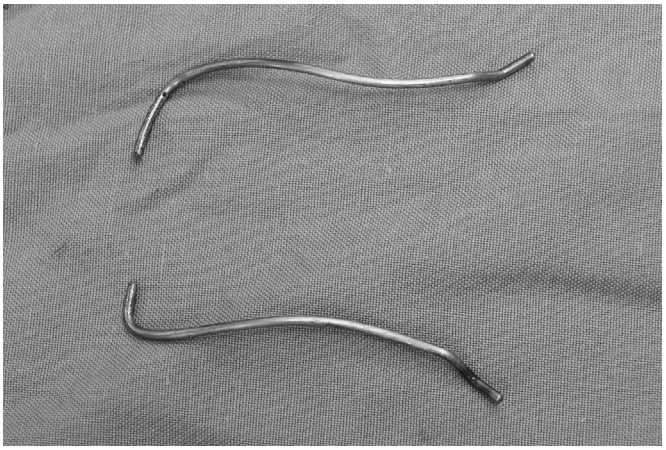

Fig. 4. The divided cranial spring ex vivo.

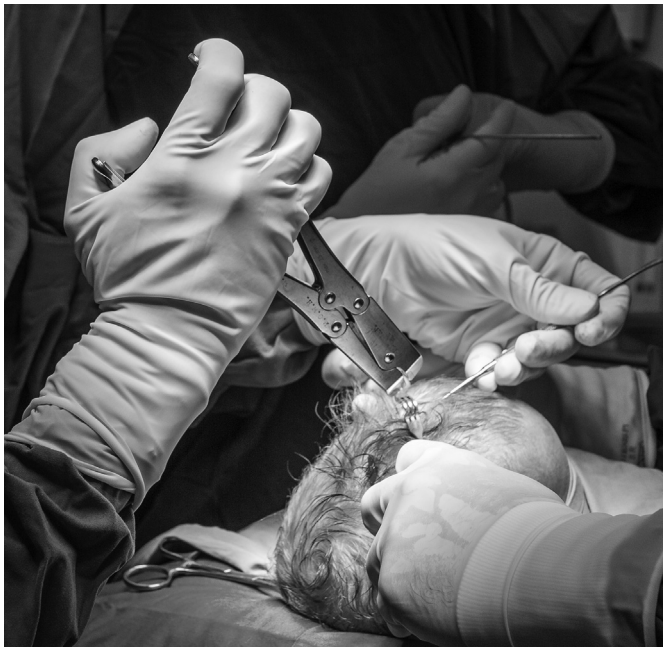

Fig. 2. The cutting of the cranial spring at its midpoint.

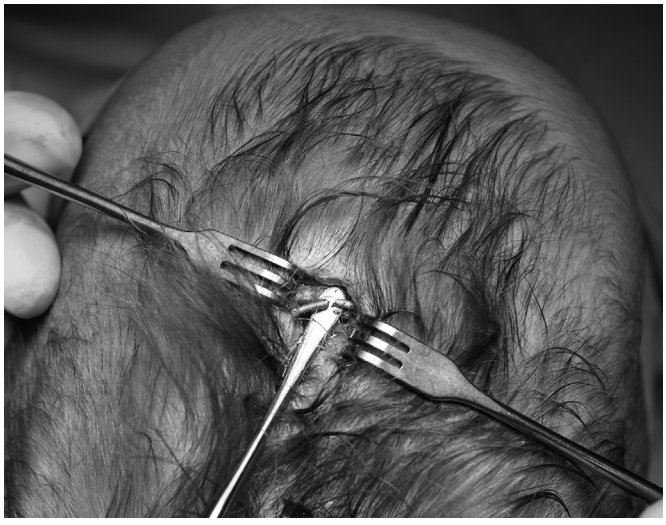

Fig. 3. The cut cranial spring in situ.

3. Discussion

A great variety of surgical approaches exists worldwide for the treatment of scaphocephaly (Doumit et al., 2014). In general terms these can be considered as earlier procedures with less dissection (such as strip craniectomy and SAC) and later procedures that consist of removal of the majority of the calvarial bone (total cranial vault remodelling). There has been increasing interest in recent years in techniques involving less extensive procedures in craniofacial surgery (Taylor and Maugans, 2011; Proctor, 2012). Two modern, less invasive treatments that are practised across a number of centres are endoscopically assisted strip craniectomy with or without postoperative helmet therapy and SAC (Mackenzie et al., 2009; Le et al., 2014; Gerety et al., 2015). Both techniques aim to correct cranial form through early intervention on malleable bone, and have a focus on limiting overall soft tissue dissection. Strip craniectomies rely on the period of rapid infant brain growth to drive shape change, while with SAC shape change is powered by the implantable device. When comparing these two early interventions, a major point of difference is the need with SAC for a second procedure to remove cranial springs some months after the initial operation. This additional surgical morbidity is recognised as a major drawback of this technique.

We describe a technique for the removal of cranial springs used for the treatment of sagittal craniosynostosis. The aim of our approach is to reduce the area of dissection and hence some of the surgical morbidity associated with the removal procedure. We endeavour to address some of the concerns regarding the need for a second surgery by describing our experience with this procedure.

The available literature describing the use of cranial springs contains relatively little detail regarding the variety of approaches used for spring removal (Table 1). It is evident from the current literature that there is a variety of different approaches. A number

Table 2
Spring removal at the Sydney Children's Hospital, Randwick from January 2015 to January 2018.

$n = 19$			
Variable	Average	Min/max	SD
Operation time (minutes)	38	8/115	30.89
Length of hospital admission (days)	1	1/1	0
Age (months)	8	5/13	1.88
Incisions	*n*	% total	
Stab	15	79%	
Whole incision reopened	4	21%	

of authors approached spring removal by reopening the full length of the surgical scar and performing wide soft tissue dissection (Rodgers et al., 2017; de Jong et al., 2013; van Veelen and Mathijssen, 2012). Other authors offered brief descriptions that suggest that their approach to removal involved less dissection (Lauritzen et al., 2008; Maltese et al., 2007; Sanger et al., 2007). Few surgeons described cutting the in-situ spring to aid in its removal (van Veelen and Mathijssen, 2012; Maltese et al., 2007; de Jong et al., 2013). Maltese et al. (2007) described a spring removal technique similar to that outlined here. A single 1 cm cut above the hairline was used in 23 cases of SAC for the treatment of hypotelorism in metopic craniosynostosis. The midpoint of the single spring was then cut to allow the two halves to be pulled free. These authors also utilised an omega-shaped spring with bayonet-style footplates, a similar design to our own springs. To our knowledge there is no description of cutting omega-shaped springs in half to facilitate removal in SAC for scaphocephaly. Van Veelen and Mathijssen also described a technique of spring removal that involved dividing the spring with a Kirschner wire cutter (van Veelen and Mathijssen, 2012). Their spring design was different from ours and utilized a helical coil in the midpoint, and hooked footplates. In this study the full length of the existing transverse scar was reopened and then each spring was cut twice, as close to each foot plate as possible. This technique would appear to be more related to the difficulties associated with removing hooked footplates, than an attempt to limit incisions and dissection. De Jong et al. described the use of a similar style of helical spring with hooked footplates for use in posterior cranial vault expansion (de Jong et al., 2013). They described the spring removal process as cutting the springs at their midpoint to allow for a rotational movement of each half, thereby freeing the hooked footplate from the bone. To gain access to the springs the authors reopened the entire coronal incision and redissected the soft tissues. It would again seem that their primary reason for cutting these springs related to the footplate design and not an attempt to limit the extent of soft tissue disruption during the removal process.

In an attempt to simplify the techinque for spring removal, individuals have experimented with partially resorbable materials. Sanger et al. describe a crainal spring with resorbable footplates and its use in an experimental swine model. The cited reasoning for working on the development of such a device is to allow for removal of the spring through one incision site at the apex of the spring (Sanger et al., 2007). We describe a surgical technique currently in use that allows for a single incision approach and utilises unmodified cranial springs. Awareness of the technique we describe for spring removal may be useful to other surgeons when selecting their initial spring design. It can be seen that bayonet footplates have a significant advantage over hooked footplates in terms of the morbidity associated with the spring removal procedure.

The limitations of the technique we describe relate to the procedure being performed in the cranial midline and over the sagittal sinus. While we have never encountered an injury to this structure during these procedures, the theoretical risk exists of perforating the soft, newly developed midline interpositional bone, and damaging the underlying sinus. Other difficulties that could be encountered with our described approach relate to difficulty in freeing and removing the cut spring halves. Our experience is that once the spring is divided, any residual internal forces that are acting on the footplates are released, and the two halves can be slid out of their positions with minimal to moderate traction force. It is possible in cases of excessive bony overgrowth for the foot plates to be more fixed. The risk of encountering this difficulty increases when springs remain in situ for longer periods of time. With spring removal booked at 3 months following SAC, we have had little difficulty in removing the cut halves. If such an intraoperative difficulty were encountered we would advocate making additional small incisions directly over the foot plate of the trapped spring half and freeing it directly from the overgrown bone. We would caution against using excessive force to pull a spring half free due to the risk of avulsing adjacent structures.

4. Conclusion

SAC has been accepted as a technique for the treatment of scaphocephaly. It offers acceptable outcomes, with the possibility of reducing surgical morbidity compared with more extensive skull remodelling procedures. A recognised drawback of the SAC approach is the need for a second surgery to remove the implanted devices. This additional surgical intervention carries some increased morbidity and surgical risk when compared with treatments that can be performed in a single stage. While many excellent descriptions exist of the techniques used to place cranial springs, there is little written about their removal. The published descriptions of spring removal demonstrate a wide range of approaches, with no overall consensus.

Here we describe a simple technique for the removal of cranial springs in the treatment of scaphocephaly. Our technique focuses on minimal soft tissue disruption in an attempt to minimise patient morbidity. We describe our experience with spring removal and with this technique. In 79% of cases in our institution, the procedure to remove cranial springs is a short (less than an hour) day surgery. In the remaining 21% of cases surgical dissection of the implanted device is more challenging and requires additional operative time. We have not experienced major complications as a result of spring removal surgery.

Conflicts of interest

The authors of this manuscript wish to disclose no financial support or conflicts of interest encountered during the preparation of this work.

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