



EDITORIAL

“Horses for courses”

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ONE can organize the myriad techniques for managing sagittal synostosis-induced scaphocephaly in a 2 × 2 table according to dynamic and static techniques on one axis and compressive and decompressive procedures on the other, and perhaps even include a third axis for open extensile versus minimal access exposures. The idea of using a dynamic, minimal access decompressive technique is very appealing for a number of reasons, most of all for the opportunity to harness the viscoelastic properties of the infant skull and the powerful functional matrix of the rapidly growing brain in the first few months of life. Therefore, it is exciting to imagine the potential of a simple spring in creating a satisfactory change in cranial configuration and improving craniocerebral disproportion.

Spring-assisted cranioplasty seems to fit the bill quite nicely, although this concept is not new. Claes Lauritzen from Göteborg, Sweden, introduced this technique in 1997 and has shared his extensive experience.^{11–13} Applications of this method have included improvement of hypotelorism in metopic synostosis, correction of brachycephaly in Apert syndrome, working around potentially hazardous anomalous venous drainage, and the correction of nonsynostotic scaphocephaly without cranial osteotomy and ventricular shunt cranial deformity.^{2,4,5,10,15} The workhorse application of spring-assisted cranioplasty has focused on the correction of nonsyndromic sagittal synostosis scaphocephaly.⁹

Opponents of the use of springs in the infant skull cite the lack of control and predictability in bone expansion, the immediate effect of the spring that dissipates over time, the potential for dural and/or venous sinus tears, skin erosion, increased complication rate, and the need for a subsequent surgery for removal.¹⁴ Regardless, the outcomes of surgery speak for themselves, and the popularity of spring-assisted cranioplasty has not abated.

The article by Borghi et al. represents the first notable publication from the Great Ormond Street Hospital for Children (GOSH) group on the use of springs in the management of craniosynostosis.¹ This group has been using the spring-assisted cranioplasty technique since 2008, and this is a welcome opportunity to review the progress they have made in applying the minimally invasive surgery and taking advantage of bone-fluid physiology in the correction of scaphocephaly. The focus of their paper is spring biomechanics and kinematics (a separate manuscript that describes the clinical outcomes in 100 consecutive cases of nonsyndromic scaphocephaly has been accepted for publication). As is often the case, a novel idea that seems to have significant clinical application makes the journey from the bench to the bedside.

A body of work using an animal model has examined the physiological effects of springs on the craniofacial skeleton.^{3,6–8} Experimental work in the rabbit by Davis and colleagues has demonstrated that cranial springs alter the growth vector of adjacent sutures, cause thickening of cranial sutures and adjacent cranial bone, and cause differential strain patterns on the endo- and ectocranial surfaces.^{3,6–8} The ability to mould and shape the cranium through the application of spring-derived force is powerful. There is a paucity of literature about the same influences in the human infant.

Therefore, the current study represents a welcome opportunity to assess the biomechanics and kinematics of springs in the management of 60 infants (mean age 5.2 ± 0.9 months) with nonsyndromic sagittal synostosis. The surgical technique involves creating paramedian strip craniectomies and placing 2 springs of various thicknesses across the midline. The goal is to achieve an on-table expansion of 3 cm. Spring selection (1.0-, 1.2-, and 1.4-mm thickness springs are available) is arbitrarily based on bone thickness and surgeon expertise. Various combina-

tions of spring thickness are routinely employed. Springs are removed at 3 months, and the spring opening distance is measured on the operating table, at 1 day postoperatively, at 3 weeks postoperatively, and at the time of spring removal. Spring dynamics and kinematics were assessed using a standard mechanical testing device. While the emphasis of this paper is not clinical, the authors describe measuring percentage changes in the cephalic index from preoperatively to the time of the second follow-up at 3 weeks postsurgery.

Several important findings from their paper should be noted. First, compression mechanical testing of the spring types generated force/opening curves that confirmed what many already intuitively know: the tighter the spring is coiled, compressed, or crimped, the greater the force it can generate. Second, as the thickness of the wire increases, so does the force generated across the bone edges in a nonlinear fashion. It is interesting to see that the force generated at a 20-mm crimping in the thickest springs (model S14) is almost 4 times greater than the equivalent measure for the thinnest springs (model S10). Older infants with ostensibly thicker bone were noted to require thicker springs, but no data are presented to corroborate this. Interestingly, the springs expand to almost the pre-insertion configuration, and with time (and opening), the force thus generated dissipates. The most intriguing aspect of their study is the suggestion that there is no difference in either the force or the spring opening distance at the second follow-up (3 weeks) as compared with that at removal (3 months) independent of age (and therefore bone thickness). The spring kinematic data show that by 10 days postimplantation, the spring is 98% open and expansion comes to a halt. This would confirm the general impression that the spring effect is rapid and occurs early after insertion. There are no clinical details in their paper to demonstrate whether morphological changes continue to occur in the skull between 10 days postimplantation and the time of spring removal.

Ultimately, the effectiveness of any technique will be based on objective measures, parent and patient satisfaction, and finally public acceptance. Will this child pass the “supermarket test”? There is a paucity of clinical data in this study; no pre- or postoperative details about the mean cephalic index in this patient cohort are presented. What is interesting, however, is the data in their Fig. 8, which demonstrate an inverse correlation between patient age and the percentage change in cephalic index between preoperatively and the second follow-up (3 weeks postimplantation). Younger patients have a greater change in cephalic index than the older patients in the study. This may intuitively suggest that thinner bone is a factor. However, a closer look at the 45 data points in this figure reveals that 15 patients had less than 3% improvement in the cephalic index and 2 patients had a negative improvement, suggesting a worsening morphology. Although the cephalic index is not the ideal metric to assess all aspects of the scaphocephalic skull, it is concerning that improvement is modest at best in one-third of the patients in their study.

A deficiency of their paper relates to the lack of guidance or practical advice for the surgeon interested in adding this technique to his or her surgical armamentarium. What are the minimal forces necessary to cause a rea-

sonable change in the shape of the skull? Why wouldn't a surgeon default to the strongest spring? Do the springs translocate through bone in the same fashion that titanium plates do? What is the tolerance of thin bone to the placement of springs? What judgements are considered in spring placement? How do the biomechanical findings in this study impact the patient in a practical manner? What learning points have they noted in the evolution of this procedure?

“Horses for courses” is an allusion to the concept of applying the best response for a situation or the best means to achieve a specific end, and that there are no hard and fast rules when choosing a technique to correct scaphocephaly. The authors have considerable experience in the application of this technique, and one has to assume that in the 8 years they have performed spring-assisted cranioplasty, they have been able to produce satisfactory results in a safe and predictable manner and comparable to those obtained with other minimally invasive operations.

In summary, the authors are to be congratulated for providing information about their experience in using springs to correct cranial dysmorphism associated with sagittal synostosis and acknowledging the limitations and concerns surrounding this technique. Despite the fact that spring-assisted cranioplasty is entering its 3rd decade of existence, there remains much to understand about this powerful yet simple technique.

It brings to mind a much bigger question when managing this complex group of patients. How much surgery is enough? Where is the balance between level of invasiveness and outcome? Hope continues to spring eternal that this balance will be achieved. For the next generation of craniofacial surgeons, this will be an important topic for study. The *cri de coeur* of the International Society of Craniofacial Surgeons as voiced by Paul Tessier—“*Pourquoi pas?*”—perhaps needs to be revisited and translated into a more conservative and reflective “*Devrions nous?*”

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Disclosures

The author reports no conflict of interest.

Response

Alessandro Borghi, PhD,^{1,2} Silvia Schievano, PhD,^{1,2} David Dunaway, FRCS(Plast),^{1,2} and N. u. Owase Jeelani, FRCS(NeuroSurg)^{1,2}

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We thank Dr. Forrest for his comprehensive and thoughtful review of our paper. As correctly pointed out, this work primarily focuses on spring biomechanics: another publication from our group, reporting clinical data and clinical outcomes, forms the body of a separate paper currently in press.

Dr. Forrest has correctly reported that springs have been used at our institution since January 2008: to date, about 300 cases utilizing more than 750 springs have been performed. A number of clinical studies in the literature (also from our unit) support a particular technique with limited case experience and follow-up periods. We have, with some difficulty, resisted this temptation and withheld publishing our experience until we felt comfortable with

the evidence we are presenting. We can confirm that the morbidity profile of this patient cohort compares rather favorably with our own historic cohorts and with the currently “accepted” profile for a large craniofacial practice within the literature. The figures are large enough and speak for themselves.

Outcome analysis remains difficult across the spectrum of craniofacial interventions and the correction of scaphocephaly is no exception. While it is clear that this procedure enables the majority of our patients to pass the “supermarket test” (in our departmental audits, over 90% of parents score the aesthetic results of these procedures as an 8 or more out of 10, with 10 being maximum satisfaction), we can confidently state that this technique does not work well enough in all patients. It is excellent at treating the occipital bulge and posterior vertex height and good at addressing biparietal widening, but is limited at treating the frontal bossing and pterional pinching. So, for a child who presents at an early age (3 months) with significant frontal bossing, we would not expect an optimal result. Following discussion with the parents, we may still advocate proceeding, with the expectation that frontoorbital remodeling may be required at a later stage instead of a total calvarial remodeling. This matter is analyzed further in the clinical outcomes paper. For our unit, the biggest advantage is the minimal nature of the intervention with its single-digit transfusion rate and overnight stay in a regular hospital bed.

The thrust of our paper remains the spring kinematics in this patient cohort, and while studies in the literature report spring outcomes in animal models and in clinical cohorts, the non-standardized nature of the springs and wire forms used across various centers makes the biomechanics studies difficult. By employing a standardized design in a stereotypical fashion over 9 years, we have been able to analyze the viscoelastic properties of the pediatric calvarium and the changes obtained by applying force vectors on it. As our understanding of the biomechanics increases, it will be possible to formulate guidelines to aid the surgeon new to the technique and help with informed consent. Computer modeling techniques such as finite-element modeling and statistical shape modeling are likely to increase the predictability of spring cranioplasty and allow for surgical planning.

We share with Dr. Forrest the opinion that the best operation for these children is no operation if the results can be achieved by other noninvasive means or, until such a technique becomes available, by one that has the most favorable intervention/outcome ratio. Within our practice, the spring-assisted procedure outperforms other techniques according to this criterion.