Long-term growth and alignment after occipitocervical and atlantoaxial fusion with rigid internal fixation in young children

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OBJECTIVE The long-term consequences of atlantoaxial (AA) and occipitocervical (OC) fusion and instrumentation in young children are unknown. Anecdotal reports have raised concerns regarding altered growth and alignment of the cervical spine after surgical intervention. The purpose of this study was to determine the long-term effects of these surgeries on the growth and alignment of the maturing spine.

METHODS A multiinstitutional retrospective chart review was conducted for patients less than or equal to 6 years of age who underwent OC or AA fusion with rigid instrumentation at 9 participating centers. All patients had at least 3 years of clinical and radiographic follow-up data and radiographically confirmed fusion. Preoperative, immediate postoperative, and most recent follow-up radiographs and/or CT scans were evaluated to assess changes in spinal growth and alignment.

RESULTS Forty children (9 who underwent AA fusion and 31 who underwent OC fusion) were included in the study (mean follow-up duration 56 months). The mean vertical growth over the fused levels in the AA fusion patients represented 30% of the growth of the cervical spine (range 10%–50%). Three different vertical growth patterns of the fusion construct developed among the 31 OC fusion patients during the follow-up period: 1) 16 patients had substantial growth (13%–46% of the total growth of the cervical spine); 2) 9 patients had no meaningful growth; and 3) 6 patients, most of whom presented with a distracted atlantooccipital dislocation, had a decrease in the height of the fused levels (range 7–23 mm). Regarding spinal alignment, 85% (34/40) of the patients had good alignment at follow-up, with straight or mildly lordotic cervical curvatures. In 1 AA fusion patient (11%) and 5 OC fusion patients (16%), we observed new hyperlordosis (range 43°–62°). There were no cases of new kyphosis or swan-neck deformity, evidence of subaxial instability, or unintended subaxial fusion. No preoperative predictors of these growth patterns or alignment were evident.

CONCLUSIONS These results demonstrate that most young children undergoing AA and OC fusion with rigid internal fixation continue to have good cervical alignment and continued growth within the fused levels during a prolonged follow-up period. However, some variability in vertical growth and alignment exists, highlighting the need to continue close long-term follow-up.

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KEY WORDS occipitocervical; craniocervical; atlantoaxial; fixation; fusion; spine
Both occipitocervical (OC) and atlantoaxial (AA) instability are common problems encountered by pediatric spine surgeons. There are a wide variety of possible etiologies for pediatric OC and AA instability, including trauma, Down syndrome, os odontoideum, infection, mucopolysaccharidosis, atlantoaxial rotatory subluxation, juvenile rheumatoid arthritis, tumors, spondyloepiphyseal dysplasia, iatrogenic causes, and others. It has been shown that trauma is the most common cause of OC and AA instability, with younger children being more likely to sustain upper cervical injuries than older children.

Because untreated or unrecognized instability may result in neurological injury, surgical fusion of the cranio cervical junction is sometimes necessary. Many methods of OC and AA fusion have been described in the treatment of children over the years, but semirigid wire-and-loop fixation constructs are the most popular.

Over the past few decades, a variety of rigid screw fixation constructs have been described for application in children. They are associated with higher fusion rates, lower complication rates, and improved biomechanics and fewer issues pertaining to adjacent-level fusion than their semirigid counterparts. Furthermore, these rigid constructs permit stabilization without external halo orthoses and their attendant risks.

There is also evidence that they allow earlier recovery and rehabilitation.

However, due to the lack of long-term follow-up data, concern still exists regarding the effects of rigid OC and AA fusion and instrumentation in the pediatric spine. Previous reports, with small numbers of patients, have documented disturbances of vertebral growth, adjacent-level instability, unintended fusion, abnormal cervical curvatures, and hyperlordosis, or “crankshifting.” Also, since it is generally accepted that children reach biomechanical spinal maturity around 9 years of age, it is unknown whether techniques for placing OC and AA rigid instrumentation put young children (≤ 6 years old) at even higher risk for age-related postfusion growth disturbance.

In an attempt to address these concerns, we performed a multicenter study through the Pediatric Cranio cervical Society, investigating children 6 years of age or younger who underwent AA or OC fusion with rigid instrumentation and had at least 3 years of follow-up before reaching biomechanical maturity. We examined vertical growth of the construct in relation to the growth of the entire cervical spine, overall spinal alignment, adjacent-segment instability, and unintended fusion during the follow-up period.

Methods

After acquiring institutional review board approval from each institution, pediatric neurosurgeons from 9 centers compiled and submitted de-identified data of young children who underwent rigid fusion and placement of instrumentation from the occiput to C-2 (OC fusion) or from C-1 to C-2 (AA fusion) between 1995 and 2010. Entry criteria included: 1) age less than or equal to 6 years of age at time of surgery, 2) clinical and radiographic follow-up for at least 36 months postoperatively, 3) radiographically documented fusion, and 4) available imaging studies (CT scans, radiographs, or both) preoperatively, postoperatively (within 1 month of surgery), and at long-term follow-up. Patients were excluded if preoperative images demonstrated autofusion of any cervical levels or if instrumentation extended caudal to C-2. The most recent follow-up radiograph was used in all cases. Specific data on the use of bone morphogenetic protein and halo orthoses were not collected as part of this study, but neither was routinely used (personal communication).

Clinical charts and electronic medical records were examined to collect data regarding age, sex, etiology, presenting symptoms, and symptom improvement during follow-up. Imaging studies were assessed for markers of instability, such as osteophytes, new spondylolisthesis, or excessive movement on flexion-extension radiographs if available, and subaxial fusion. Measurements were performed to assess vertical (rostral-caudal) and axial (anterior-posterior) growth, cervical alignment, and curvature. Similar to prior studies, alignment was assessed and categorized using the technique described by Toyama et al. (Fig. 1), and curvature was measured using the technique described by Nakagawa et al. (Fig. 2A). Hyperlordosis was defined for this study as curvature greater than 40°. The axial growth measurement was the difference in the minimum anterior-posterior distance of the spinal canal within the fusion construct between a preoperative or postoperative CT scan and the follow-up CT scan.

Similar to previous studies, vertical growth within the fusion mass was calculated as a proportion of the entire cervical spine growth to serve as an internal control (Fig. 2B and C). In patients undergoing OC fusion, the vertical heights of the fusion mass and cervical spine were measured from the basion to the midpoint of the inferior endplate of C-2 or C-7, respectively (Fig. 2B). For patients undergoing AA fusion, the vertical heights of the fusion mass and cervical spine were measured from the most rostral aspect of the anterior arch of C-1 to the midpoint of the inferior endplate of C-2 or C-7, respectively (Fig. 2C). Differences in these measurements were calculated between follow-up and postoperative images. The percentage of cervical spine growth that occurred within the fused construct was then calculated as the ratio of the vertical growth of the fusion mass to the vertical growth of the cervical spine multiplied by 100: (Follow-Up Fusion Mass – Postop Fusion Mass)/(Follow-Up Cervical Spine – Postop Cervical Spine) × 100.

Vertical growth within the construct was defined as substantial if it was equal to or greater than 10% of the entire cervical spine growth, unchanged if it was less than 10%, or reduced if there was a loss of height within the construct during the follow-up period.

Statistical Analysis

Student t-test, Fisher exact test, and ANOVA were each used as appropriate to assess for associations between the pre- and intraoperative variables of age, etiology, sex, presenting symptoms, or construct type with the outcome variables of growth pattern, cervical angle, and hyperlordosis. A p value of < 0.05 was considered significant.
Results

Forty patients from 9 institutions were included in the study. The mean age of all patients at the time of surgery was 42 months (range 14–83 months), and 21 patients (53%) were boys. Instability was classified as congenital (n = 24), traumatic (n = 15), or secondary to tumor (n = 1). The mean clinical and radiological follow-up duration was 56 months (range 36–101 months). Nineteen patients presented with myelopathy with or without weakness, 11 patients presented with pain, and 3 patients presented with torticollis. Ten patients did not have signs or symptoms referable to the instability. Of the 30 symptomatic patients, 90% (27/30) experienced clinical improvement, while 3 myelopathic patients (10%) remained the same clinically during the follow-up period. No patient experienced worsening of presenting symptoms (Table 1).

There were no radiological indicators of subaxial instability on follow-up imaging. These indicators include osteophytes, new or worsened spondylolisthesis, abnormal movement on flexion-extension radiographs, or new unintended subaxial fusion. Because of the preference for plain radiographs over CT scans to minimize radiation exposure while assessing spinal alignment only 3 patients underwent both follow-up CT scanning and either preoperative or postoperative CT scanning, from which axial growth could be calculated. In all 3 of these patients, the minimum anteroposterior diameter of the spinal canal within the fused levels changed by 1 mm or less during the follow-up period. As a control, anteroposterior diameters were also measured at C-4 in these patients, and canal diameter changes were all less than 1 mm at this level as well.

Atlantoaxial Fusion

Nine patients underwent fusion for AA instability. Their mean age was 35 months. There were 2 boys and 7 girls. Four patients presented with a congenital etiology, 4 with a traumatic etiology, and 1 with instability secondary to tumor. The mean radiological follow-up period was 54 months. The following screws were used: C-1 lateral mass screws and C-2 pars screws in 5 patients, C1–2 transarticular screws in 3 patients, and C-1 lateral mass screws with C-2 laminar screws in 1 patient.

The mean percentage of cervical growth within the fusion mass was 30% (range 10%–50%) (Table 1). Among the follow-up studies, upright radiographs were available in 7 of 9 patients. All alignments were lordotic or straight, with a mean cervical curvature of 21° (range 7°–43°), which was essentially unchanged. One patient had a lordotic angle of 43°, consistent with hyperlordosis. Radiographs obtained in a representative patient are shown in Fig. 3.

Occipitocervical Fusion

Thirty-one patients underwent OC fusion. Their mean age was 42 months old. There were 19 boys. Etiologies were congenital in 20 and traumatic in 11 patients. The mean radiological follow-up duration was 57 months. Oc-
Occipitocervical Fusion: Vertical Growth

During the follow-up period, 3 different vertical growth patterns of the fusion construct were seen among patients who underwent OC fusion. In 52% (16/31) of these patients, substantial vertical growth was demonstrated within the fusion construct. This consisted of 13%–46% (mean 28%) of the vertical growth of the entire cervical spine (Fig. 4). In 29% (9/31) of patients, essentially no growth was exhibited within the fusion construct during the follow-up period (Fig. 5). In 16% (6/31) of patients, a reduction was seen in the height of the fusion construct, ranging from 7 to 23 mm (mean 12 mm). Five of these patients initially presented with atlantooccipital dislocation and one patient with Down syndrome and basilar invagination. None of the variables examined (age, etiology, sex, presenting symptoms, or construct type) were statistically associated with any of the 3 growth patterns.

Occipitocervical Fusion: Alignment

No patients developed new kyphosis or swan-neck abnormalities. In 26 (84%) of 31 patients, a straight or lordotic cervical curvature was present, with an angle of less than 32° of lordosis. Nineteen (73%) of these 26 patients underwent upright radiography at follow-up, and the mean angle of cervical curvature was 15°. The mean change in cervical curvature for these patients, from postoperative to follow-up, was 3.6° more lordotic. Radiographs obtained in a representative patient are shown in Fig. 4.

Five (16%) of 31 patients were considered to have hyperlordosis (cervical curvature > 40°) at follow-up, with angles ranging from 43°–62°. Radiographs obtained in a representative patient are shown in Fig. 6. Three of five of these follow-up studies were upright radiographs appropriate for measurements of alignment. The other 2 patients had only supine studies, but the patients were clinically hyperlordotic, so these measurements were included as well. There was no pattern among these 5 patients as they were heterogeneous with respect to all studied clinical variables including age, sex, etiology of instability, presenting symptoms, and type of construct.

Discussion

In this article, we demonstrate that nearly 5 years after young children have undergone OC or AA rigid instrumentation and fusion, the majority of patients continue to have good spinal alignment and continued vertical growth across the fusion construct. There were no cases of postoperative kyphosis, instability, or adjacent-segment disease. After AA fusion, all but one patient maintained nor-
mal physiological alignment. However, after OC fusion greater variability exists. Most patients exhibit consistent growth and good OC alignment, but a small proportion of patients had hyperlordosis, lack of vertical growth within the fused levels, or a reduction in the height of the fusion mass. These differences among patients were not associated with any of the clinical variables investigated in this study.

It has been previously shown that fusion is sometimes necessary in young patients in whom there is evidence of craniofacial instability. In the past 2 decades, rigid cervical screw fixation techniques have been regularly used in children on a consistent basis. These techniques demonstrate higher fusion rates, lower complication rates, superior biomechanics, and less adjacent-level fusion than bone and wire constructs. Rigid OC and AA fixation can also eliminate the need for external halo orthoses placement and has been shown to allow earlier recovery and rehabilitation than wire-based constructs. However, crankshafting, adjacent-level disease, and other growth disturbances have been raised as legitimate concerns after fusion in the very young. Although several prior studies have examined wiring constructs or rigid instrumentation in older children, very little is known about growth and alignment after rigid AA or OC fixation in children under 7 years old.

### Table 1. Patient presentation, surgery, and clinical outcome

<table>
<thead>
<tr>
<th>Patient Characteristics</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of patients</td>
<td>40</td>
</tr>
<tr>
<td>Boys</td>
<td>21 (53)</td>
</tr>
<tr>
<td>Girls</td>
<td>19 (47)</td>
</tr>
<tr>
<td><strong>Etiology</strong></td>
<td></td>
</tr>
<tr>
<td>Congenital</td>
<td>24 (60)</td>
</tr>
<tr>
<td>Traumatic</td>
<td>15 (38)</td>
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<tr>
<td>Pathological</td>
<td>1 (2.5)</td>
</tr>
<tr>
<td><strong>Presentation</strong></td>
<td></td>
</tr>
<tr>
<td>Myelopathy (w/ or w/o weakness)</td>
<td>19 (48)</td>
</tr>
<tr>
<td>Pain</td>
<td>11 (28)</td>
</tr>
<tr>
<td>Torticollis</td>
<td>3 (7.5)</td>
</tr>
<tr>
<td>No signs/symptoms</td>
<td>10 (25)</td>
</tr>
<tr>
<td><strong>Surgery</strong></td>
<td></td>
</tr>
<tr>
<td>AA fusion</td>
<td>9 (23)</td>
</tr>
<tr>
<td>OC fusion</td>
<td>31 (78)</td>
</tr>
<tr>
<td><strong>Clinical outcome</strong></td>
<td></td>
</tr>
<tr>
<td>Improved myelopathy</td>
<td>16/19 (84)</td>
</tr>
<tr>
<td>Stable myelopathy</td>
<td>3/19 (16)</td>
</tr>
<tr>
<td>Worsened myelopathy</td>
<td>0/19 (0)</td>
</tr>
<tr>
<td>Improved pain</td>
<td>11/11 (100)</td>
</tr>
<tr>
<td>Improved torticollis</td>
<td>3/3 (100)</td>
</tr>
<tr>
<td>Remained asymptomatic</td>
<td>10/10 (100)</td>
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*Three patients presented with both pain and myelopathy; their symptoms are counted in each symptom group.

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**Fig. 3.** Typical AA fusion patient. Lateral radiographs of an AA fusion patient in whom bilateral transarticular screws were placed when he was 46 months old. Postoperative (A) and 86-month follow-up (B) radiographs demonstrate good alignment; 10% of the patient's cervical spine growth occurred within the fusion mass.

**Fig. 4.** OC fusion patient with substantial growth. Lateral x-rays of an OC fusion patient who had screws placed in C2 pars, C1 lateral mass, and occiput at 35 months of age. A: Postoperative radiograph is in forced flexion as part of a flexion-extension study. B: Radiograph at 44 months of follow-up demonstrates that 31% of the vertical growth of the cervical spine occurred within the fused levels.

**Fig. 5.** OC fusion patient with minimal growth. Lateral radiographs of an OC fusion patient in whom a C-2 pars screw and a C-2 laminar screw, in addition to occipital screws, were placed when the patient was 14 months of age. Postoperative (A) and 40-month follow-up (B) radiographs demonstrating stable physiological lordosis of 25°. Vertical growth within the fused levels made up only 7% of the total cervical spine growth in this patient.
Growth and alignment after OC fusion in young children

Growth

In most patients (25/40, 63%), satisfactory vertical growth was demonstrated within the fused levels. However, some variability was seen between treatment groups. Patients undergoing AA fusion had the most consistent vertical growth, as all patients had some growth within the fusion construct (mean 30% of the entire cervical spine; range 10%–50%). This may be due to the consistent growth of the vertebral bodies above and below the instrumentation at C-1 and C-2, respectively (Fig. 3).

Similarly, roughly half (52%; 16/31) of the patients undergoing OC fusion had normal vertical growth within the construct (mean 22% of the entire cervical spine; range 13%–46%). We suspect that this is due to continued genetically driven spinal growth within and around the instrumented segments. These results are consistent with a prior study, with shorter follow-up, demonstrating mean vertical growth of 34% (range 17%–50%) within the fused segments. Bone remodeling and normal growth patterns around rigid fixation have also been described in young children and animal models in the orbit, skull, and long bones.11,15,26

However, 9 patients (29%) exhibited essentially no growth within the OC fusion, and 6 patients (19%) demonstrated a decrease in the distance from the basion to the midpoint of the inferior endplate of C-2 during follow-up. Interestingly, 5 of the 6 patients with height loss presented with severe OC distraction from traumatic atlantooccipital dislocation. The most likely reason for postoperative loss of OC height in this group is the artificially high OC starting distance. That is, despite OC reduction compared with the preoperative images, the postoperative images still demonstrated an excessive OC distance. During the follow-up period, bony growth and remodeling within the construct resulted in a less distracted, more physiologically normal-appearing alignment (Fig. 7). One patient developed basilar invagination over the follow-up period, leading to a loss of vertical height within the construct.

Spinal canal narrowing after cervical fusion in children has been raised as a concern but has been reported infrequently.44 Although axial diameter of the spinal canal could only be accurately assessed in 3 patients in this study, we did not observe any significant change in the axial diameter of the spinal canal during the follow-up period.

Alignment

In 1989, Dubousset et al.10 and Shufflebarger and Clark41 first described the crankshaft phenomenon of increasing lordosis and rotation in young children with scoliosis treated by posterior thoracolumbar instrumentation and fusion prior to skeletal maturity. A similar phenomenon involving only hyperlordosis has also been reported in children undergoing posterior OC fusion.4,34,39,47 Contrary to these reports, 85% of patients in the current study maintained straight or mildly lordotic cervical alignment (< 32°) after nearly 5 years of follow-up, with a mean increase in lordosis of 3.6°. The small amount of increasing lordosis may be due in part to avoiding fusion across vertebral body growth plates, or may be due to only one or two motion segments being fused. However, 1 patient undergoing AA fusion and 5 patients undergoing OC fusion developed lordosis of greater than 40°, which we define as hyperlordosis. We used 40° as a cutoff because we are not aware of any widely accepted definition of cervical hyperlordosis in young children and there were no patients in our series who had follow-up lordosis between 32° and 43°. For reference, a recent study suggested that a similar measurement of cervical alignment, between extensions of the inferior endplates of C-2 and C-7, in the very young is 6.5° of lordosis, and this decreases in adolescence.1

The hyperlordosis phenomenon takes time to develop and prior studies have reported that a longer duration between surgery and skeletal maturity results in greater increases in lordosis.39,47 Mean increases in cervical cur-

FIG. 6. Hyperlordosis. Lateral radiographs of an OC fusion patient in whom C-2 pars screws, C-1 lateral mass screws, and occipital screws were placed at 50 months of age. Postoperative radiograph (A), though supine, shows markedly less hyperlordosis than the 83-month follow-up radiograph (B), demonstrating 62° of lordosis.

FIG. 7. Atlantooccipital dislocation. Lateral radiographs of an OC fusion patient who had C1–2 transarticular screws and occipital screws placed for a severe atlantooccipital dislocation at 54 months of age. A: Postoperative radiograph still shows some degree of dislocation. B: Radiograph obtained 38 months after surgery demonstrates further reduction of the dislocation with concomitant occipit–C2 fusion.
tature over the follow-up period after these procedures have been reported between 8° and 25°, with the largest change occurring in the study with the longest follow-up. In the only prior report that investigated spinal curvature after rigid fixation of the OC junction in young children, the mean increase in lordosis over the follow-up period was 12°. In the current study, the 5 patients treated with OC fusion who developed hyperlordosis had an average increase of 33° in cervical lordosis that developed the follow-up period. This increase is greater than those reported in previous studies, and it may reflect our longer follow-up duration (mean 56 months) compared with that of the prior reports (mean 28 months). Importantly, in this study the length of follow-up for patients in the hyperlordotic and normal alignment groups were similar (60 and 58 months), suggesting that not all patients have hyperlordotic growth at different rates but, rather, that some patients experience the phenomenon and some do not. Unfortunately, due to the small sample size, we were unable to detect any associations between clinical variables and the development of hyperlordosis including sex, age, cause of instability, presenting symptoms, or type of rigid construct used.

The authors of the original description of crankshafting in thoracolumbar scoliosis patients later described its prevention by using anterior approaches, but the morbidity associated with anterior approaches to the occipitocervical junction has prevented their application for this indication. It has been suggested that to avoid pathological cervical hyperlordosis, young children should undergo fixation in a mild degree of flexion. However, in our study, 3 of 5 OC fusion–treated patients in whom hyperlordosis developed had less than 15° of lordosis on initial postoperative imaging, suggesting that this strategy may not prevent hyperlordosis in the long term.

Unintended Fusion and Instability

Adjacent-segment instability and unintended fusion have been reported after OC fusion in children in studies with over 7 years of follow-up. Development of instability or unintended fusion at adjacent levels was not seen in our study patients. While this may be because our follow-up period was slightly shorter (mean 56 months), it might also reflect the fact that fusion constructs tended to be longer in the earlier studies, increasing the moment arms and stress at adjacent segments. Furthermore, the use of rigid internal fixation and structural bone grafts in this study, rather than wire constructs with on-lay bone grafts in prior studies, may have eliminated unintended adjacent-level fusion.

We are well aware of limitations of our study. Its retrospective design, small patient numbers, and heterogeneity of surgical techniques are all objects of potential criticisms. The length of follow-up is short, especially with regard to assessing unintended adjacent-segment fusion. Another limitation is the inherent well-known difficulty of precisely measuring anatomical features on plain radiographs. Difficulties with measuring elements of the craniovertebral junction and interpreting these measurements include poor resolution of plain radiographs, tilt or rotation of the patient, parallax, complex bony skull base

anatomy and complex craniovertebral junction abnormalities in these patients, and poor ossification of bony elements in this age group. However, a similar study with potentially more accurate CT or MR images is unlikely to be conducted because of the increased radiation exposure associated with CT scanning and the sedation required for MRI. Furthermore, researchers cannot assess spinal alignment using supine imaging studies. Another limitation is the lack of knowledge regarding normal cervical spine growth, alignment, and curvature in young children. Furthermore, we defined “substantial” vertical growth as greater than 10% and “hyperlordosis” as greater than 40° without known clinical correlates.

Conclusions

This report represents the first multicenter effort to provide long-term outcome data after OC or AA fusions with rigid instrumentation in young children who have not reached biomechanical spinal maturity. We have demonstrated that most of these children continue to have good alignment and continued growth at the fused levels throughout prolonged follow-up period without developing kyphosis, instability, or adjacent-segment disease. However, some variation in vertical growth and alignment exists, highlighting the need to continue close long-term follow-up.

References


**Disclosure**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Supplemental Information**

**Previous Presentation**

Portions of the current work were presented at the 37th Annual Meeting of the American Society of Pediatric Neurosurgeons, Costa Rica, January 26–31, 2014.

**Author Contributions**

Conception and design: Kennedy, Brockmeyer, Anderson. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Kennedy, Brockmeyer, Anderson. Critically revising the article: Kennedy, McDowell, Couture, Jea, Leonard, Lew, Pincus, Rodriguez, Tuite, DiLuna, Brockmeyer, Anderson. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Kennedy. Statistical analysis: Kennedy. Administrative/technical/material support: Anderson. Study supervision: Brockmeyer, Anderson.

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