



3D printed models can guide safe halo pin placement in patients with diastrophic dysplasia

Verinder S. Sidhu¹ · Tegan L. Cheng^{2,3} · Jonathon Lillia² · Corinne Bridge¹ · David G. Little^{1,2,3} · Randolph J. Gray¹

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Abstract

Purpose To trial the use of three-dimensional (3D) printed skull models to guide safe pin placement in two patients with diastrophic dysplasia (DTD) requiring prolonged pre-fusion halo-gravity traction (HGT).

Methods Two sisters aged 8 (ML) and 4 (BL) with DTD were planned for staged fusion for progressive kyphoscoliosis. Both sisters were admitted for pre-fusion HGT. Models of their skulls were generated from computer tomography (CT) scans using Mimics Innovation Suite and printed on a Guider II in polylactic acid. The 3D models were cut axially proximal to the skull equator, in-line where pins are usually inserted, allowing identification of the thickest skull portion to guide pin placement.

Results Eight pins were inserted into each patient's skull. Postoperative CT scans demonstrated adequate pin position. Pre-traction Cobb angles were 122° and 128° for ML and BL, improving to 83° and 86° following traction. Duration of HGT was 182 and 238 days for ML and BL. Prior to fusion, both patients returned to theatre twice for exchange of loose pins and there was one incidence of pin site infection. Surgery was performed via a posterior instrumented fusion. Postoperatively, both patients remained in their halos for 3 months. One pin in BL was removed for loosening. Both patients achieved fusion union by 9 months.

Conclusion 3D models of the skull can be a useful tool to guide safe pin placement in patients with skeletal dysplasias, who require prolonged pre-fusion HGT for severe deformity correction.

Keywords 3D models · Scoliosis · Halo-gravity traction · Skeletal dysplasia

Introduction

Halo gravity traction (HGT) is a well-established technique for deformity correction prior to definitive spinal fusion surgery in the treatment of severe paediatric and adolescent scoliosis. Traction prior to surgery allows for gradual deformity correction, decreasing the risk of neurological injury that can occur with acute correction of severe deformities [1–6].

HGT has most commonly been used for patients in the correction of neuromuscular, congenital and severe idiopathic scoliosis (AIS), particularly for thoraco-lumbar

curves [3]. Despite the advent of computer tomography (CT) scanning, concerns still exist regarding the safety of HGT in younger paediatric patients (less than 8 years old) and patients with skeletal dysplasias, due to their smaller and thinner skulls, increasing the risk of complications such as pin loosening, inner cortex penetration and catastrophic failure [7].

The purpose of this paper is to describe the use of three-dimensional (3D) printed models as an adjunct to guide safe halo pin placement in two patients with diastrophic dysplasia (DTD), who required prolonged HGT prior to definitive posterior fusion.

Materials and methods

Two sisters, aged eight and four (ML and BL respectively), with diagnosed DTD were referred to the outpatient orthopaedic spinal clinic soon after birth for assessment and management. Both patients were followed with serial

✉ Verinder S. Sidhu
Verinder.s.sidhu@gmail.com

¹ Department of Orthopaedic Surgery, The Children's Hospital at Westmead, Sydney, NSW, Australia

² EPIC Lab, Kids Research, The Children's Hospital at Westmead, Sydney, NSW, Australia

³ Discipline of Child and Adolescent Health, Sydney Medical School, The University of Sydney, Sydney, NSW, Australia

radiographs. Due to the cephalad location of the kyphoscoliosis (cervico-thoracic), bracing was attempted but was found to be ineffective and eventually abandoned.

Serial imaging demonstrated progressive worsening of each patient's kyphoscoliosis. By the age of eight, the erect X-rays of ML demonstrated a complex cervico-thoracic kyphoscoliosis with a Cobb angle of 122° in the sagittal plane (between T5 and T9 levels) and magnetic resonance imaging (MRI) displaying spinal cord stenosis and cord signal change at the level of maximal kyphosis (T5–T6). By the age of four, the erect X-rays of BL demonstrated a cervico-thoracic kyphoscoliosis with a Cobb angle of 128° in the sagittal plane (between T5 and T7 levels) and an MRI displaying spinal cord stenosis and cord signal change at the level of maximal kyphosis (T5–T7). There were no features of congenital scoliosis found on either patient's MRI. Figures 1 and 2 show preoperative imaging for both patients.

After discussion with multidiscipline colleagues (surgical, paediatric and allied health) and with both parents, the decision was made to proceed with staged posterior spinal fusion given the severity of each patient's kyphoscoliosis. Both patients were to be admitted to hospital and receive inpatient HGT to allow progressive curve correction (with halos to be placed under general anaesthesia), prior to definitive posterior spinal fusion.

Given their underlying diagnosis of DTD and to guide safe pin placement in the best quality bone during halo application, a 3D model of each patient's skull was made using preoperative CT scans. This was conducted at the Engineering Prototypes and Implants for Children (EPIC) laboratory at the Children's Hospital Westmead. Preoperative CT scans were segmented using Mimics Innovation Suite (Materialise, Leuven, Belgium) and printed at scale in polylactic acid (PLA) using a Guider II printer (FlashForge 3D, Zhejiang, China).

The resultant printed models were taken into the operating theatre at the time of halo insertion. After general anaesthesia, the halo ring was placed over each 3D model and the patient's skull. Correlation between the patients' bony landmarks and the models was then used to axially cut each model in the designated plane of pin insertion (Fig. 3). This allowed the models to be used as a reference to identify the thickest portion of each patient's skull and to guide pin placement for halo assembly. After pins were placed into each patient's skull and the halo assembled, the position of pins was checked with CT scans day 1 postoperatively prior to application of traction, as a safety measure to ensure that pins had not penetrated the inner table due to the dysplastic and thin width of each patient's skull. Further, this allowed confirmation of adequate pin placement, which was important due to the expected prolonged duration of HGT. We



Fig. 1 Preoperative imaging (X-rays—**a, b** and magnetic resonance imaging—**c**) for ML upon admission and prior to HGT demonstrating Cobb angle of 122°

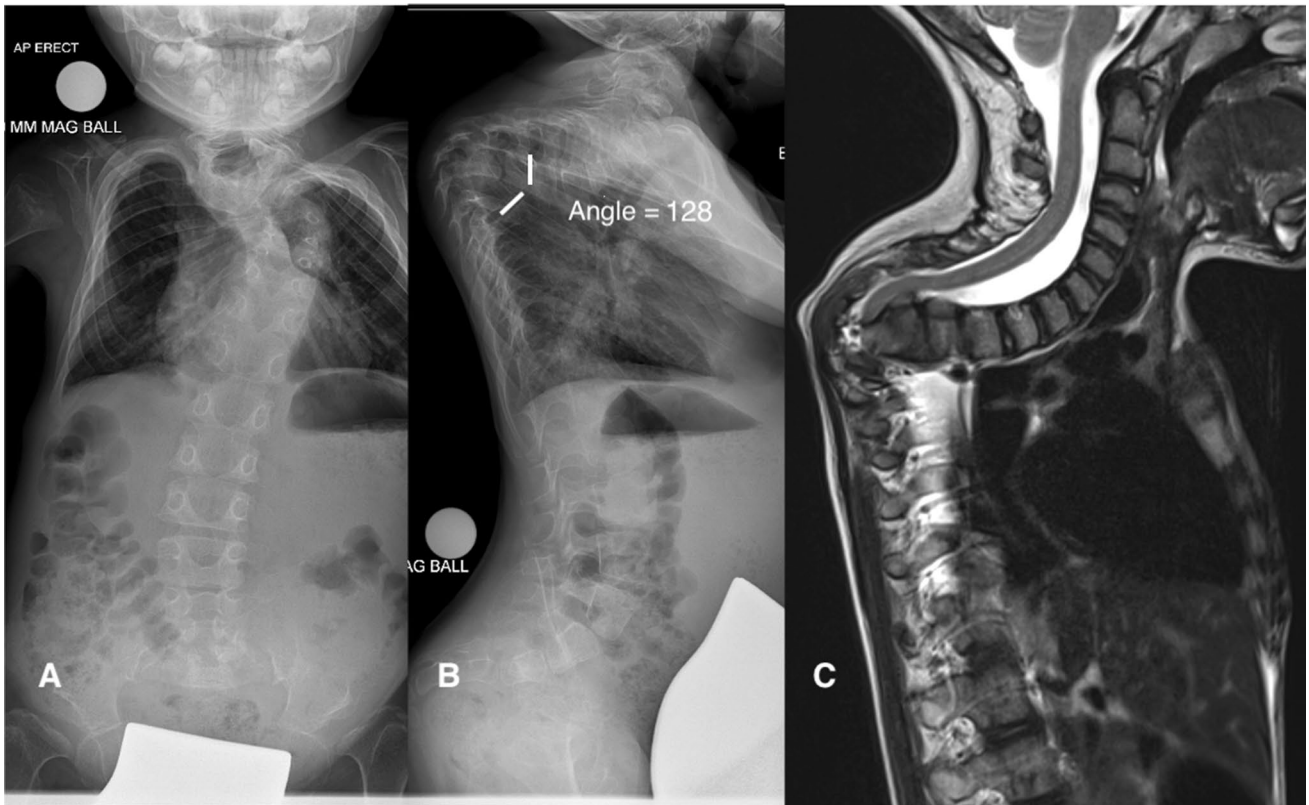


Fig. 2 Preoperative imaging (X-rays—**a, b** and magnetic resonance imaging—**c**) for BL upon admission and prior to HGT demonstrating Cobb angle of 128°

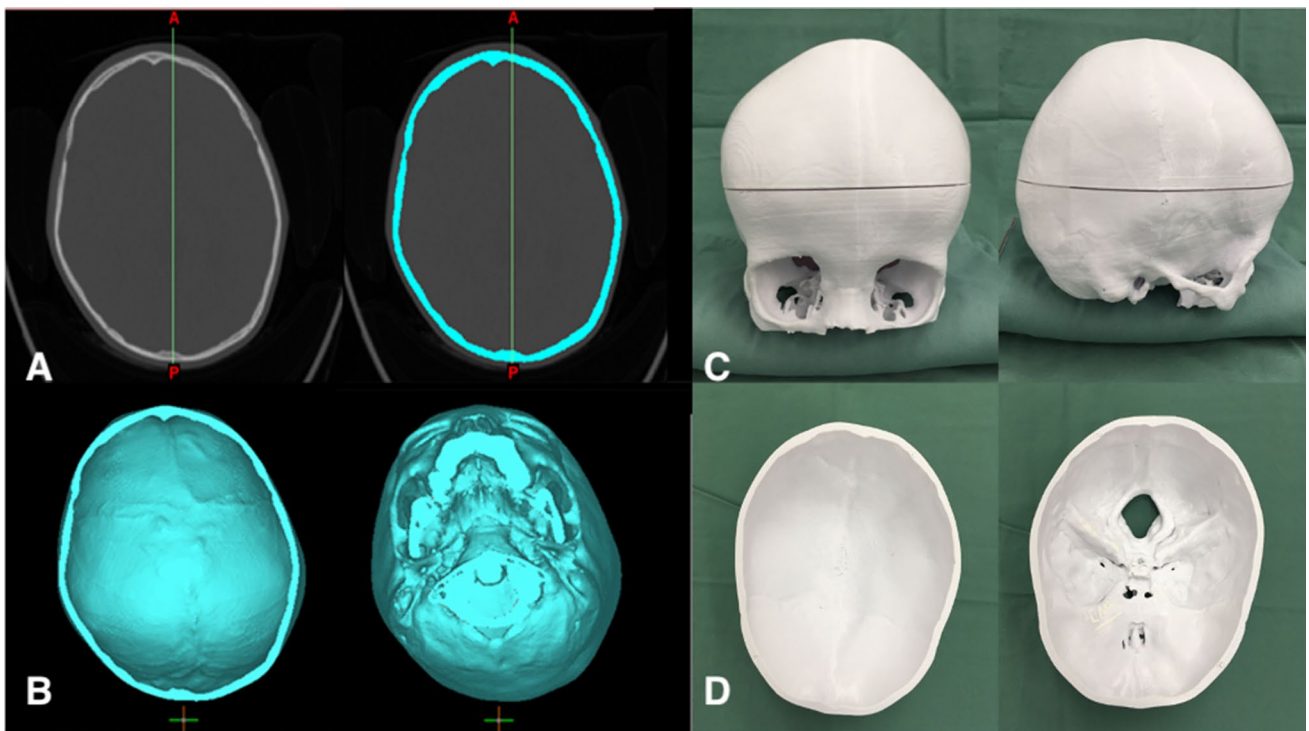


Fig. 3 Segmented images using the mimics innovation suite (**a, b**) and resultant 3D models created from each patient’s CT scan (**c, d**)

chose to use eight pins initially in line with current best practice guidelines for younger patients and patients with skeletal dysplasia [6].

Both patients then remained as inpatients (attending the in-hospital school), with sequential increase in traction weight proportional to body weight, aiming to achieve gradual deformity correction of 50% of the starting kyphosis. This was assessed with monthly erect radiographs and this determined the period of HGT, prior to definitive posterior spinal fusion. Each patient was monitored and examined daily for evidence of pin site infection, loosening or cranial nerve dysfunction.

Results

Both patients underwent halo placement under general anaesthesia as planned in mid-April 2018. The 3D models for each patient were referenced in the operating room to identify the thickest portion of the skull to help determine pin placement. Bony landmarks from each patient and their respective models were used to allow correlation for pin placement. Eight pins were used initially for both ML and BL, using 1.8 kg (kg) of torque for each pin. Postoperative CT scans demonstrated adequate pin position without inner cortex penetration (Fig. 4). The initial traction weight used for ML was 1 kg (admission weight 13.3 kg, with a height of 78.2 cm) and for BL, 500 g (admission weight 10.3 kg, with a height of 66.1 cm). An additional three pins were

inserted for each patient on two occasions (once in late April and once in early August) using the 3D printed models and the postoperative CT brain scans to increase the strength of the construct, allowing allow additional traction weight to be added. Traction weight was increased to 6.3 kg for BL and 4.5 kg for ML after the additional pins were inserted in early August. Traction was maintained for at least 20 h per day. Walking frames capable of allowing traction whilst both patients were upright were used throughout the day and traction beds were used at night.

Serial imaging demonstrated deformity improvement for both patients over the course of the year. ML remained in HGT for a duration of 182 days and BL, for 238 days prior to definitive fusion. The degree of correction determined the duration of traction, aiming for a 50% correction of the starting kyphosis. The improvement of Cobb angles in ML was to 83° (from 122°) and in BL, to 86° (from 128°) (Figs. 5, 6). ML's height prior to fusion was 88 cm and BL's was 75.5 cm, with weights of 17.6 kg and 13.6 kg, respectively. Posterior fusion was undertaken in late 2018 for both patients using a pedicle screw, rod and bone graft construct, without intra or postoperative complications. Both patients remained in their halos postoperatively to support the fusion mass for a further 3 months. The halos were removed in the outpatient clinic at this time and definitive fusion was achieved by 9 months for both patients (Figs. 7, 8).

Minor complications occurred in both patients. BL had one episode of pin cellulitis in late 2018 prior to fusion, which was treated with saline dressings and oral antibiotics.

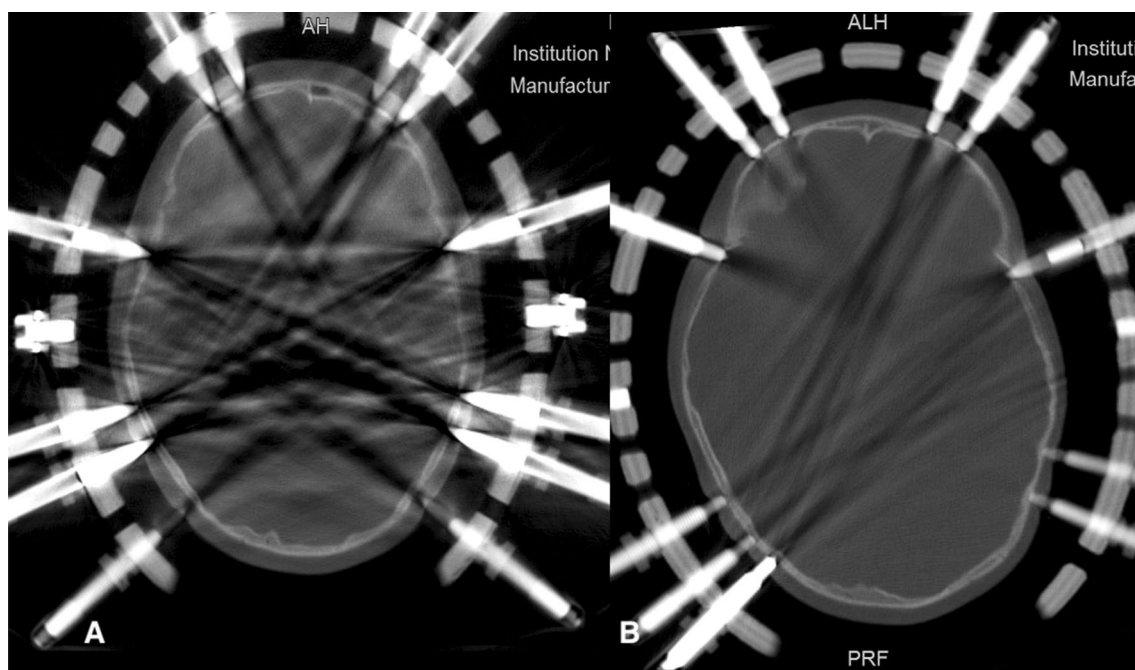


Fig. 4 Postoperative computer tomography scans following halo-pin placement (ML—**a** and BL—**b**), which demonstrate safe pin depth

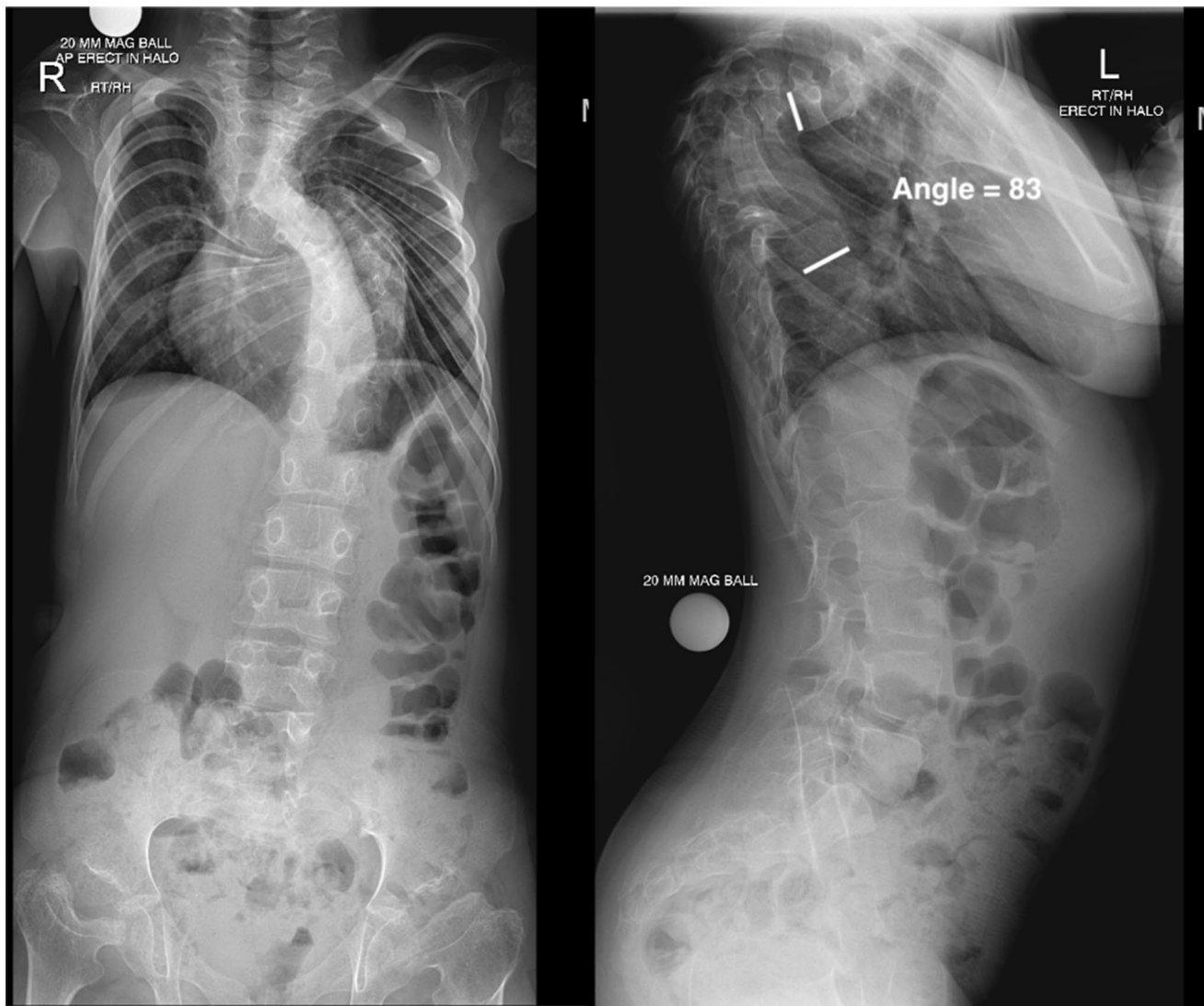


Fig. 5 Erect X-rays of ML after 182 days of HGT and prior to definitive posterior fusion, demonstrating curve correction

After fusion, BL required removal of two pins due to aseptic loosening in early 2019. After halo removal, both patients experienced occipito-cervical paravertebral muscle weakness which was treated successfully with cervico-thoracic vis a brace and physiotherapy. These braces are evident in Figs. 7 and 8 and were used for 6 months after halo removal for 16 h per day, along with physiotherapy to improve occipito-cervical muscle weakness.

Discussion

HGT is a well-established technique for gradual deformity correction in paediatric patients with rigid severe scoliosis to prevent neurological complications associated with single-stage acute deformity correction and definitive fusion

[3–6, 8–11]. Current best practice guidelines suggest that HGT may be effective for gradual curve correction prior to definitive fusion in patients of all ages, with any underlying scoliosis aetiology (including skeletal dysplasias) [6, 12]. For younger patients and for patients with skeletal dysplasia, these guidelines recommend the use of more halo pins, with lower torque upon insertion. However, the authors of these guidelines acknowledge that there was very little high level evidence to guide these recommendations and there are few reports or published studies dedicated to halo application and the safe use of prolonged HGT in patients with skeletal dysplasia.

Challenges in placing halo pins in patients with skeletal dysplasia include thin cortical bone, reduced volume of medullary bone and the young age of patients, all of which can reduce pin pull-out strength [6, 12]. This study demonstrates

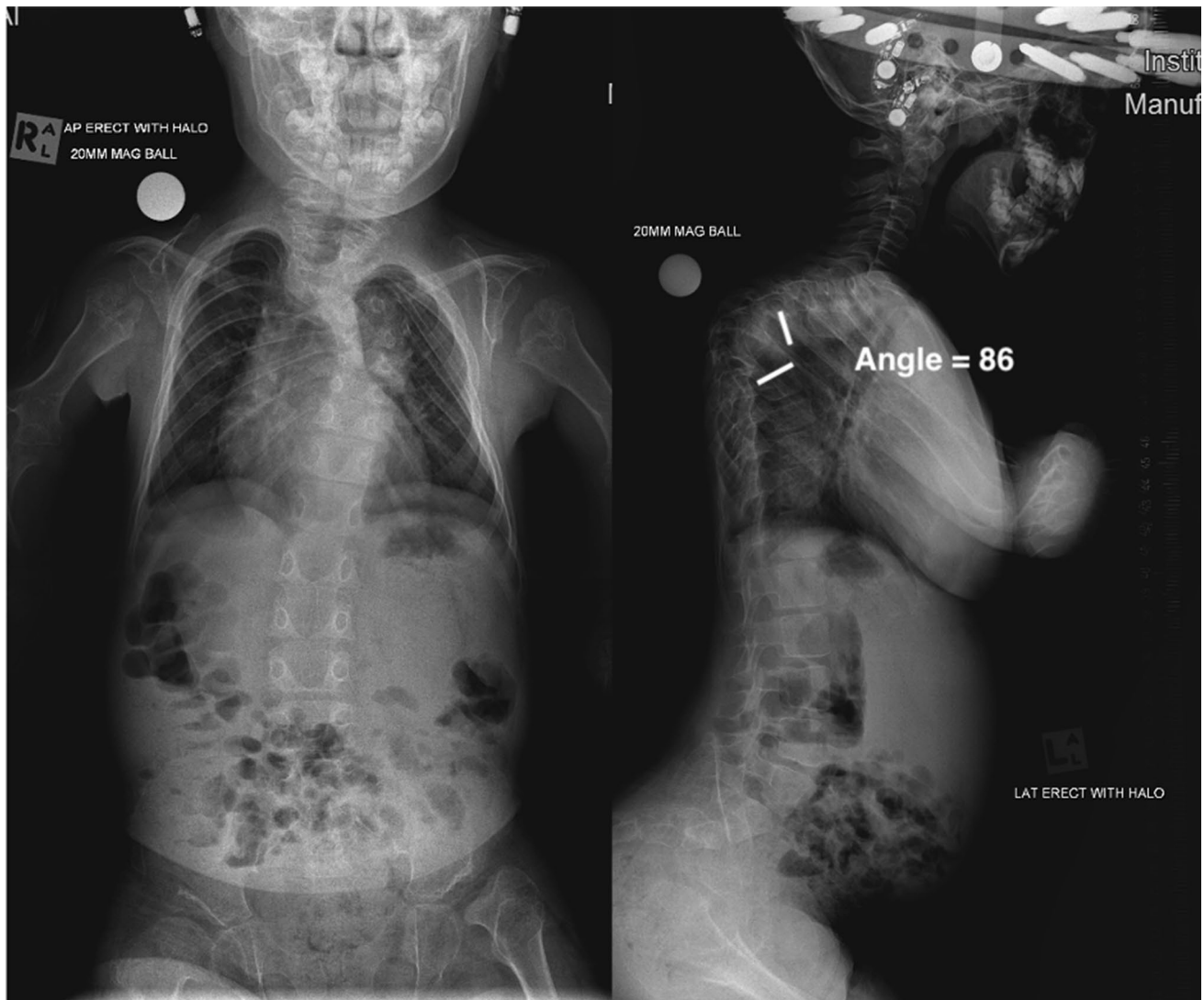


Fig. 6 Erect X-rays of BL after 238 days of HGT and prior to definitive posterior fusion, demonstrating curve correction

that the use of 3D printed models is additional method to assist in pin placement for young paediatric patients with skeletal dysplasia requiring prolonged HGT prior to definitive fusion. In the two patients in this study, the 3D printed models allowed pin positioning in thicker cortical bone and allowed judgement of pin depth, which allowed for a long duration of HGT (greater than 6 months). In previous studies investigating HGT in patients with skeletal dysplasia, the duration of HGT has been considerably shorter [12]. It is possible that the use of 3D models in this study contributed to the long duration of HGT, with only mild complications experienced in both patients.

Whilst we were unable to find other reports of the use of 3D models for halo pin placement, 3D models have been used elsewhere in scoliosis surgery, most commonly as

sterile guides for pedicle screw placement as an alternative to navigation methods. Studies investigating 3D models for pedicle screw placement have demonstrated safe screw placement with the potential for reduced operating and fluoroscopy time, particularly for more complex deformities [13, 14]. We believe that halo pin placement could represent another application for the use of 3D models for safe hardware placement in scoliosis deformity correction.

There are drawbacks associated with the use of 3D models for halo placement and the methods used in this study. Access to 3D printers is not universal and requires consultation between surgeons and engineers and unlike navigation techniques, there can be difficulty correlating models with patient anatomy intraoperatively. We found that using correlation between the bony landmarks from

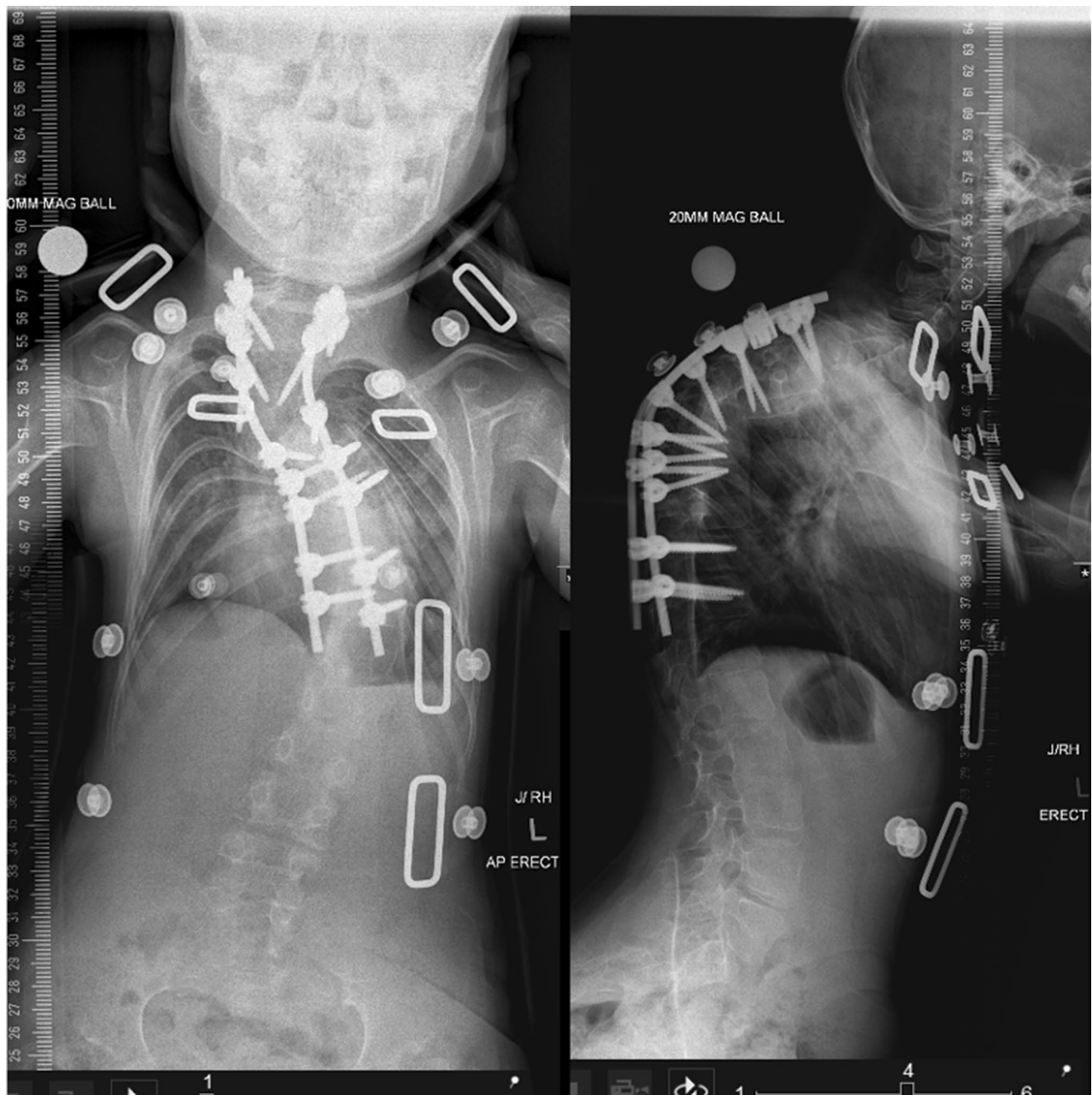


Fig. 7 Erect X-rays 9 months post-fusion for ML and 6 months after halo removal

the 3D models and the patient's anatomy was useful to guide pin placement, which was validated by accurate pin positioning on postoperative CT scans in both patients. However, although not available at our institution, we acknowledge that an intraoperative CT scan may have been a useful technique to judge safe pin placement whilst the patient was still under general anaesthesia. Further comparative studies with a larger number of patients are required to determine whether 3D models offer an advantage over conventional pin insertion.

Conclusions

This study demonstrates that 3D printed models can serve as a useful adjunct for the safe placement of pins in young paediatric patients with skeletal dysplasia. Both patients tolerated prolonged HGT with minimal complications, which allowed gradual deformity correction prior to definitive posterior spinal fusion. Further comparative studies are required to investigate whether this technique affords a significant advantage over conventional pin placement techniques.

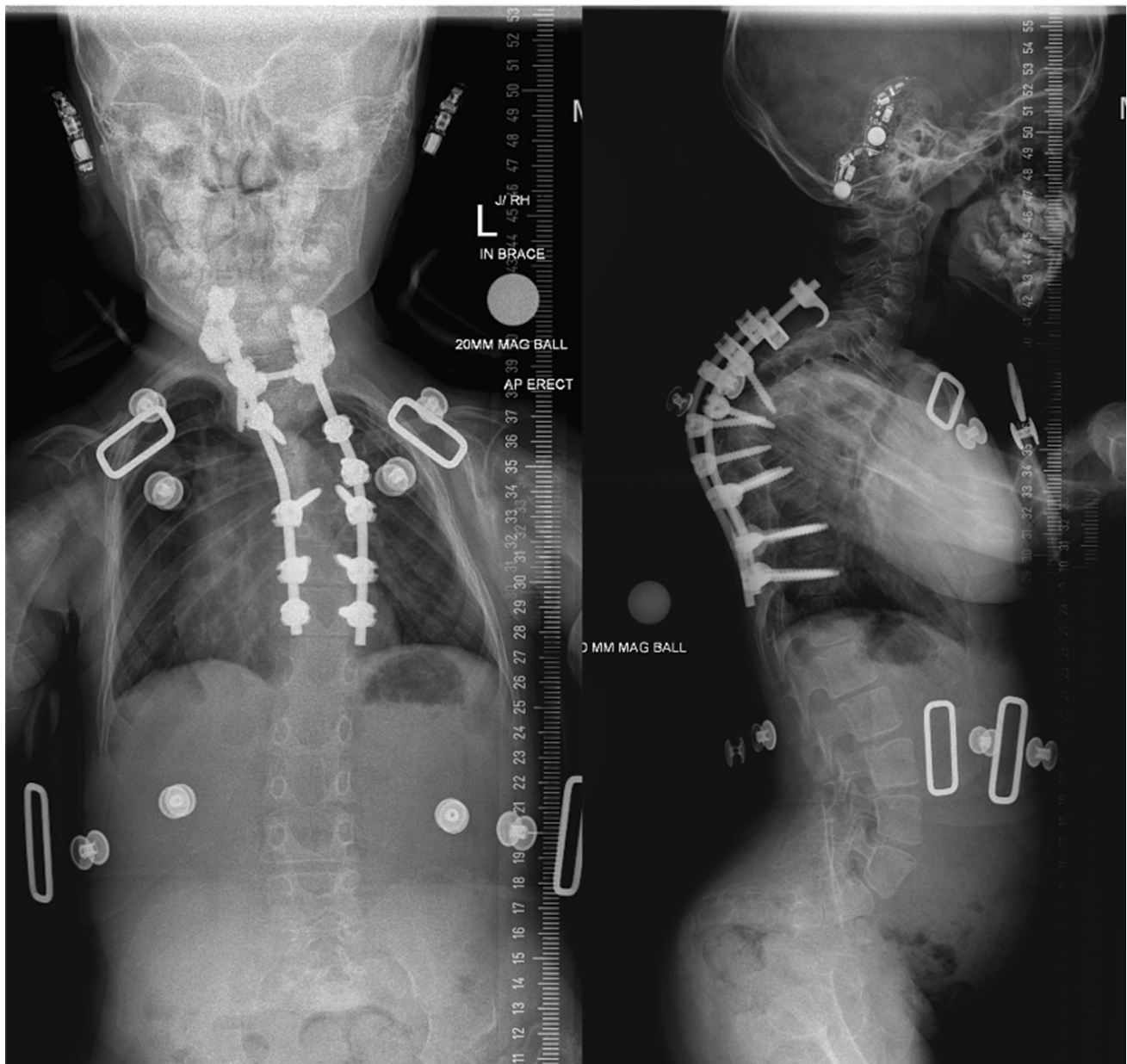


Fig. 8 Erect X-rays 9 months post-fusion for BL and 6 months after halo removal

Author contributions Each author contributed sufficiently to this study to be considered an author according to the international committee of medical journal editors (ICMJE) criteria.

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Availability of data Data can be made available upon request from the corresponding author.

Compliance with ethical standards

Conflict of interest There are no conflicts of interest to declare from each author.

Ethics approval Ethics approval was gained from the hospital ethics board (Children's Hospital Westmead, Sydney, Australia) prior to the study.

Consent to participate and consent for publication The parents of both patients consented to participation and publication of this study.

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