Case Report

Surgical planning for cervical deformity based on a 3D model

ABSTRACT

The treatment of fixed cervical deformity is complex, but the principles guiding its correction remain the same as in deformity of other spinal regions, with the goal of deformity correction that results in a solid fusion with adequate decompression of the neural elements. In these challenging cases, osteotomies are necessary to mobilize the rigid spine and to obtain the desired correction, but they can be associated with increased risk of complications. Therefore, careful preoperative planning and a complete understanding of the anatomic variations allow patient-tailored approaches with and case specific techniques for the optimal and safe treatment of a variety of complex cervical deformities. We present a case report with a complex spinal deformity where a 3D model was used for surgical strategy that allowed us to "simulate" the osteotomies and get a better correction of the cervical deformity.

Keywords: Cervical deformity, osteotomies, surgical planning, three-dimensional model

INTRODUCTION

Severe cervical deformities are among the most challenging problems for spinal surgeons and can cause disability and pain. Disability, in the form of myelopathy, can lead to gait disturbance, loss of manual dexterity, and bowel and bladder dysfunction.[1] While flexible deformities can be treated in a relatively straightforward way with a variety of surgical options, patients with an ankylosed cervical spine often require osteotomies for appropriate deformity correction and neural decompression.[2,3]

The treatment of fixed cervical deformity is complex, but the principles guiding its correction remain the same as in deformity of other spinal regions, with the goal of deformity correction that results in a solid fusion with adequate decompression of the neural elements.[4] In these challenging cases, osteotomies are necessary to mobilize the rigid spine and to obtain the desired correction, but they can be associated with increased risk of complications. Therefore, careful preoperative planning and a complete understanding of the anatomic variations allow patient-tailored approaches with case-specific techniques for the optimal and safe treatment of a variety of complex cervical deformities.[5] In the modern era, medical imaging has seen great advances. It has become more available, less invasive, and more informative. Magnetic resonance imaging (MRI) and computed tomography (CT) imaging have permitted detailed two-dimensional (2D) visualization of the problem with a degree of customization of the surgical approach. In this way, the surgeon can greatly improve a patient's quality of life by understanding the nature and subtleties of the intrinsic deformity.[5,6] Among recent innovations, three-dimensional (3D) modeling has been introduced into the surgical arena as a tool for better understanding the complex underlying anatomy, specifically in spine deformity surgery.[7,8]

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It represents a promising research and clinical area that could be used to improve and facilitate greater quality in diagnosis and presurgical planning.

CASE REPORT

We present a case of a 66-year-old male, diagnosed with a mild cervical myelopathy associated with a fixed cervical kyphotic deformity. Surgical decompression and deformity correction were recommended three staged surgery was planned [Table 1]. The cervical CT images of the patient [Figure 1a-d] are imported into the Mimics Innovation Suite (Materialise NV, Belgium), a commercial and certified medical imaging manipulation software suite [Figure 2a-e].

After defining the appropriate density range (between 226 and 1872 Hounsfield units), the bone is precisely segmented using an automatic thresholding tool. Then, the algorithm interpolates all 2D masks to generate a 3D model of the cervical spine. This model is then "edited" to include only the specific region of interest, to make it suitable for 3D printing [Figure 2b and c]. The final model [Figure 2d-f], ready to be 3D printed, is exported in the Standard Tessellation Language file format.

Figure 1: (a) Preoperative magnetic resonance imaging Sagittal T2. Severe deformity from C3 to C6. (b) Computed tomography scan demonstrates multiple ankylosed points. Important kyphosis is also demonstrated (c and d) anterior–posterior and lateral X-rays

The model is then 3D printed with an in-house 3D System Project 3510 SD printer. The process consists of jetting and ultraviolet-curing successive layers of proprietary acrylic resins [Figures 2g, h and 3]. The layers have a thickness of 32 μm, and the XY resolution of the printhead is 375 dots per inch. Rigid and translucent resin (Visijet M3 Crystal) has been used to generate the physical model [Figure 2h]. During the process, a paraffin support (Visijet S300) is automatically generated around the part. This support is eliminated afterward by melting at 65°C and the part is manually cleaned before use.

Analysis of the 3D model clearly shows the location and extent of ankylosis, in addition to other bone details [Figure 4]. Particular attention is paid to the uncovertebral joints at each level from the anterior surface to the neural foramen. Attention is also paid to the facet joints at each level, particularly on their lateral aspects. Required osteotomies for deformity correction were planned using the fine detail of the 3D model. When compared to conventional MRI and CT imaging, definite ankylosis was identified in several locations, which was not noted on the 2D imaging [Figure 4d; yellow arrows].

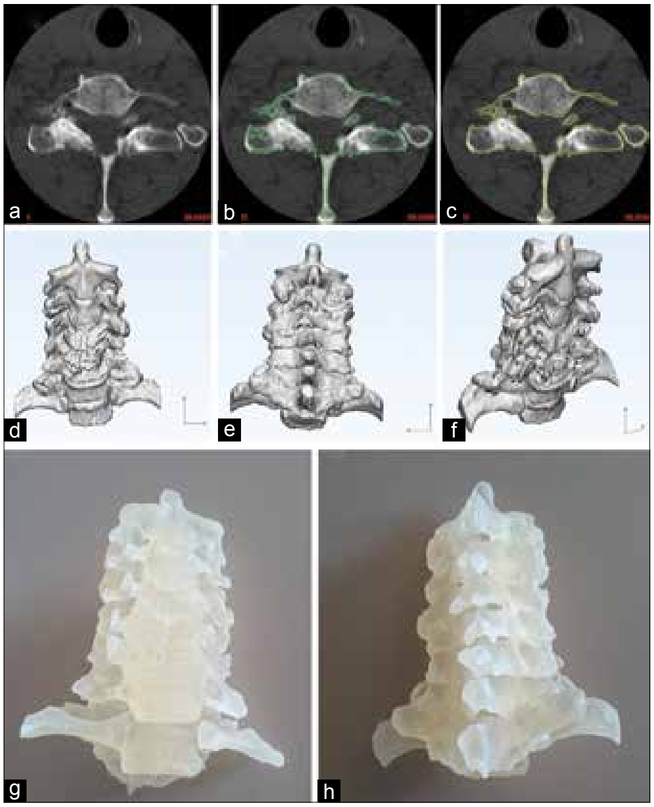

Figure 2: Computed tomography scan slices, before segmentation (a) showing the contour of an intermediate three-dimensional model (b) showing the contour of the final three-dimensional model (c) final three-dimensional model ready for three-dimensional printing, anterior view (d) posterior view (e) and oblique view (f) final model (g and h)

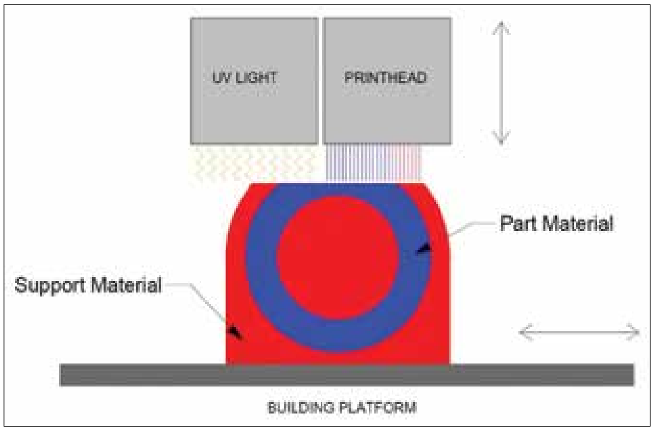

Figure 3: Three-dimensional printing principle

Surgical multilevel osteotomies were planned and based according to the ankylosed points identified previously over the 3D model [Figure 4a]. A two-stage surgery was planned involving placement of cervical pedicle screws and a posterior release. The second stage involved a multilevel anterior release with restoration of anterior column height using an expandable cage and plate, followed by posterior rod placement and posterior column shortening with bone grafting.

For the first stage of surgery, a standard midline posterior approach was used to expose from C1 to C7 [Figure 5a-d]. A reference arc was place on C2, followed by a 3D fluoroscopic acquisition (O arm, Medtronic). Pedicle screws were placed at C3 and T1 bilaterally. Peripedicular "strip-like" osteotomies were performed at C3/4, C4/5, C5/6, and C6/7 bilaterally [Figure 5e and f] such that there was complete discontinuity of bone posterior to the nerve roots at each level. The wound was then closed.

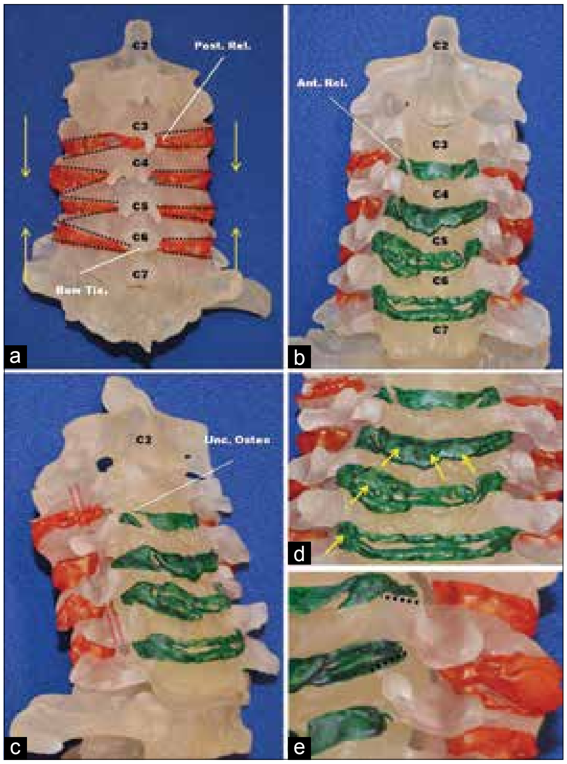

Figure 4: Preoperative three-dimensional model of a patient with kyphotic deformity and severe spine ankylosis. (a) (First stage of the surgery) Posterior view of the cervical spine. Osteotomies were planified according to the model and marked in red. Black dotted line shows the extension of the bone removal. Yellow arrows show the intention to get lordosis from the posterior osteotomies during stage three of the surgery. (b) Anterior view of the three-dimensional cervical spine. Discectomies were made, and lateral extension and uncal osteotomies were planned to "completely disconnect" the posterior from the anterior spine. (c) Oblique view of the three-dimensional model showing the relationship of the anterior extension of the uncal osteotomy with the vertebral artery and the posterior ankylosis. (d) Anterior view of the three-dimensional model showing (yellow arrows) severe ankylosis and planned osteotomies (green). (e) Oblique view of the spine showing "disconnection" in a black dotted line

The second stage was performed several days later. The patient was positioned supine initially, and using a "carotid-" type incision, the anterior spine from C2 to C7 was exposed. Multilevel discectomies at C3/4, C4/5, C5/6, and C6/7 were performed using the operating microscope. Uncal release was performed at each level bilaterally initially using a high-speed cutting drill, with the final bone removal laterally performed using an ultrasonic bone dissector as far as the adjacent soft tissues and vertebral artery [Figure 5f]. This completed the 360° bone release, facilitating correction of the malalignment. This technique was used on all involved levels. Midline multilevel trench corpectomies were performed at C4, C5, and C6. A PEEK expandable cage was placed and expanded to restore neutral alignment, confirmed on 2D fluoroscopy. A cervical plate was placed from C3 to C7 [Figure 6a-d]. The wound was then closed over a Jackson-Pratt deep drain. The patient was turned over to a prone position on the Jackson table, the posterior cervical area was prepped and draped, and the posterior incision was reopened. Rods were conformed to a lordotic curvature, placed into the pedicle screw heads, and secured under fluoroscopically controlled compression to achieve lordosis. Autologous bone graft was placed into the osteotomy defects bilaterally.

DISCUSSION

For the past few decades, the use of 3D printing has been mainly limited to engineering and prototyping applications, primarily due to the high cost of 3D printers and the required software. Recently, the cost has decreased, and the availability of 3D printing services has increased, allowing applications for 3D printing to grow. Medical 3D printing is an emerging technology capable of readily producing accurate anatomical models; however, evidence for the use of 3D prints in surgical planning remains limited.[6,9]

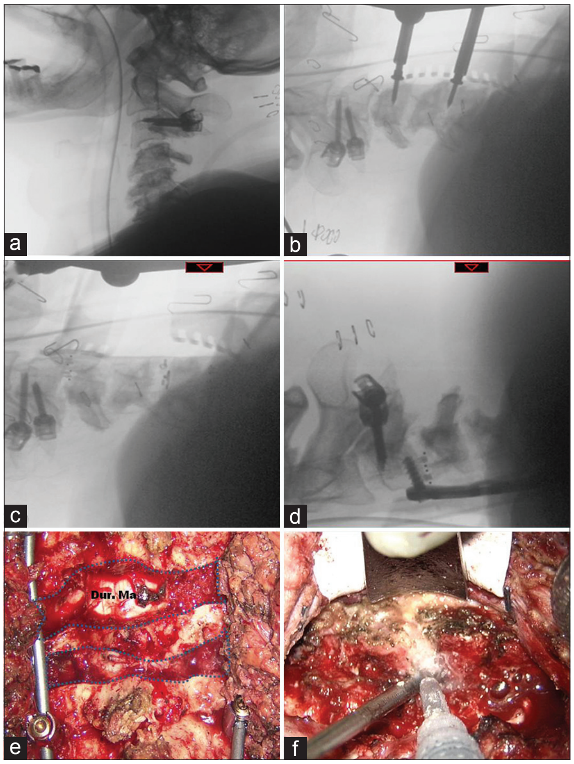

Figure 5: Transoperative and postoperative imaging. (a) Stage 1 posterior "bow tie" osteotomies and placement of the terminal screws. (b and c) Stage two, anterior release with complete disconnection. (d) Stage three posterior contraction and rod placement. (e) Posterior view (during stage three of the surgery) shows intraoperative "bow tie" osteotomies. Pedicular screws can be seen along with rods. Dura or Dura Mater can be seen in the photograph. (f) Anterior uncinate osteotomy with the bone scalpel, lateral extension was defined previously in the three-dimensional model

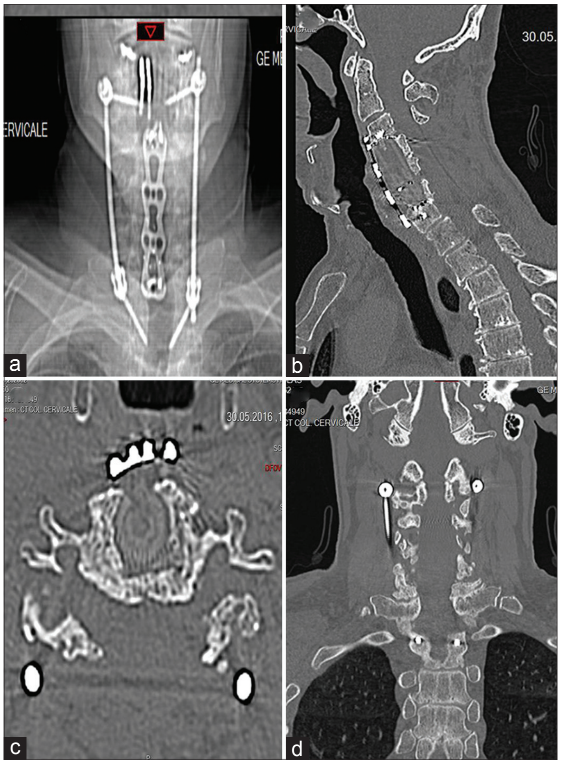

Figure 6: (a) Post op X ray. (b) post op sagittal CT scan (c) post op axial CT Scan showing the disconnection between posterior and anterior part of the vertebra. (d) Coronal post op CT scan showing all osteotomies

Table 1: Surgical flow chart

Stage 0	CT MRI 3D Model
Stage 1	Posterior Release *Bow Tie* Osteotomies Pedicular Screws
Stage 2	Anterior Multilevel Corpectomy/Discectomy Uncinate Osteotomies Cages/Expandable Cage/Plate
Stage 3	Posterior Stabilization Placement of Rods Contraction

Neurosurgical planning is a critical step for correct decision-making. Numerous attempts have been made in different fields to understand the pathologies and complex anatomical structure. As a modern concept, we can now compare the current practice that depends on MRI and CT imaging with 3D printed models to augment surgical planning and education.[7]

Analyzing the sagittal plane and providing individualized surgical planning on the basis of multiplanar 2D imagery can be a complicated exercise, with the goal of achieving appropriate correction and lordosis in cervical deformity. We must emphasize the importance of optimal correction of fixed cervical deformities on clinical outcome and the quality of life of patients.[4] Multiple forms of digital measurement software have been used but without attaining widespread usage. To achieve the goal of deformity correction, today's surgeon can be guided by more accurate and less variable techniques. Custom-made models provide life-size 3D visualization without the limits of current imaging techniques. Constructed to recreate in detail each patient, 3D models provide an ideal "inert reality," a step beyond virtual reality in which the surgeon can manipulate the model from all angles for a complete understanding of specific ankylosis points and can better "simulate" the surgery for an optimal result. The full impact of using 3D models for detailed bone resection remains yet to be analyzed. It is nonetheless certain that it could successfully become part of the patients' workup in selected cases.[1,9]

CONCLUSION

Appreciation of the complex 3D anatomy and corresponding pathology of the spine remains difficult with 2D imaging, such as CT and MRI, even though it remains the standard for the pre- and post-operative evaluation of the spine patient.[9] As 3D printing technology evolves and costs decrease, patient-specific 3D printing may become more widespread and even routine for both clinical and educational uses.

Preoperatively, 3D models can be used to improve surgeons' and patients' understanding of related pathology. With much current attention focused on the importance of sagittal balance in spinal reconstruction, such tools can also enhance 3D interpretation and surgical planning.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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