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PICTORIAL REVIEW

3D cinematic rendering of the calvarium, maxillofacial structures, and skull base: preliminary observations

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ABSTRACT

Three-dimensional (3D) visualizations of volumetric data from CT have gained widespread clinical acceptance and are an important method for evaluating complex anatomy and pathology. Recently, cinematic rendering (CR), a new 3D visualization methodology, has become available. CR utilizes a lighting model that allows for the production of photorealistic images from isotropic voxel data. Given how new this technique is, studies to evaluate its clinical utility and any potential advantages or disadvantages relative to other 3D methods such as volume rendering have yet to be published. In this pictorial review, we provide examples of normal calvarial, maxillofacial, and skull base anatomy and pathological conditions that highlight the potential for CR images to aid in patient evaluation and treatment planning. The highly detailed images and nuanced shadowing that are intrinsic to CR are well suited to the display of the complex anatomy in this region of the body. We look forward to studies with CR that will ascertain the ultimate value of this methodology to evaluate calvarium, maxillofacial, and skull base morphology as well as other complex anatomic structures.

INTRODUCTION

The development of multislice CT scanners that are capable of the acquisition of volumetric data sets consisting of isotropic voxels has paved the way for the incorporation of three-dimensional (3D) CT images into clinical practice. Currently, both maximum intensity projection (MIP) and volume rendering (VR) methods are commonly used as adjuncts to axial images and multiplanar reformations in cases of complex anatomy and physiology.

Cinematic rendering (CR) is a novel 3D technique that provides photorealistic images from volumetric CT data.^{1,2} The CR reconstruction method utilizes the same basic steps as traditional VR; namely, the axial thin-slice, isotropic voxel data set is stacked to create the 3D volume, each voxel within the volume is assigned a color and transparency based on its relative tissue composition, and then light is projected through the volume in order to create the 3D image. However, where CR differs from VR is in the lighting model that is used. Instead of the ray casting utilized for VR image reconstruction, CR makes use of numerous rays of light that are propagated through the volumetric data set and take into account scatter and the effects of adjacent voxels (a so-called, global lighting model).³ This more

complex lighting model allows for realistic shadowing and the creation of highly detailed, photorealistic 3D images.

In the following pictorial review, we demonstrate our initial experience with the application of CR methodology to the normal calvarium, maxillofacial structures, and skull base; additionally, multiple associated pathologies are demonstrated as a means to convey the potential utility of this new imaging technique in diagnosis and patient treatment planning.

CASE SERIES

Figure 1 shows the appearance of normal skull anatomy from a 53-year-old male patient with both traditional VR (Figure 1a–c) and with CR (Figure 1d–f). In the frontal and lateral views (compare Figure 1d,e to Figure 1a,b), the depth perception provided by CR through realistic shadowing effects allows for improved display of maxillofacial structures. For example, in comparing Figure 1a–d, the increased shadowing deep to the zygomatic arch more accurately reflects the relative position of the arch, as it overlies the bony structures along the medial aspect of the temporal and infratemporal fossae. Further, in comparing Figure 1b–e, the superior orbital fissure and the bony

Figure 1. (a–c) VR images from a 53-year-old male undergoing imaging for pre-operative evaluation for sinus surgery and with no significant pathology visible. These images demonstrate the 3D appearance of some of the complex anatomy of the skull including the zygomatic process [arrow head in (a)], the superior orbital fissure [arrow in (b)], and the foramen ovale [thin arrow in (c)]. (d–f) CR images demonstrating the same aspects of normal anatomy as in (a–c). Note that the complex lighting model utilized in CR creates realistic shadowing effects that can aid in understanding the relative anatomic relationships in regions with particularly complex anatomy. 3D, three-dimensional; CR, cinematic rendering; VR, volume rendering.

framework outlining the perimeter of the orbit are both more realistically displayed by the CR image in Figure 1.

A global overview of complex maxillofacial fractures is difficult to achieve with two-dimensional (2D) images, and 3D methodologies have been extensively utilized in this clinical space.⁴

Figure 2. A 36-year-old male patient with multiple complex facial fractures after an initial stage of surgical repair demonstrated with VR [(a–c)] and CR [(d–e)]. The findings include mandibular fractures bilaterally and combined Lafort 2 and 3 type fractures through the midface bilaterally. Note that the artefacts from metallic dental hardware [arrow heads in (a) and (d)] do not significantly interfere with interpretation of these images. This patient had been found down after a bicycle accident at unknown speed. CR, cinematic rendering; VR, volume rendering.

Figure 3. CR images from a 45-year-old male with recurrent sinonasal squamous cell carcinoma. The same view with differing settings provides detailed information on (a) overlying soft tissue, (b) combined soft tissue and bone, and (c) bone-only aspects of this complex case. CR, cinematic rendering.

Figure 2a–c shows multiple different VR views of a 36-year-old male patient, who experienced significant facial trauma and was found to have both extensive midface and mandibular fractures. Both the VR and CR images provide detailed views of the fractures, although the CR images (Figure 2d–f) are able to use shadowing to improved effect to improve perception of depth in the images and ease understanding of how the fracture fragments are oriented. In particular, the extension of the fractures into the orbits as well as the degree of fragment displacement in the mandibular angles is better demonstrated with the CR images. The braces on the patient's teeth create mild streak artefact, but this does not limit the ability to apprehend the salient features of this case.

Figures 3 and 4 show large squamous cell carcinomas in two different patients. Figure 3 is from a 45-year-old male with recurrent sinonasal squamous cell carcinoma that has had a significant destructive impact on the central face including throughout the sinuses, the nasal cavity, and the maxilla. As with VR, CR can provide information on different tissue types by adjusting the display parameters to better visualize soft tissues *vs* higher attenuating objects. In Figure 3, the images include a soft tissue example (Figure 3a), a mix of soft tissue and underlying bone (Figure 3b), and a bone-only example (Figure 3c). The sum total of all three images provides a detailed overview of the extensive destructive process associated with this patient's tumor.

Figure 4 provides another example of a squamous cell carcinoma, in this case arising from the skin and growing into a large fungating mass with underlying destructive changes in the skull and overlapping and obscuring vision from the 50-year-old male patient's left eye. Figure 4a,b are axial and coronal 2D post-contrast CT images that show the large size of the tumor as well as how the tumor has eroded through the skull. On the VR images (Figure 4c,d), an improved global visualization of the mass and how much of the skull has been destroyed is provided. The CR images (Figure 4e–h) provide an even greater level of detail, and once more the photorealistic shadowing more clearly delineates relative anatomic relationships by shadowing out the inner table on the opposite side of the calvarium that would otherwise be visible through the large left frontal defect (compare Figure 4d to Figure 4h).

Figure 5 provides an example of a 38-year-old patient with polyostotic fibrous dysplasia affecting multiple facial bones. While the

Figure 4. (a) Axial and (b) coronal post-contrast 2D CT images from a 50-year-old male with a large fungating skin squamous cell carcinoma (red arrow heads) that has invaded and caused destructive changes to a portion of the left frontal calvarium [arrows in (a)]. (c, d) VR images provide a global perspective on the large size of the mass [arrow head in (c)], which covers the patient's left eye. The destructive changes to the underlying skull [arrow in (d)] are also well seen with VR. (e–h) CR images utilizing window settings that allow for partial transparency of the soft tissues [(e, f)] and that highlight bone and contrast-enhanced vascular structures. The large mass is again well-evaluated [arrow heads in (e, f)] as well as the erosive changes in the left frontal calvarium [arrows in (g, h)]. Perhaps the most striking difference between VR and CR in this example is that the more realistic shadowing possible with CR allows for easier visualization of the through-and-through nature of the calvarial erosion because the inner table of the skull opposite to the defect is in shadow [compare (d, h)]. 2D, two-dimensional; CR, cinematic rendering; VR, volume rendering.

2D images (Figure 5a–c) provide visualization of the expanded nature of the involved bones as well as the typical ground-glass appearance of the lesions, the VR (Figure 5d) and CR (Figure 5e,f) provide a better overall appreciation of the degree of facial deformity, including highlighting the significant narrowing of the superior orbital fissure and near-obliteration of the right side of the nasal cavity. The more realistic quality of the CR images may aid in pre-operative planning for complex cases like this, in which the patient was to undergo debulking surgery to improve bite mechanics.

As a final example in this series, Figure 6 shows a very densely calcified mass projecting from the right occipital bone of the calvarium. This 42-year-old female patient had presented with headache and subsequently, underwent resection of this lesion. Although the mass had been suspected to be a meningioma, the surgical pathology was instead consistent with an intracranial osteoma. Although VR would also have shown this mass to good effect, the shadowing of the interface of the mass with the inner table that suggests the lesion is arising from a bony stalk would have been difficult to display without CR.

DISCUSSION

The series of cinematically rendered cases of calvarial, maxillo-facial, and skull anatomy and pathology presented in the cases in this manuscript highlight the potential important differences

Figure 5. Images from a 38-year-old female with polyostotic fibrous dysplasia. (a) Axial, (b) sagittal, and (c) coronal 2D non-contrast CT images show the marked deformity associated with the abnormal bone morphology and also highlight the ground-glass attenuation of the affected bones. However, it is difficult to discern the overall extent of involvement from only 2D images in this case. (d) VR as well as (e, f) CR 3D images provide an improved overview of the process relative to the 2D images. For a patient such as this, who required debulking of the maxilla because of severe malocclusion, the photorealistic quality of the CR images may ultimately prove of value in pre-operative planning. 2D, two-dimensional; CR, cinematic rendering; VR, volume rendering.

between CR and traditional VR. On a fundamental level, the most apparent differences between CR and VR are a direct result of the complex global lighting model employed by CR and the

Figure 6. An intracranial osteoma (arrow head) in a 42-year-old female patient is well-demonstrated in multiple CR images. Note in (a, c) that this window level incidentally also includes the fiducial markers overlying the frontal calvarium as this patient was being prepped for surgery to remove the mass. CR, cinematic rendering.

consequent realistic shadowing that adds a depth to the CR images that is not typically achievable with other 3D methods. This added depth and intuitive display of the relative anatomic positions of structures within the imaged volume, along with enhanced surface detail relative to VR, combine to produce the photorealism inherent to CR. In regions of complex anatomy, particularly with overlying or overhanging structures, the shadowing in CR can improve anatomic understanding—examples of this include, [Figure 1](#) relative to the zygomatic arch and structures in the orbits and in [Figure 3](#) with the eroded fragments of the bones comprising the nasal and oral cavities and the paranasal sinuses. A further demonstration of this effect can be appreciated in [Figure 4](#), where the inability of traditional VR to accurately reflect the shadowing within the cranial cavity makes it difficult to discern if there is through-and-through destruction of the left frontal bone ([Figure 4d](#)), whereas the complete erosion through the table is inner obvious with CR ([Figure 4h](#)). The realistic shadowing in CR images is particularly well demonstrated when comparing the right orbit of the patient with polyostotic fibrous dysplasia in [Figure 5](#), where the severe narrowing of the posterior aspect of the orbit is depicted in a superior manner by CR ([Figure 5e](#)) in comparison to VR ([Figure 5d](#)).

Beyond shadowing, the CR global lighting model is well-suited to the display of small anatomic structures due to intrinsic very high surface detail. This aspect of the technique is demonstrated in [Figure 1](#) for the orbits and skull base, where even very small foramina and bony detail is realistically depicted. Further, in

regards to the large squamous cell carcinoma in [Figure 4](#), even very small vessels within the matrix of tumor neovascularity can be resolved and appreciated, as aspect of CR that suggests it can play an important role in pre-operative planning in complex cases such as this.

CR remains a new technique for which the ultimate clinical applications and limitations have not been definitively established. However, the remarkable detail relative to traditional VR image reconstruction suggests important applications that should be extensively investigated as CR becomes more widely available and clinically utilized. Recently, examples of CR images in the context of musculoskeletal trauma⁵ and chest cardiovascular pathologies⁶ have been presented and qualitatively compared to other 3D imaging methods. For example, the realistic shadowing effects and detail of the images are likely to find acceptance in surgical and procedural guidance. Furthermore, the trend towards utilization of 3D printing as part of pre-operative planning⁷ may help to push clinical adoption of CR; simply put, CR images recapitulate the appearance of 3D printed models to a degree that was heretofore impossible and this may obviate the need for physical 3D printed models in some cases. Lastly, as patients become more actively involved in medical decision-making, the images provided by CR may be a valuable means of conveying information to patients. We look forward to the development of studies that will answer important questions regarding the value of CR in appropriate clinical settings.

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