Clinical Radiology

Cinematic Rendering of Paediatric Musculoskeletal Pathologies: Initial Experiences with CT

--Manuscript Draft--

Manuscript Number:	
Full Title:	Cinematic Rendering of Paediatric Musculoskeletal Pathologies: Initial Experiences with CT
Article Type:	Original Paper
Corresponding Author:	Susan Cheng Shelmerdine, FRCR PhD Great Ormond Street Hospital For Children NHS Foundation Trust London, UNITED KINGDOM
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Great Ormond Street Hospital For Children NHS Foundation Trust
Corresponding Author's Secondary Institution:	
First Author:	Aisling Fagan, FRCR
First Author Secondary Information:	
Order of Authors:	Aisling Fagan, FRCR
	Owen J Arthurs, FRCR, PhD
	Neil Sebire, FRCPath MD
	Susan Cheng Shelmerdine, FRCR PhD
Order of Authors Secondary Information:	
Abstract:	Cinematic rendering (CR), is a novel post-processing technique similar to volume rendering (VR), which allows for a more photorealistic imaging reconstruction by using a complex light modelling algorithm, incorporating information from multiple light paths and predicted photon scattering patterns. Several recent publications have argued that CT gives a better “realism” and “expressiveness” experience over VR techniques in adult imaging. CR has also been shown to improve visualization of musculoskeletal and vascular anatomy compared with conventional CT viewing, and may help non-radiologists to understand complex patient anatomy. In this pictorial review we provide an overview of how CR could be used in paediatric musculoskeletal imaging, particularly in complex diagnoses, surgical planning, and patient consent processes. We present a direct comparison of VR and CR reconstructions across a range of congenital and acquired musculoskeletal pathologies, highlighting potential advantages and areas for further research.

Main Title:

Cinematic Rendering of Paediatric Musculoskeletal Pathologies: Initial Experiences with CT

Running Title:

Cinematic rendering for paediatric musculoskeletal radiology

Author Names:

Aisling Fagan [a], faganai@tcd.ie

Owen J Arthurs [a, b, c], Owen.arthurs@gosh.nhs.uk

Neil J Sebire [a, b, c] neil.sebire@gosh.nhs.uk

Susan C Shelmerdine [a, b, c], susan.shelmerdine@gosh.nhs.uk

Affiliations:

a) Great Ormond Street Hospital for Children NHS Foundation Trust, London WC1N 3JH, UK

b) UCL Great Ormond Street Institute of Child Health, London, UK

c) NIHR Great Ormond Street Hospital Biomedical Research Centre, London, UK

Corresponding Author Details:

Name: Susan Shelmerdine

Address: Great Ormond Street Hospital for Children NHS Foundation Trust, London WC1N 3JH, UK

Email: susie_c_s@yahoo.co.uk

Telephone: +44 0207 405 9200

Keywords: Cinematic rendering, CT, musculoskeletal, paediatric, volume rendering

Type of manuscript: Pictorial Review

Word count: 2487

Figure count: 13

Table count: 0

Acknowledgements:

None

Declarations of Competing Interests

Research Support:
OJA is funded by a National Institute for Health Research (NIHR) Career Development Fellowship (NIHR-CDF-2017-10-037). The views expressed are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health.

Role of Funding Source:
The funding sources stated had no involvement or influence on the conception, data collection or analysis of this study.

Relationships:
There are no additional relationships to disclose

Patents and Intellectual Property:
There are no patents to disclose

Other activities:
There are no additional activities to disclose

Author Contributions

1 Guarantor of integrity of the entire study - SCS
2 Study concepts and design – AF, OJA, NJS, SCS
3 Literature research – AF, SCS
4 Clinical studies – not applicable
5 Experimental studies / data analysis – not applicable
6 Statistical analysis – not applicable
7 Manuscript preparation – AF, OJA, NJS, SCS
8 Manuscript editing – AF, OJA, NJS, SCS

ABSTRACT

Cinematic rendering (CR), is a novel post-processing technique similar to volume rendering (VR), which allows for a more photorealistic imaging reconstruction by using a complex light modelling algorithm, incorporating information from multiple light paths and predicted photon scattering patterns. Several recent publications have argued that CT gives a better “realism” and “expressiveness” experience over VR techniques in adult imaging. CR has also been shown to improve visualization of musculoskeletal and vascular anatomy compared with conventional CT viewing, and may help non-radiologists to understand complex patient anatomy.

In this pictorial review we provide an overview of how CR could be used in paediatric musculoskeletal imaging, particularly in complex diagnoses, surgical planning, and patient consent processes. We present a direct comparison of VR and CR reconstructions across a range of congenital and acquired musculoskeletal pathologies, highlighting potential advantages and areas for further research.

Cinematic Rendering of Paediatric Musculoskeletal Pathologies: Initial Experiences with CT

ABBREVIATIONS

2-D	Two Dimensional
3-D	Three Dimensional
BKA	Below Knee Amputation
CR	Cinematic Rendering
CT	Computed Tomography
DDH	Developmental Dysplasia of the Hip
FDA	Food and Drug Administration
FNA	Femoral neck anteversion
MDT	Multi-Disciplinary Team
MIP	Maximum Intensity Projection
MRI	Magnetic Resonance Imaging
SUFE	Slipped Upper Femoral Epiphysis
VR	Volumetric Rendering

MANUSCRIPT

Introduction

Three dimensional (3-D) imaging modalities for musculoskeletal diseases provide many advantages over routine two dimensional (2-D) planar radiographic imaging, as they involve the manipulation, rotation and post-processing of volumetric datasets to produce a variety of imaging reconstructions, helping better understand anatomical relationships of different structures. The most commonly used post-processing tool for creating 3-D reconstructions is the 'volume-rendering' technique (VR). In recent years, a newer rendering technique has been developed and termed "cinematic rendering" (CR) (*Syngo.via, Siemens Healthineers, Forcheim, Germany*)[1]. This has been shown to provide a more 'photorealistic' imaging reconstruction by using a light modelling algorithm which incorporates information from various light paths and predicted patterns of photon scattering [2].

Several recent publications have demonstrated the superior 'expressiveness' and 'realism' of CR over VR techniques for adult musculoskeletal [3,4] and cardiovascular diseases [5,6], and has even been demonstrated to reduce 'time to comprehension of surgical anatomy' amongst general surgeons (56.6 seconds for CR vs 75.0 seconds in conventional CT imaging) [7]. Despite CR having passed the Food and Drug Administration (FDA) approval for clinical usage [8], applications in children's imaging have not yet been explored, possibly due to the lack of availability and awareness of CR, and relatively less CT use in general paediatric radiology. Prior work by Dappa et al[2] comparing VR and CR in adult body imaging did not find any major differences in the diagnostic value (for radiologists) between the two techniques, however they did report that the perception of depth and soft tissue structures was more realistic using CR. This benefit could potentially be helpful in certain situations where there is complex anatomy and need for careful pre-surgical planning. It is therefore important that 'use-cases' and examples are demonstrated and presented to stimulate discussion and research for it's usage in paediatric radiology.

In this pictorial review, we present a variety of common and unusual developmental musculoskeletal pathologies in children. We demonstrate examples of both the VR and CR reconstructions, and invite readers to decide for themselves whether these differences would convey an added benefit for their clinical practice or for educational purposes.

How does cinematic rendering work?

CR and VR are computerized reconstruction techniques for conventional volume acquired datasets. CR and VR both involve the mapping of acquired voxel densities into a display colour. Conventional VR uses weighted sums of percentages tissue type across a volume to determine colour and transparency of each voxel, and simulated light rays to create a projection volume to modulate colour [9].

CR uses of a Monte Carlo path tracing method to simulate how photons have passed through the imaged tissue from all directions [2,10]. As there are theoretically an infinite number of directions from which a photon could travel, the Monte Carlo simulation generates a random number of light paths, which are averaged over time to create an image, approximating photon travel from all directions. This complex interaction of light rays better imitates how we visualise objects in real-life, resulting in the so-called 'photorealistic' image. The path tracing method also takes into account any overlying structures, generating shadows to help improve depth perception of the final digital 3-D model [2,10].

In order to derive the most realistic 3-D images, the CR technique is best reserved for imaging datasets that show a high contrast difference between tissue types, for example bony structures or vascular structure following IV contrast (compared to the background soft tissue density) on CT [2]. Although CR can be also applied to isovolumetric MRI datasets, much of the current evidence for its use comes from CT, the focus of this review.

Paediatric Musculoskeletal Use-Cases

In the paediatric population only small case series assessing cardiac anomalies [11,12] and case reports for post-mortem fetal [13] and intra-uterine imaging [14] have been published. Musculoskeletal anomalies are well suited for CR reconstruction, given the marked differences in tissue densities between bone and soft tissue [15]. Despite concerns regarding radiation dosage, a variety of childhood complex musculoskeletal pathologies are still best imaged by CT. High quality 3-D rendered models demonstrating the spatial relationship of osseous and soft tissue abnormalities are particularly important for congenital, infectious, neoplastic and traumatic changes in complex anatomical regions [16,17], examples of which are provided here.

Congenital Developmental Anomalies

Congenital (developmental) musculoskeletal anomalies cover a diverse range of pathologies, and may affect a single location (i.e. a single ray or limb) or multiple bones in the form of a skeletal dysplasia. Not all anomalies may be identified at birth, with some presenting later in childhood typically after minimal trauma or after investigation for an unrelated disease. Plain radiography is typically the first line tool, however where the anatomy is complex, or where surgery is being considered, CT imaging may be performed.

Tarsal Coalition

CT is often used to assess tarsal coalition in children; to identify whether the coalition is osseous or non-osseous, detect associated degenerative changes, and also the extent of the involved facets in a subtalar coalition [18]. The CR technique could be used to provide improved visualisation of the underlying anatomy, which is known to play a part in surgical planning and prognosis of patient outcomes [19] (**Figure 1**). Surgical intervention typically involves resection of the coalition before the onset of degenerative changes. Although radiologists may be comfortable reviewing multiplanar images, the photorealistic CR reconstructions could help better demonstrate presence of osteophytes and tarsal malalignment for non-radiologists, and in some rare cases, identify more than one tarsal coalition. Post-surgical imaging with CR reconstructions may potentially better highlight complications such as incomplete coalition resection[20].

Developmental Dysplasia of the Hip (DDH)

CT has a role in confirming successful hip reduction after closed reduction and spica casting (**Figure 2**), and in the evaluation of surgical outcomes (**Figure 3**). Where repeated surgeries are required, having a realistic 3-D CR model may be helpful for explaining to parents and the child how their pelvis and hips appear (compared to normal examples), and provide a better understanding of what type of surgery is planned. Although studies have yet to compare patient and parental experiences between CR and VR models; it is known that having unique and customised three-dimensional models do help to contribute to a patient's understanding of their own disease, potentially improving adherence to treatment plans[21].

Skeletal Dysplasias

Cinematic rendering from post-mortem CT has been used to demonstrate lethal skeletal dysplasias (thanatophoric dysplasia and osteogenesis imperfecta), for both medical education and future pregnancy counselling [13], but could be used to better demonstrate skeletal appearances of other dysplasias particularly given that many have ongoing multisystemic complications, and many require orthopaedic procedures to improve their activities of daily living.

CT may be performed for pre-surgical planning for orthopaedic procedures, or reasons unrelated to the musculoskeletal system, where CR may be opportunistically performed. This could apply to a multitude of different pathologies such as mucopolysaccharidoses (**Figure 4**) or those that affect the spine (**Figure 5**) and cause limb length discrepancy and arrested growth. In the adult literature, CR has been useful in depicting complex maxillofacial anatomy in a case of fibrous dysplasia [22]. It is possible that CR could be useful for similar such cases in the paediatric population particularly for patient understanding and education.

Traumatic Injuries

Patterns of injury sustained through major trauma differ in children compared to adults and national guidelines recommend targeted CT imaging depending on the nature of the injury (for both major trauma [23] and suspected physical abuse [24]). CR could be helpful in demonstrating complex fractures and differentiating these from normal anatomical variants.

This is particularly helpful for skull fractures, where differentiating normal suture lines from complex fractures can be difficult. Volume rendering has previously been shown to be superior to conventional 2-D CT viewing in the detection of linear skull fractures in a paediatric population [25] and CR could help improve upon the VR images (**Figure 6**).

In the absence of a plausible mechanism of injury, rib fractures are highly specific for underlying suspected physical abuse [26]. Studies have shown that CT imaging is more sensitive in the detection of rib fractures (over plain radiography) [27,28], and CR reconstructions could provide a more 'sanitised' and understandable model showing the patterns of injury during medicolegal proceedings for members of a lay jury (**Figure 7**). This has been supported by work from the adult literature where CR was found to be superior to VR in terms of 'expressiveness' of traumatic injury patterns on post-mortem CT, and suitable for judicial review, as assessed by forensic pathologists [29].

Certain appendicular fractures in children may warrant CT imaging over plain radiography, particularly where injury patterns are complex (e.g. comminuted ankle fractures [30,31] (**Figure 8**)) or in the assessment of post-traumatic complications. CR has previously been reported to be of particular help in adult musculoskeletal imaging for the identification of small fracture fragments, and in the detection of vascular injuries [4]. In a separate study assessing use of CR in ankle sprains [3], there was a significantly higher preference for the CR (over VR) reconstructions amongst radiologists and orthopaedic surgeons in the visualisation of accessory ossicles and fractures. This is of particular relevance in the paediatric population where normal anatomical variants may be more commonly seen and mistaken for injuries.

In addition to musculoskeletal pathology, CR has been shown to provide improved visualisation of underlying vascular anatomy (over 2-D CT images) for undergraduate medical education [32] and several studies have published examples of CR use in depicting cerebrovascular [33], mesenteric [34] and aortic vascular pathology [35]. In relation to trauma, we have found that traumatic pseudoaneurysms can be well depicted in relation to surrounding bony anatomy (**Figure 9**) and may help in explaining treatment plans during patient consent for interventional procedures.

Finally, CR reconstructions have been used by radiologists to accurately identify skin lacerations in stab injuries and gunshot wound entry points, given that it can accentuate the appearances of raised and depressed areas[36] (**Figure 10**). This can be achieved by using specific presets available within the Syngo.via software (Siemens Healthineers, Forcheim, Germany) to give optimal setting for demonstrating skin, subcutaneous tissue and muscles. Understanding the trajectory and nature of the penetrating trauma could potentially help radiologists better identify associated injuries [37]. Where medicolegal proceedings occur, the CR reconstructions again could provide sanitised images for a jury.

Infection

CT imaging can be used in the assessment of skeletal abnormalities arising from the sequelae of infection (e.g. growth disturbances, joint destruction, pathological fractures). In the adult literature CR has been used to better demonstrate lytic lesions of the skull in the setting of syphilitic osteomyelitis [38]. In children, some of the most challenging post-infective osseous complications can be seen following meningococcal sepsis (**Figure 11**) [39]. These typically arise secondary to physeal growth arrest in the limbs, sometimes presenting several years after the acute illness [40]. In these cases, CT is commonly performed for pre-surgical planning [41]. CR reconstruction may help to inform the surgical approach and provide more realistic images for discussion at multidisciplinary team (MDT) meetings, where non-radiologists and allied health professionals may find them easier to comprehend.

Osseous Tumours

Typically, a combination of CT and MRI are used in the workup both malignant and benign paediatric bone tumours. When assessing an exophytic tumour such as an osteochondroma, CR can be particularly useful to demonstrate the location and appearances of the lesion, as well as the relationship to adjacent anatomical structures (**Figure 12**). More aggressive lesions can also be assessed for associated destructive changes to the surrounding bone and soft tissue (**Figure 13**).

In the adult literature, CR has been used to provide realistic 3-D reconstructions for the assessment of other tumours (e.g. pelvic tumours [42] and chest wall tumours [43]), although it is yet unclear whether their use has helped to improve patient outcomes in the same way that has been reported when using 3-D printed models. For example, when 3-D printed models of osteosarcomas in adolescents were used, it was found that there was a reduction in volume of blood loss, operative time and intra-operative radiation dose [44] during surgery. It is plausible that CR could provide a similar benefit as 3-D printed models, with faster post-processing model reconstruction times and at a lower cost (than 3-D printing) – although this remains to be evaluated in larger comparative trials.

Potential Pitfalls

Despite the improved aesthetic appearances of the CR there are clear potential drawbacks in relying on this technique alone, some of which are similar to the VR technique. These include the potential to 'mask' important findings, either by incorrect windowing or the superimposition of overlying structures [5,33]. Furthermore, where the pathology is subtle or injuries (e.g. fractures) are present without significant displacement or angulation, they may be easily overlooked and 'smoothened out' by the reconstruction algorithm [29]. As such, any 3-D reconstruction (CR and VR) should thus always be reviewed with the original source material (e.g. axial CT slices)[33], as is conventional radiology practice. Care should also be taken in these circumstances to determine whether the three-dimensional model should be shown at all, as it could provide false reassurance if the findings are too subtle to demonstrate.

As with all post-processing software, the quality of the CR reconstruction also depends on the original CT image quality. Image reconstructions require thin, isovolumetric slices in order to create accurate, non-pixelated and aesthetically pleasing 3-D models. This can result in a longer post-processing times and the higher computational demand is one main drawbacks of CR (compared to VR). Real-time display of a rotating CR image is at present limited by the need for repetitive recalculation of complex light paths, which can take the reconstruction software anywhere from 5 – 30 seconds per rotation. Whilst it may only take 5 minutes in total per patient to prepare these images, it does limit 'on-the-go' reconstructions within a MDT setting and requires additional preparation time by the radiologist over VR.

Conclusion

In conclusion, cinematic rendering may provide useful 3-D reconstructions for a broad range of paediatric musculoskeletal pathologies, and could complement or replace other useful but more costly visualization techniques such as 3-D printing and augmented/virtual reality. Potential benefits of improved visualization for the patient includes better understanding of complex anatomy and proposed surgical therapies, and for the clinician, to help surgical planning and improved patient communication around consent including communication in a multidisciplinary team setting. Whilst the diagnostic value offered by CR may not necessarily be superior to those of VR for the radiologist in many cases, better anatomical understanding and visualisation could translate into improved patient outcomes (e.g. by adherence to a treatment plan by the patient, or better comprehension of the images by surgeons leading to better operative decision-making). The translation from improved image reconstruction with CR into better patient care is yet to be evaluated, however in the current absence of available use-cases within the literature, this article has shown a variety of possibilities that could be further explored for future paediatric radiology research.

FIGURE LEGENDS

Figure 1:

A 9-year-old boy with talocalcaneal coalition of the right foot. (a) VR and (b) CR reconstruction lateral views, generated from the child's presenting CT. There is osseous bridging between the middle facet of the calcaneus and the inferomedial talus, with an associated irregular appearance to the articular surfaces (arrows). The pathology is well demonstrated by both rendering techniques, but a more photorealistic version is provided by CR.

Figure 2:

A 10-month-old girl with developmental dysplasia of the left hip. Previously treated with operative open reduction of the dislocated left hip, and placed in a spica. A CT pelvis was performed to confirm femoral head relocation and plan for further surgery. (a) VR and (b) CR reconstruction of the pelvis shows that both femoral heads are enlocated, however the left capital femoral epiphysis (arrow) is significantly smaller than the right, and the left acetabular roof (dashed arrow) remains shallow. The patient subsequently underwent a left innominate osteotomy and femoral derotational osteotomy. The CR image provides a more visually appealing example of the bony anatomy for potential clinician and parental discussions in clinic. This can help aid understanding and be used in the pre-surgical consenting process.

Figure 3:

A 7-year-old girl with previous reconstructive surgery for right sided developmental dysplasia of the hip. (a) Plain radiography of the pelvis demonstrates remodelling of the right ilium (arrow) with lateral uncovering of the right proximal femoral epiphysis (dashed arrow). (b) VR and (c) CR reconstruction of a CT pelvis performed at follow-up shows how the right femoral head is mildly subluxed with lateral uncovering. The right femoral head is incompletely reconstructed on VR, whereas it is better presented with CR. This three-dimensional model may enable the patient to better understand why they experience hip pain with certain movements and can help in discussions with the orthopaedic surgeons and physiotherapists regarding what procedures or exercises may help in the patient’s longer term rehabilitation.

Figure 4:

A 12-year-old boy with Morquio syndrome. A CT thorax was performed for breathing and suspected airway difficulties, however (a, b, c) VR and (d, e, f) CR reconstruction of the rib cage (a, d) and spine (b, c, e, f) demonstrate many of the characteristic musculoskeletal features of the underlying mucopolysaccharidosis. (a, b) The views of the rib cage demonstrate irregular proximal humeral metaphyses (solid arrow) and widened ‘oar-like’ rib appearances (dashed arrows). (b, e) The lateral views of the spine demonstrate widespread platyspondyly with anterior beaking of the thoracolumbar vertebral bodies (arrows) and (c, f) mid-thoracic scoliosis (white brackets). These images would serve as an excellent example in radiology teaching, demonstrating many characteristic appearances of this rare disease entity.

Figure 5:

A 2-year-old girl with Sprengel deformity. A CT thorax was performed to better assess underlying congenital tracheal stenosis, however the musculoskeletal anomalies are well depicted on 3D rendering. (a, b) VR and (c, d) CR reconstructions reveal an elevated right scapula (solid arrow) and omovertebral bar (dashed arrows). Note is also made of a hypoplastic right 4^{th} rib and posterior vertebral segmentation anomalies of the lower cervical and upper thoracic spine. Better ‘photorealism’ and depth perception is offered by the CR reconstructions.

Figure 6:

A post-mortem CT study was performed on a 5-year-old boy following a fall from a height. (a) VR and (b) CR reconstruction of the skull demonstrates numerous fractures, including those of the right frontal bone (black arrow), left parieto-occipital bone (white arrow), right mandible (dashed arrow) as well as bilateral zygomatic fractures. These three-dimensional images are better suited for demonstrating injury patterns to a jury for potential medico-legal proceedings, however care should be also taken to point out other non-displaced fractures where relevant, as these may not always be easily demonstrated on VR or CR.

Figure 7:

A 2-year-old girl with several healing rib fractures admitted with unexplained loss of consciousness. (a) VR and (b) CR reconstructions of the ribcage from a CT thorax demonstrate several left sided rib fractures with callus formation (solid arrows), a right scapula fracture with callus (arrowhead) and a left sided 4^{th} rib fracture without callus formation. Underlying findings raised concerns for suspected physical abuse. The CR image demonstrates the callus formation on the ribs in a more realistic manner than the VR, although the right scapula fracture is better highlighted with the VR.

Figure 8:

An 11-year-old boy with acute ankle trauma after a skiing accident. (a, b) VR and (c, d) CR reconstructions from the CT ankle demonstrate a Salter Harris type 2 injury of the distal tibia with transverse distal metaphyseal impacted tibial fracture (sold arrow). There is also a subtle greenstick fracture of the distal fibula (dashed arrow) which is less apparent on these models, and therefore a potential pitfall if only relying on the CR/VR to detect all injuries. The multiplanar imaging should always be reviewed in addition to the models provided.

Figure 9:

A 4-year-old boy post laceration injury to the leg. (a) Maximum intensity projection (MIP) images of a CT angiogram of the right leg demonstrates two large pseudoaneurysm arising from the anterior tibial artery (arrows). (b) VR and (c) CR reconstructions with soft tissue overlay of the right leg demonstrate the relationship of these pseudoaneurysms to the adjacent tibia and fibula bones. This relationship is better depicted with the CR model, as the muscle, bone and vasculature are well differentiated from each other.

Figure 10:

A post-mortem CT performed on a 2-month-old boy with gunshot wounds to the head. By using different post-processing rendering settings with CR it is possible to reconstruct the (a) surface skin rendering, (b) subcutaneous fat layer, (c) the cartilaginous and internal soft tissue density appearances and (d) only bony densities. Multiple skull fractures and residual shrapnel fragments are demonstrated. Using CR may provide 'sanitised images' for medicolegal proceedings and also prove helpful in reducing metallic artefact from shrapnel, to better demonstrate the fracture fragments.

Figure 11:

A 3-year-old boy with history of meningococcal septicaemia, with resultant bone infarction, fracture and bony non-union. (a, c) VR and (b, d) CR reconstructions of the right forearm were performed after CT for presurgical planning. They are shown in coronal (a,b) and sagittal (c, d) reconstruction planes. There is an angulated distal radial (solid arrow) and distal ulnar (dashed arrow) pseudoarthrosis. No callus formation is present. Both models provide similar detail of the relevant pathologies, however the shading correction of the CR model appears more realistic.

Figure 12:

A 13-year-old girl with hereditary multiple exostoses. CT of the right forearm was performed to guide surgical removal of the exostoses. (a), (b) Frontal and (c), (d) lateral views of the right forearm are demonstrated in both CR (a, c) and VR (b, d). These demonstrate several exostoses at the distal ulna and distal radius (arrows), with distal radial bowing (dashed arrows) and associated radio-capitellar subluxation (arrowhead). Both models provide similar detail of the relevant pathologies, however the shading correction of the CR model appears more realistic.

Figure 13:

A 5-day old female patient with mesenchymal hamartoma of the chest wall (a) The admission chest radiograph demonstrates a left sided chest wall deformity (arrow). (b) VR and (c) CR reconstructions from the subsequent CT thorax better characterise the underlying left sided chest wall mass and rib expansion (arrow), with additional left 12th rib anomaly (dashed arrow). The individual ribs and chest wall lesions are better located with the CR model, given the improved depth perception. This helps define the largest rib lesion as being along the posterior left chest wall, which is less apparent with the VR model example.

REFERENCES

1. Glemser PA, Engel K, Simons D, Steffens J, Schlemmer HP, Orakcioglu B. A New Approach for Photorealistic Visualization of Rendered Computed Tomography Images. *World neurosurgery* 2018; **114**: e283-e92.

2. Dappa E, Higashigaito K, Fornaro J, Leschka S, Wildermuth S, Alkadhi H. Cinematic rendering - an alternative to volume rendering for 3D computed tomography imaging. *Insights into imaging* 2016; **7**(6): 849-56.

3. Berger F, Ebert LC, Kubik-Huch RA, Eid K, Thali MJ, Niemann T. Application of Cinematic Rendering in Clinical Routine CT Examination of Ankle Sprains. *AJR Am J Roentgenol* 2018; **211**(4): 887-90.

4. Wollschlaeger LM, Boos J, Jungbluth P, et al. Is CT-based cinematic rendering superior to volume rendering technique in the preoperative evaluation of multifragmentary intraarticular lower extremity fractures? *Eur J Radiol* 2020; **126**: 108911.

5. Johnson PT, Schneider R, Lugo-Fagundo C, Johnson MB, Fishman EK. MDCT Angiography With 3D Rendering: A Novel Cinematic Rendering Algorithm for Enhanced Anatomic Detail. *AJR Am J Roentgenol* 2017; **209**(2): 309-12.

6. Rowe SP, Johnson PT, Fishman EK. Cinematic rendering of cardiac CT volumetric data: Principles and initial observations. *Journal of cardiovascular computed tomography* 2018; **12**(1): 56-9.

7. Elshafei M, Binder J, Baecker J, et al. Comparison of Cinematic Rendering and Computed Tomography for Speed and Comprehension of Surgical Anatomy. *JAMA surgery* 2019; **154**(8): 738-44.

8. (FDA) UFaDA. US Food and Drug Administration Clearance: syngo.via (Version VB40A). 2019. https://www.accessdata.fda.gov/cdrh_docs/pdf19/K191040.pdf (accessed 15 April 2021.

9. Luccichenti G, Cademartiri F, Pezzella FR, et al. 3D reconstruction techniques made easy: know-how and pictures. *Eur Radiol* 2005; **15**(10): 2146-56.

10. Eid M, De Cecco CN, Nance JW, Jr., et al. Cinematic Rendering in CT: A Novel, Lifelike 3D Visualization Technique. *AJR Am J Roentgenol* 2017; **209**(2): 370-9.

11. Röschl F, Purbojo A, Rüffer A, Cesnjevar R, Dittrich S, Glöckler M. Initial experience with cinematic rendering for the visualization of extracardiac anatomy in complex congenital heart defects†. *Interactive cardiovascular and thoracic surgery* 2019; **28**(6): 916-21.

12. Rowe SP, Zimmerman SL, Johnson PT, Fishman EK. Evaluation of Kawasaki's disease-associated coronary artery aneurysms with 3D CT cinematic rendering. *Emergency radiology* 2018; **25**(4): 449-53.

13. Shelmerdine SC, Sebire NJ, Calder AD, Arthurs OJ. 3D cinematic rendering of fetal skeletal dysplasias using postmortem computed tomography. *Ultrasound Obstet Gynecol* 2020.

14. Rowe SP, Fishman EK. Fetal and placental anatomy visualized with cinematic rendering from volumetric CT data. *Radiology case reports* 2018; **13**(1): 281-3.

15. Rowe SP, Fritz J, Fishman EK. CT evaluation of musculoskeletal trauma: initial experience with cinematic rendering. *Emergency radiology* 2018; **25**(1): 93-101.

16. Balassy C, Miller SF. CT in children's bones and joints: when, how and common findings. *Eur J Radiol* 2013; **82**(7): 1126-34.

17. Fishman EK, Kuszyk B. 3D imaging: musculoskeletal applications. *Critical reviews in diagnostic imaging* 2001; **42**(1): 59-100.

18. Newman JS, Newberg AH. Congenital tarsal coalition: multimodality evaluation with emphasis on CT and MR imaging. *Radiographics : a review publication of the Radiological Society of North America, Inc* 2000; **20**(2): 321-32; quiz 526-7, 32.

19. Bixby SD, Jarrett DY, Johnston P, Mahan ST, Kleinman PK. Posteromedial subtalar coalitions: prevalence and associated morphological alterations of the sustentaculum tali. *Pediatr Radiol* 2016; **46**(8): 1142-9.

20. Kothari A, Masquijo J. Surgical treatment of tarsal coalitions in children and adolescents. *EFORT open reviews* 2020; **5**(2): 80-9.

21. Aimar A, Palermo A, Innocenti B. The Role of 3D Printing in Medical Applications: A State of the Art. *Journal of healthcare engineering* 2019; **2019**: 5340616.

22. Rowe SP, Zinreich SJ, Fishman EK. 3D cinematic rendering of the calvarium, maxillofacial structures, and skull base: preliminary observations. *Br J Radiol* 2018; **91**(1086): 20170826.

23. Radiologists RCo. Paediatric Trauma Protocols: Ref No. BFCR(14)8. 2014. https://www.rcr.ac.uk/system/files/publication/field_publication_files/BFCR%2814%298_paeds_trauma.pdf (accessed 20 April 2021.

24. Radiologists TRCo. Royal College of Radiologists and The Society and College of Radiogaphers. The Radiological Investigation of Suspected Physical Abuse in Children. 2017. https://www.rcr.ac.uk/system/files/publication/field_publication_files/bfcr174_suspected_physical_abuse.pdf (accessed 12th April 2018).

25. Orman G, Wagner MW, Seeburg D, et al. Pediatric skull fracture diagnosis: should 3D CT reconstructions be added as routine imaging? *Journal of neurosurgery Pediatrics* 2015; **16**(4): 426-31.

26. Kemp AM, Dunstan F, Harrison S, et al. Patterns of skeletal fractures in child abuse: systematic review. *BMJ (Clinical research ed)* 2008; **337**: a1518.

27. Shelmerdine SC, Langan D, Hutchinson JC, et al. Chest radiographs versus CT for the detection of rib fractures in children (DRIFT): a diagnostic accuracy observational study. *The Lancet Child & adolescent health* 2018; **2**(11): 802-11.

28. Hong TS, Reyes JA, Moineddin R, Chiasson DA, Berdon WE, Babyn PS. Value of postmortem thoracic CT over radiography in imaging of pediatric rib fractures. *Pediatr Radiol* 2011; **41**(6): 736-48.

29. Böven J, Boos J, Steuwe A, et al. Diagnostic value and forensic relevance of a novel photorealistic 3D reconstruction technique in post-mortem CT. *Br J Radiol* 2020; **93**(1112): 20200204.

30. Eismann EA, Stephan ZA, Mehlman CT, et al. Pediatric Triplane Ankle Fractures: Impact of Radiographs and Computed Tomography on Fracture Classification and Treatment Planning. *J Bone Joint Surg Am* 2015; **97**(12): 995-1002.

31. Leung KH, Fang CX, Lau TW, Leung FK. Preoperative radiography versus computed tomography for surgical planning for ankle fractures. *Journal of orthopaedic surgery (Hong Kong)* 2016; **24**(2): 158-62.

32. Binder JS, Scholz M, Ellmann S, et al. Cinematic Rendering in Anatomy: A Crossover Study Comparing a Novel 3D Reconstruction Technique to Conventional Computed Tomography. *Anatomical sciences education* 2020.

33. Caton MT, Jr., Wiggins WF, Nunez D. Three-Dimensional Cinematic Rendering to Optimize Visualization of Cerebrovascular Anatomy and Disease in CT Angiography. *Journal of neuroimaging : official journal of the American Society of Neuroimaging* 2020; **30**(3): 286-96.

34. de Spiegeleire X, Vanhaebost J, Coche E. Post-mortem CT angiography of mesenteric vessels using cinematic rendering vision. *Diagnostic and interventional imaging* 2019; **100**(9): 533-4.

35. Rowe SP, Chu LC, Zimmerman SL, Fishman EK. 3D CT cinematic rendering of mycotic aneurysms. *Emergency radiology* 2018; **25**(6): 723-8.

36. Chu LC, Rowe SP, Fishman EK. Cinematic rendering of skin and subcutaneous soft tissues: potential applications in acute trauma. *Emergency radiology* 2019; **26**(5): 573-80.

37. Mendoza AE, Wybourn CA, Charles AG, Campbell AR, Cairns BA, Knudson MM. Routine computed tomography after recent operative exploration for penetrating trauma: What injuries do we miss? *The journal of trauma and acute care surgery* 2017; **83**(4): 575-8.

38. Petroulia V, Surial B, Verma RK, Hauser C, Hakim A. Calvarial osteomyelitis in secondary syphilis: evaluation by MRI and CT, including cinematic rendering. *Heliyon* 2020; **6**(1): e03090.

39. Monsell F. The skeletal consequences of meningococcal septicaemia. *Archives of disease in childhood* 2012; **97**(6): 539-44.

40. Ikram A, Singhania K, Tafazal S, Tambe A. Proximal humerus deformity, in a four-limb amputee following meningococcal septicaemia. *BMJ case reports* 2018; **2018**.

41. Elrod J, Mannhard D, Mohr C, et al. Plastic and Orthopaedic Interventions and Long-Term Sequelae in Children with Meningococcal Septicemia-40 Years of Experience at the University Children's Hospital Zurich. *European journal of pediatric surgery : official journal of*

Austrian Association of Pediatric Surgery [et al] = Zeitschrift fur Kinderchirurgie 2019; **29**(5): 462-9.

42. Yang J, Li K, Deng H, et al. CT cinematic rendering for pelvic primary tumor photorealistic visualization. *Quantitative imaging in medicine and surgery* 2018; **8**(8): 804-18.

43. Costa ADS, Jr., Gellada N. Cinematic rendering for three-dimensional reconstructions of the chest wall: a new reality. *Einstein (Sao Paulo, Brazil)* 2020; **18**: eMD5223.

44. Ma L, Zhou Y, Zhu Y, et al. 3D-printed guiding templates for improved osteosarcoma resection. *Scientific reports* 2016; **6**: 23335.

Figure 1

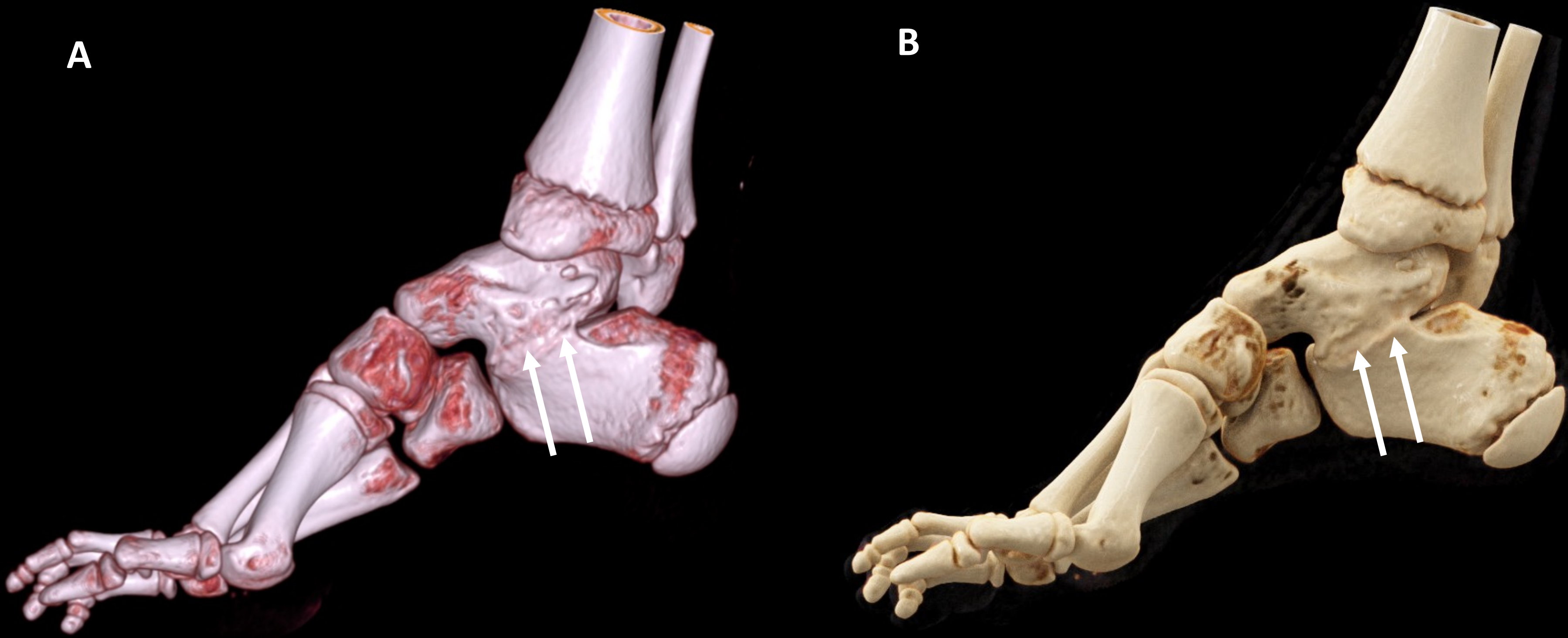

Figure 2

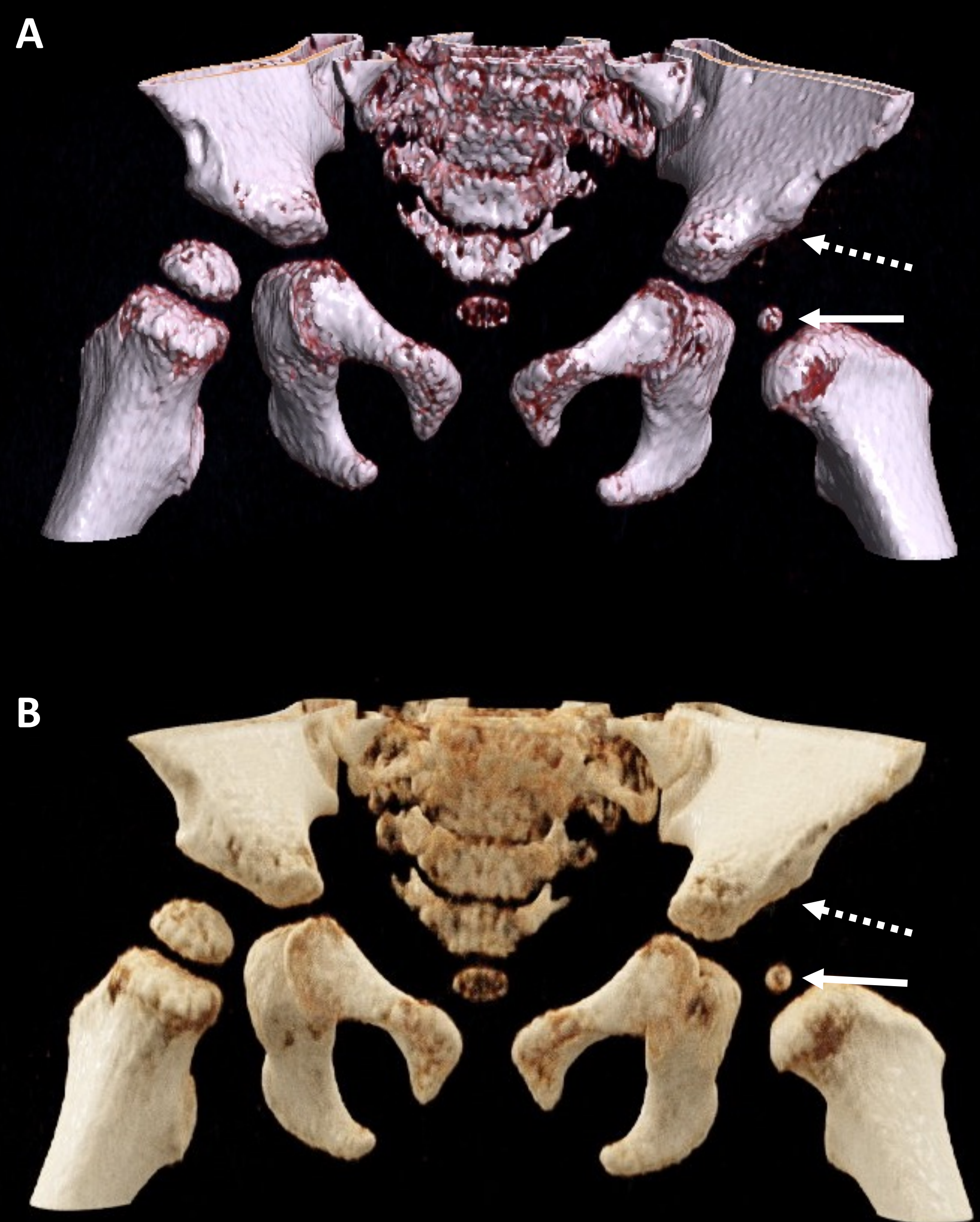

Figure 3

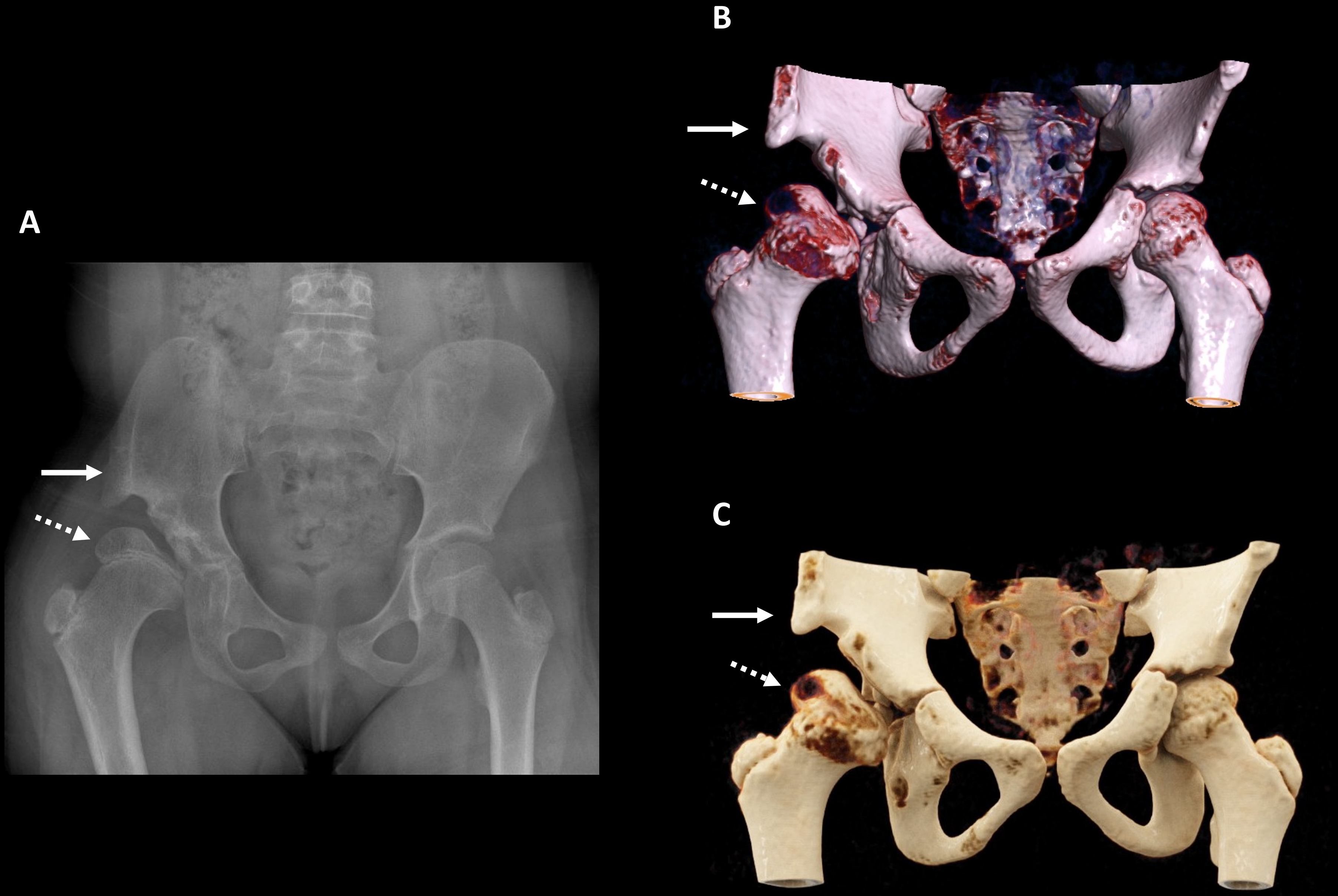

Figure 4

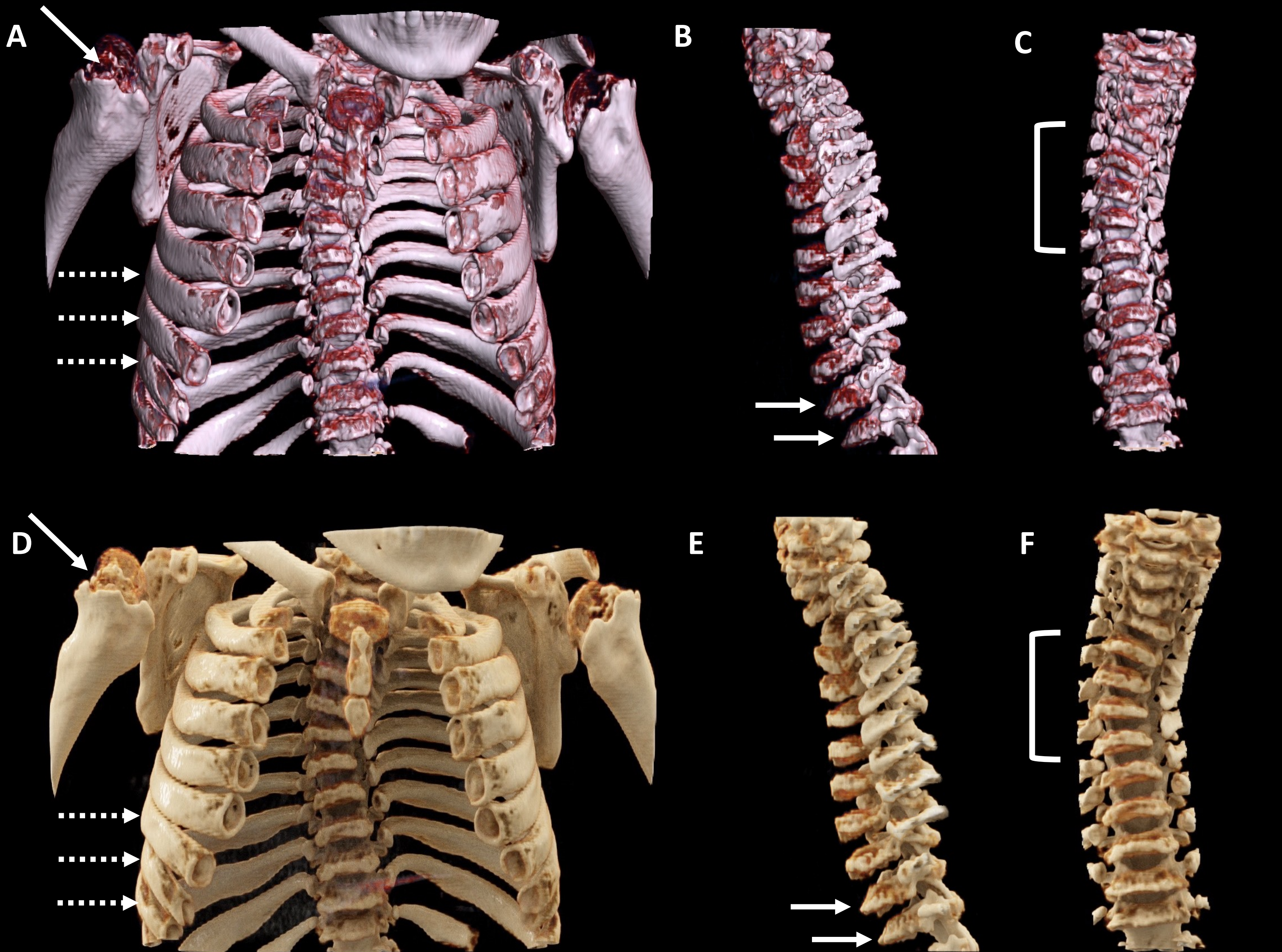

Figure 5

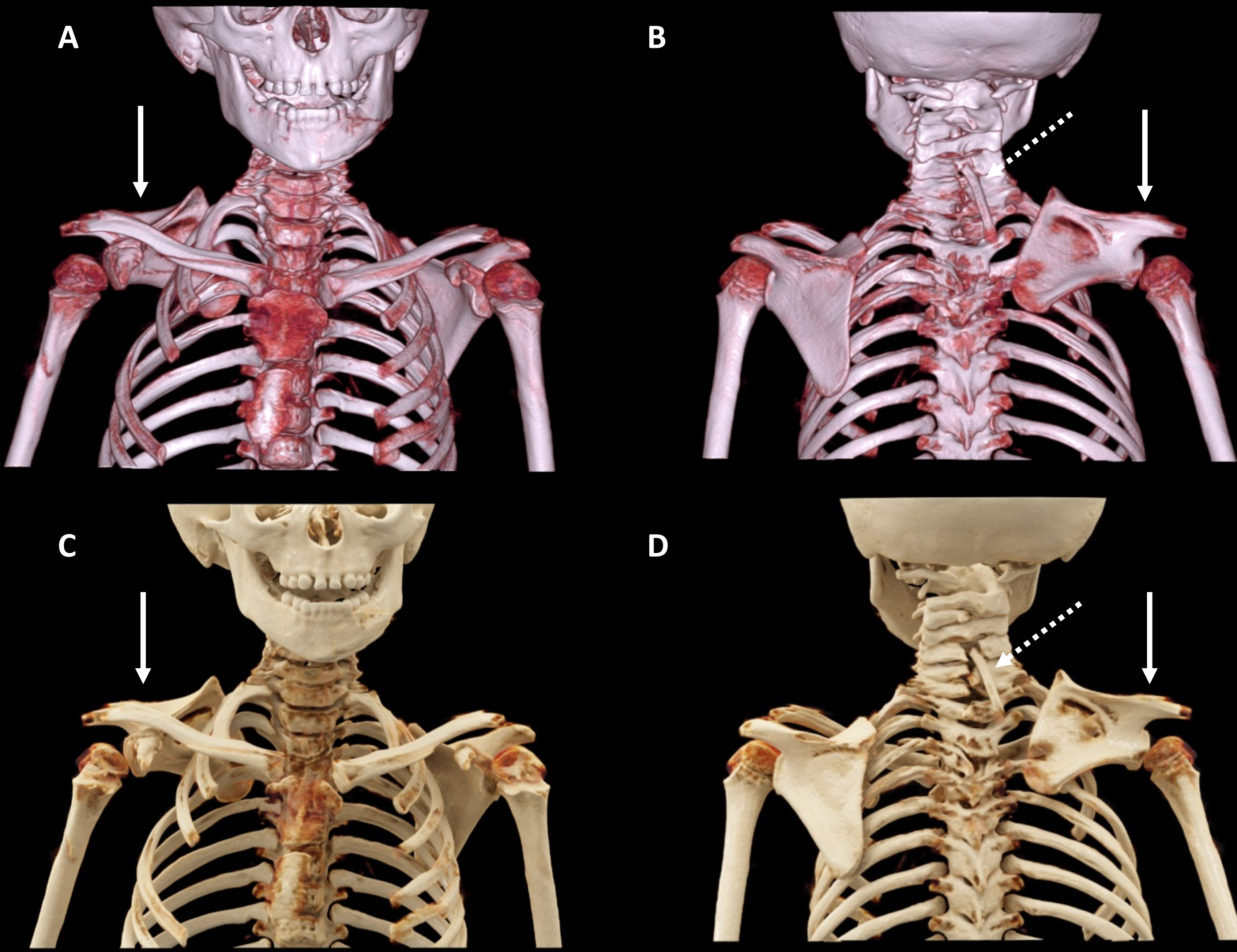

Figure 6

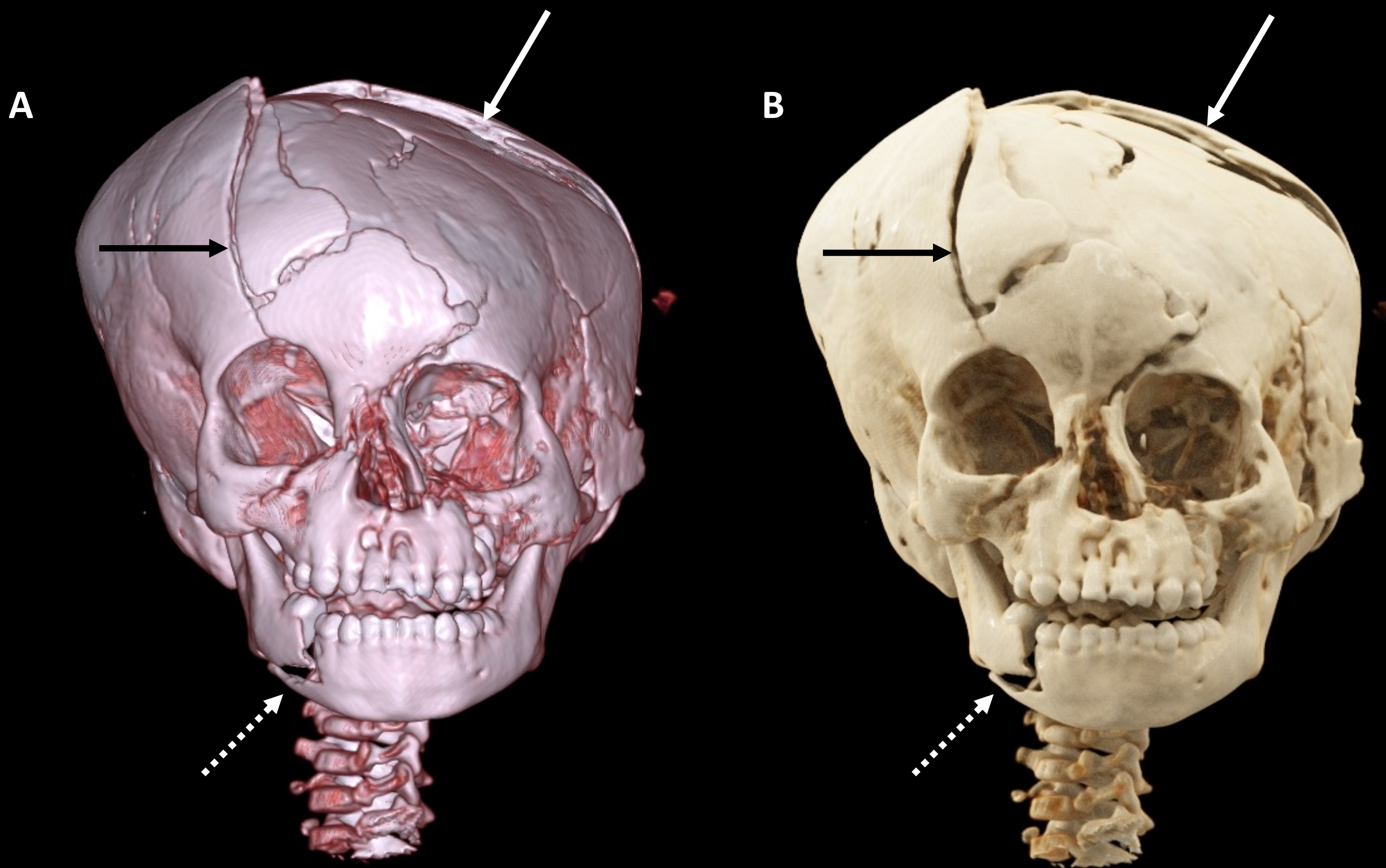

Figure 7

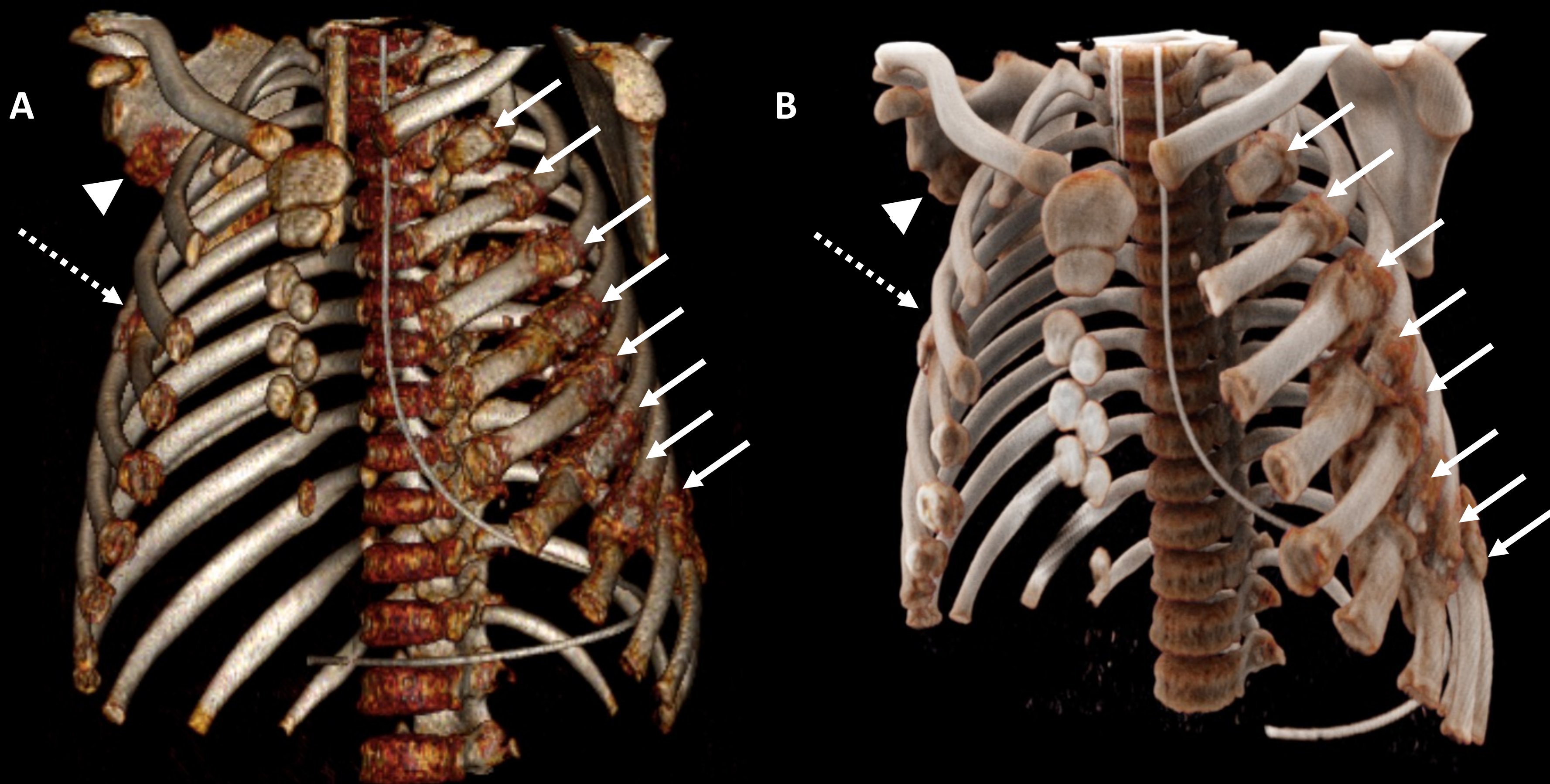

Figure 8

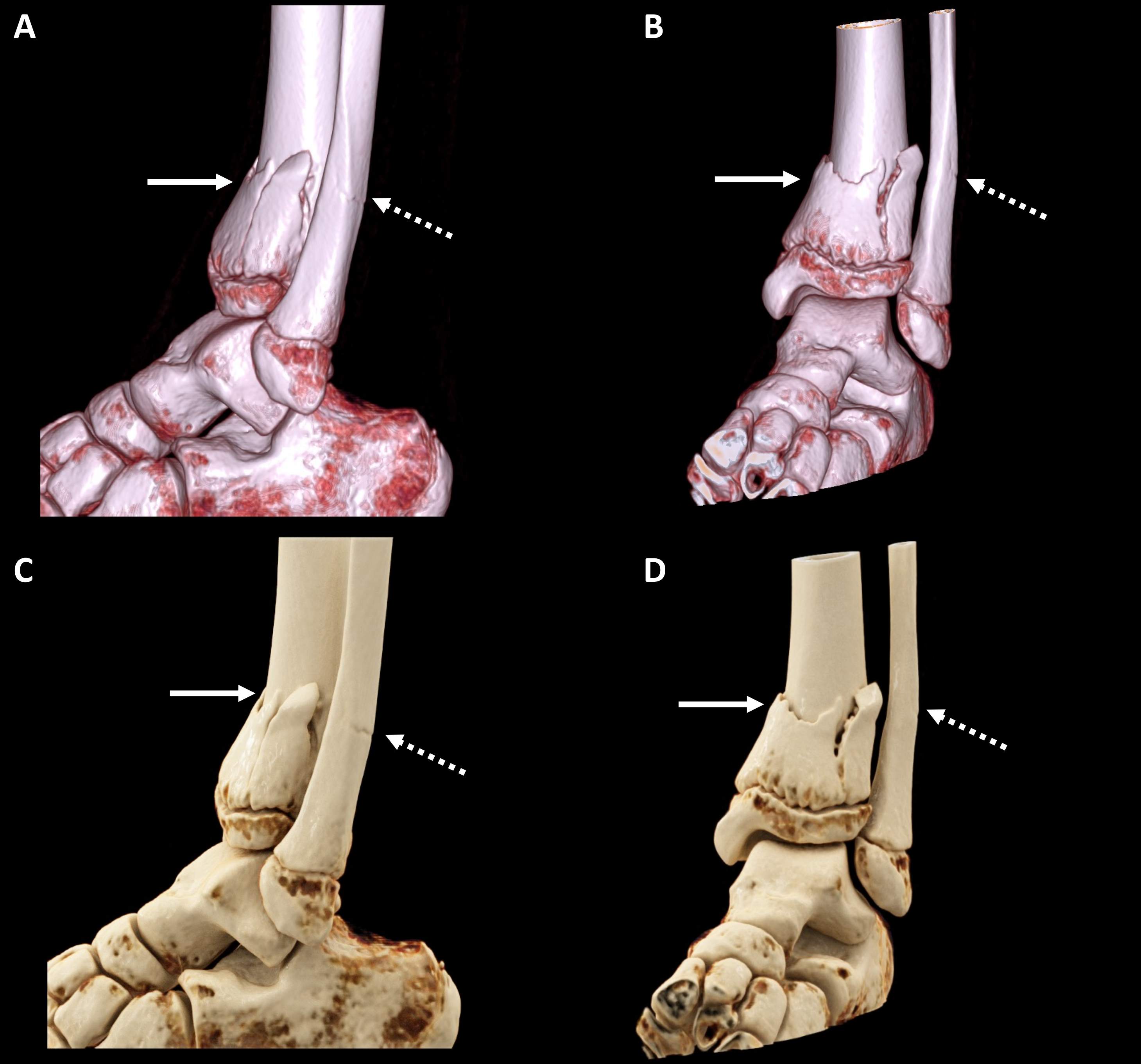

Figure 9

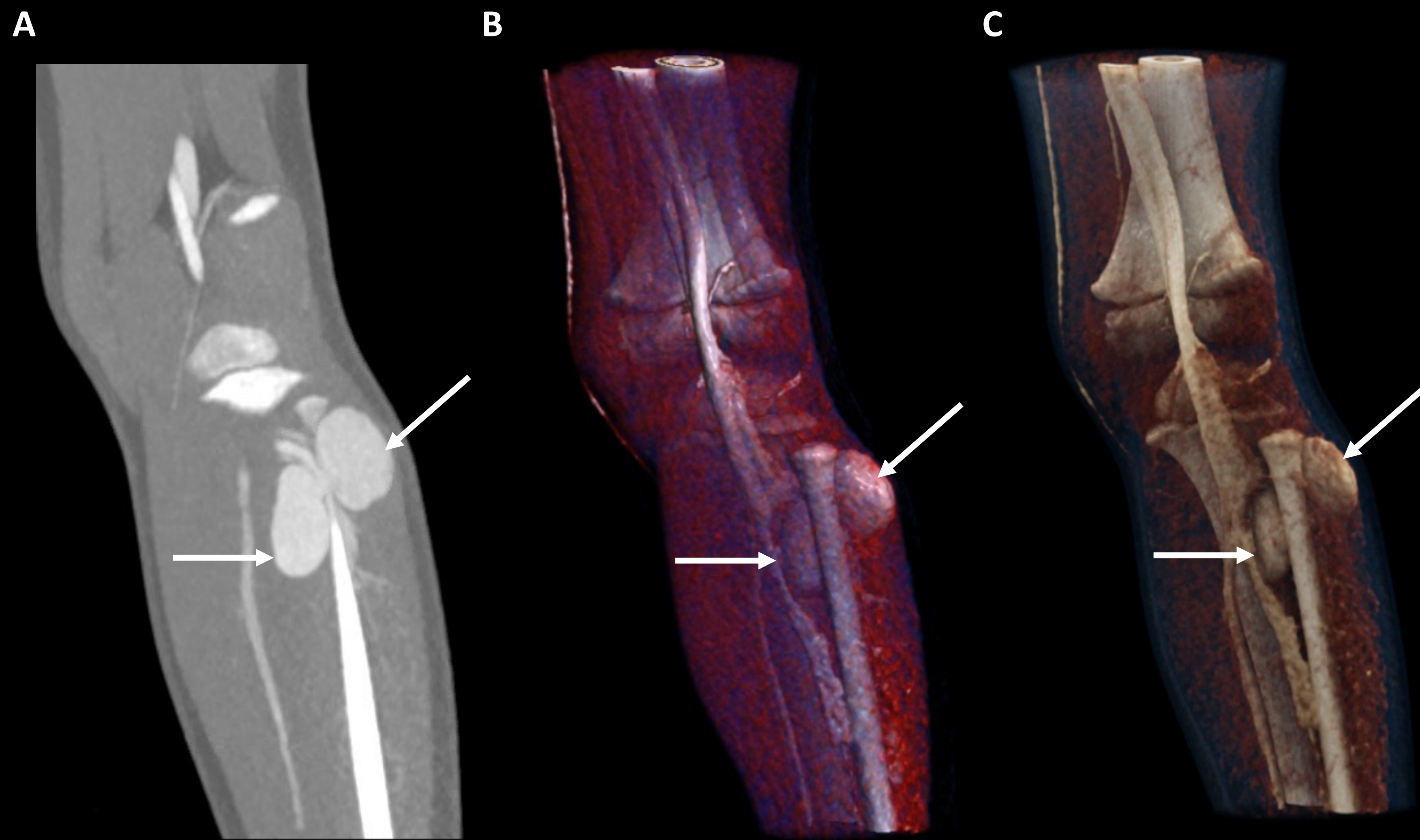

Figure 10

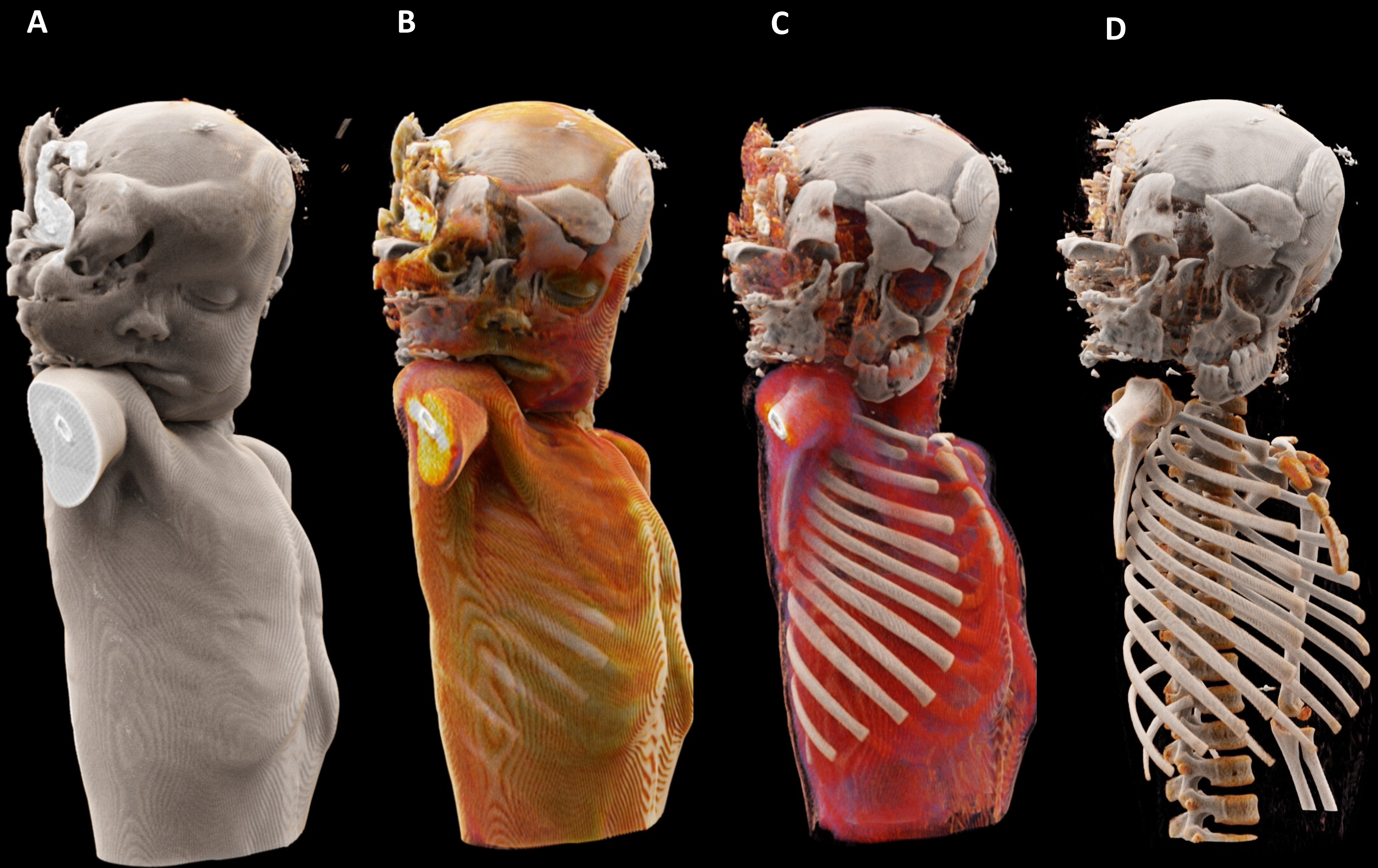

Figure 11

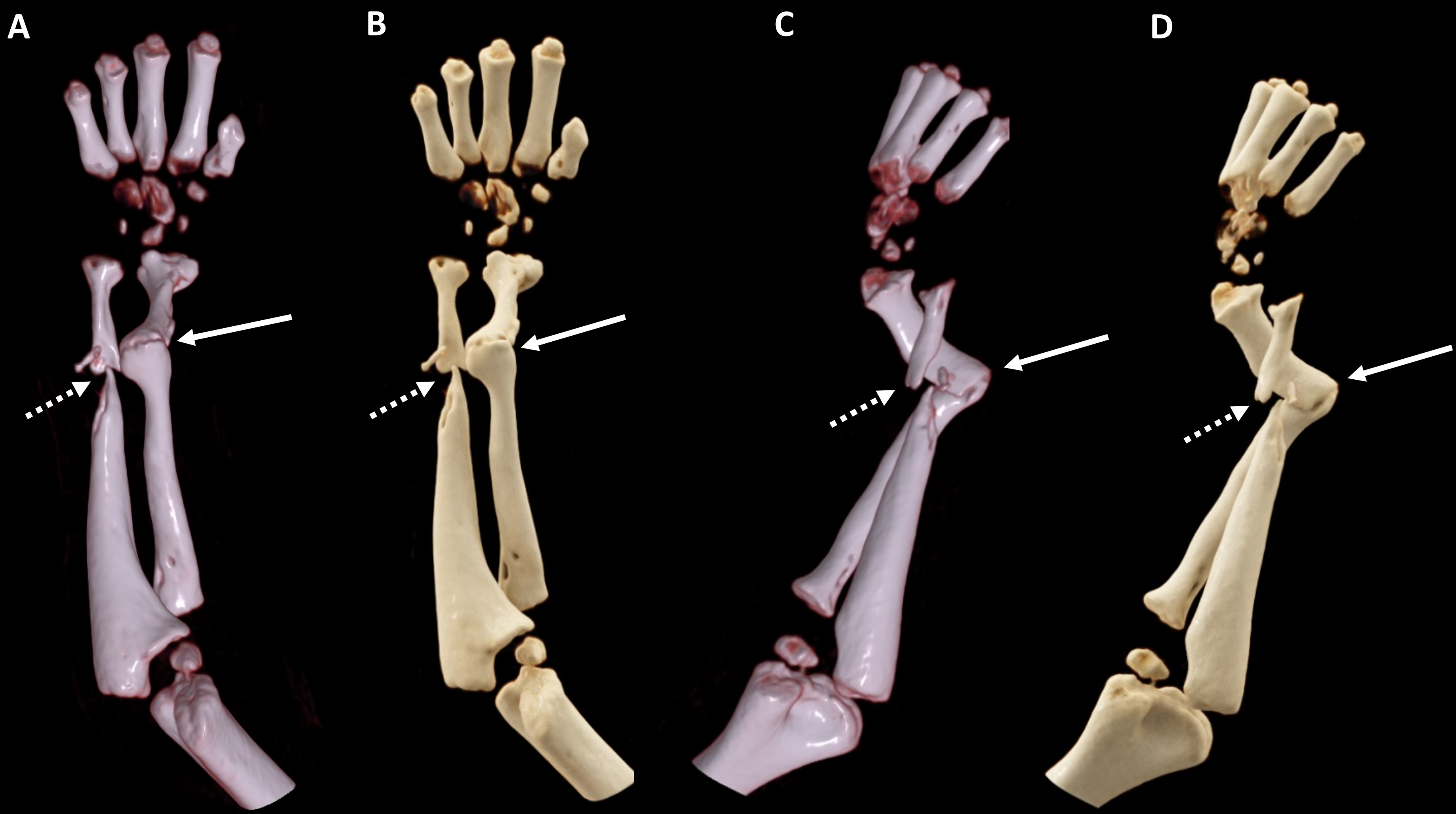

Figure 12

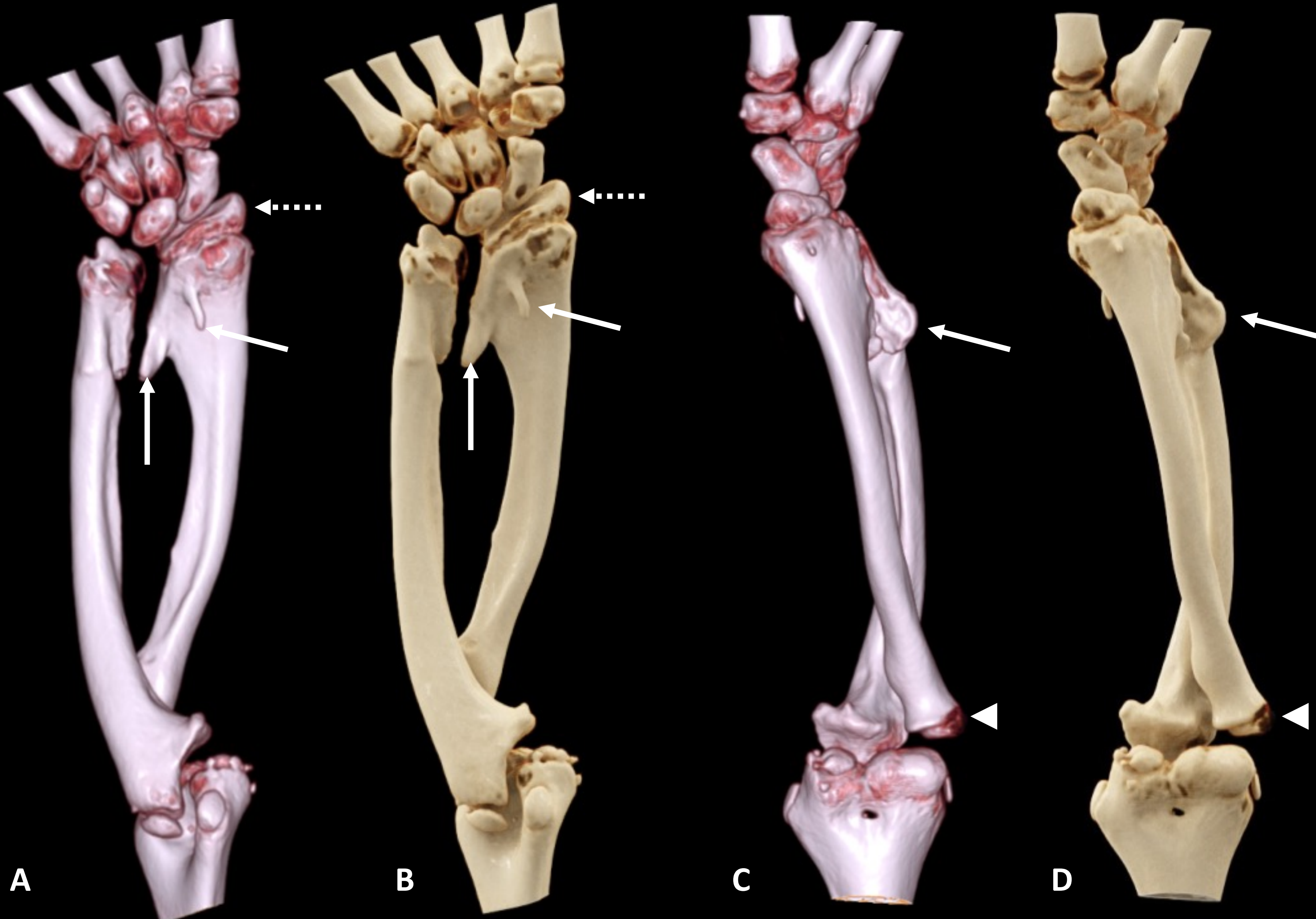

Figure 13