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Article

Photon-Counting Detector CT Scan of Dinosaur Fossils: Initial Experience

Tasuku Wakabayashi ^{1,†}, Kenji Takata ^{1,†}, Soichiro Kawabe ^{2,3}, Masato Shimada ⁴, Takeshi Mugitani ⁴, Takuya Yachida ⁴, Rikiya Maruyama ⁴, Satomi Kanai ¹, Kiyotaka Takeuchi ¹, Tomohiro Kotsuji ¹, Toshiki Tateishi ⁴, Hideki Hyodoh ⁵ and Tetsuya Tsujikawa ^{1,*}

¹ Department of Radiology, Faculty of Medical Sciences, University of Fukui, 23-3 Matsuoka-Shimoaizuki, Eiheiji, Fukui, 910-1193, Japan

² Institute of Dinosaur Research, Fukui Prefectural University, 4-1-1 Matsuoka Kenjojima, Eiheiji, Fukui, 910-1195, Japan

³ Fukui Prefectural Dinosaur Museum, 51-11 Terao, Muroko, Katsuyama, Fukui, 911-8601, Japan

⁴ Radiological center, University of Fukui Hospital, 23-3 Matsuoka-Shimoaizuki, Eiheiji, Fukui, 910-1193, Japan

⁵ Department of Forensic Medicine, Faculty of Medical Sciences, University of Fukui, 23-3 Matsuoka-Shimoaizuki, Eiheiji, Fukui, 910-1193, Japan

* Correspondence: awaji@u-fukui.ac.jp; Tel.: +81-776-61-3111; Fax: +81-776-61-8137

† These authors contributed equally to this work.

Abstract: Background/Objectives: Beyond clinical areas, photon-counting detector (PCD) CT is innovatively applied to study paleontological specimens such as dinosaur fossils. The aim of this study was to compare PCD-CT with conventional energy-integrating detector (EID) CT for dinosaur fossil analysis. **Methods:** The lower jaw of a Tyrannosaurus and the head of a Camarasaurus were imaged using a PCD-CT in ultra high-resolution mode and an EID-CT. The PCD-CT and EID-CT image quality of the dinosaurs were visually assessed. **Results:** Compared with EID-CT, PCD-CT yielded higher-resolution anatomical images free of image deterioration; achieving better definition of the Tyrannosaurus mandibular canal and the three semicircular canals of a Camarasaurus. **Conclusions:** PCD-CT clearly depicts the internal structure and morphology of dinosaur fossils without damaging them and also provides spectral information allowing researchers to gain insights into fossil mineral composition and preservation state in the future.

Keywords: PCT-CT; paleontology; dinosaur fossil

1. Introduction

Photon-counting detector (PCD) computed tomography (CT) is a next-generation imaging technology measuring X-ray photon energy levels that are converted into an electrical signal [1,2]. PCD-CT has many advantages over conventional energy-integrating detector CT (EID-CT) such as high spatial resolution, low electronic noise, improved contrast-to-noise ratio, and spectral information acquisition. There are many clinical applications of PCD-CT, from detection of minute calcifications in cardiovascular disease to precise cancer tumor mapping [3].

Beyond clinical areas, CT is innovatively applied to study paleontological specimens such as dinosaur fossils [4,5]. This non-destructive imaging technique enables internal fossil examination without requiring physical sectioning, preserving the integrity of these invaluable specimens. By leveraging PCD-CT's high-resolution capabilities, researchers will gain insights into the internal morphology and pathology of fossils, shedding light on the life and environment of ancient organisms.

This paper reports our initial experience using PCD-CT in ultra high-resolution (UHR) mode for dinosaur fossil imaging, highlighting the synergistic benefits of this technology for both medical and paleontological research. Through an interdisciplinary approach, we illustrate PCD-CT's potential for new discoveries in the field of paleontology.

2. Materials and Methods

2.1. Dinosaur Fossils

This study was approved by the Ethics Committee of the University of Fukui, Faculty of Medical Sciences (study protocol # 20220056, 29 June 2023). Two dinosaur fossils (the lower jaw of a Tyrannosaurus and the head of a Camarasaurus), stored in Fukui Prefectural Dinosaur Museum (Katsuyama City, Fukui, Japan) were carefully transported to University of Fukui Hospital.

The carnivorous Tyrannosaurus rex, often referred to as T. rex, lived during the late Cretaceous period, around 68 to 66 million years ago [6,7]. It is one of the most well-known dinosaurs, recognized for its large size and fearsome appearance. Adult T. rex specimens are recorded at lengths up to 40 feet (12 meters) and weighing up to 9 tons. The T. rex had a massive body, strong legs, and powerful jaws with sharp teeth. Studies of T. rex's teeth and jaws suggest that it possessed a crushing bite force that indicates a diet likely including both flesh and bone. Paleontologists believe it was an apex predator, preying upon herbivorous dinosaurs and scavenging as well.

The Camarasaurus, often referred to as the 'chambered lizard', is a sauropod (long-necked) dinosaur that lived during the Late Jurassic period, around 155 to 145 million years ago [8,9]. This dinosaur is recognized for its large size and is the most common North American sauropod fossil. Adult Camarasaurus specimens are recorded at lengths up to 50 feet (15 meters) with estimated weights up to 20 tons. The Camarasaurus had a robust build, with a distinctive small, square head balanced by a long, heavy tail. Paleontologists believe that it fed on plant material by the shape and wear patterns of its teeth.

2.2. CT Systems

The first clinical PCD-CT system (NAEOTOM Alpha, Siemens Healthineers) with a large 82 cm aperture uses a dual-source geometry and 0.25-second gantry rotation time to provide 66-msec temporal resolution (isocenter) [10–12]. The two detector arrays consist of dedicated PCDs with 1.6 mm thick CdTe and have 50-cm and 36-cm scanning field of views, respectively. The detector pixel layout shows 0.151×0.176 mm² subpixels (measured at isocenter). Due to the presence of collimator blades every 6 subpixels in the z-direction, the minimum effective section thickness is 0.2 mm in UHR mode and 0.4 mm in standard mode. The UHR mode features 120 detector rows (120×0.2 mm collimation) while the standard mode features 144 detector rows (144×0.4 mm collimation).

The Aquilion Lightning Helios i Edition, developed by Canon Medical Systems, is an 80-slice/160-slice EID-CT scanner with a 78 cm aperture and enables a high-speed helical scan of 0.5 mm \times 80 slices.

3. Results

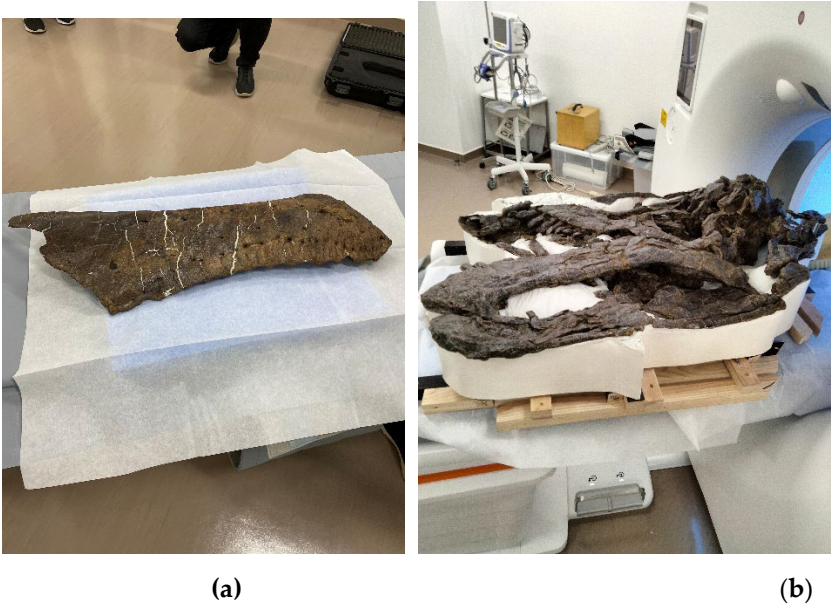
Imaging parameters for PCD-CT and EID-CT are listed in Table 1. The large 82 cm gantry bore of the PCD-CT was large enough to photograph part of the lower jaw bone of a Tyrannosaurus and the entire head of a Camarasaurus (Figure. 1A,B, respectively). Figure 1C shows a 3D image of the entire Camarasaurus head taken using PCD-CT.

Figure 2A,B show the sagittal sections of the Tyrannosaurus lower jawbone imaged with PCD-CT and EID-CT, respectively. Compared with EID-CT, PCD-CT more clearly depicts the cross-sectional patterns and the mandibular canal including a hyper-dense structure.

Figure 3A,B show the cross-sections of the Camarasaurus temporal bone imaged with PCD-CT and EID-CT, respectively. Compared with EID-CT, PCD-CT more clearly depicts the selected section of the semicircular canals.

Table 1. Experimental Details for dinosaur CT scans.

Parameters	T. rex		Camarasaurus	
	PCD CT	EID CT	PCD CT	EID CT
Slice thickness (mm)	0.2	0.5	0.2	0.5
Slice interval (mm)	0.15	0.3	0.15	0.3
Rows	120	80	120	80
Rotation time (sec)	1	0.75	1	1
Helical pitch	0.8	0.813	0.8	0.813
kVp setting	140	120	140	120
CTDI vol (mGy)	9.06	6.3	36.4	19.4
DLP (mGy/cm)	851	624.9	4509	2461.9
Focus size	S	L	S	L
Output image	70 keV	120 kVp	70 keV	120 kVp
Matrix size	1024 x 1024	512 x 512	1024 x 1024	512 x 512
FOV (mm)	320	320	500	500



(c)

Figure 1. A part of the lower jawbone fossil of a Tyrannosaurus (a) and the entire head fossil of a Camarasaurus (b) placed on the PCD-CT bed, a 3D image of the entire head fossil of a Camarasaurus taken with PCD-CT (c).

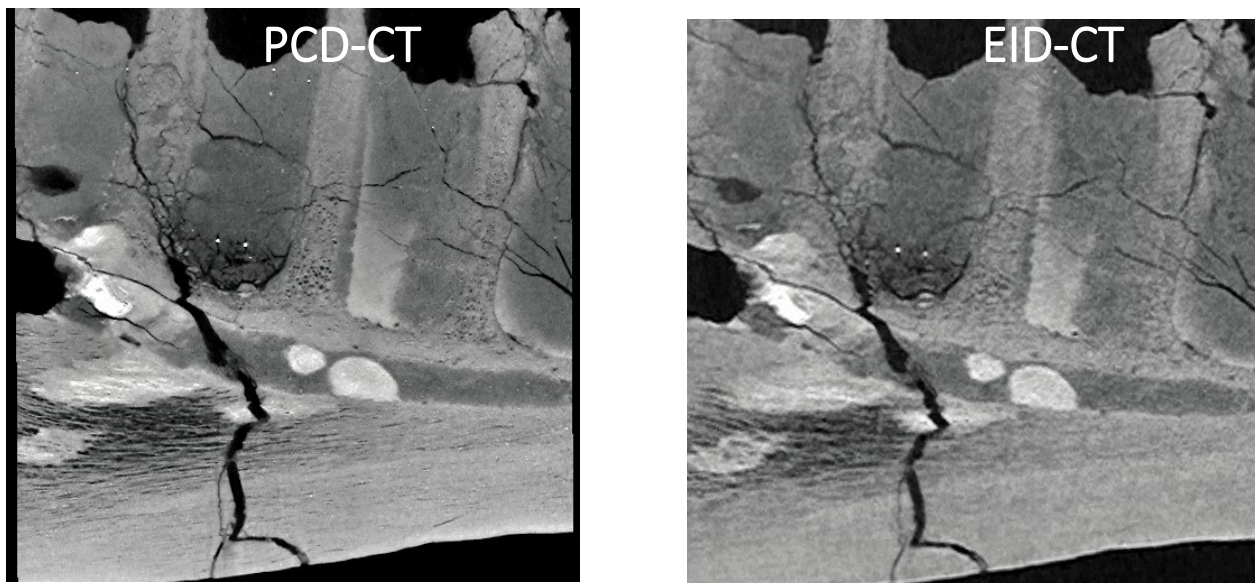


Figure 2. Sagittal sections of the Tyrannosaurus lower jawbone imaged with PCD-CT and EID-CT.

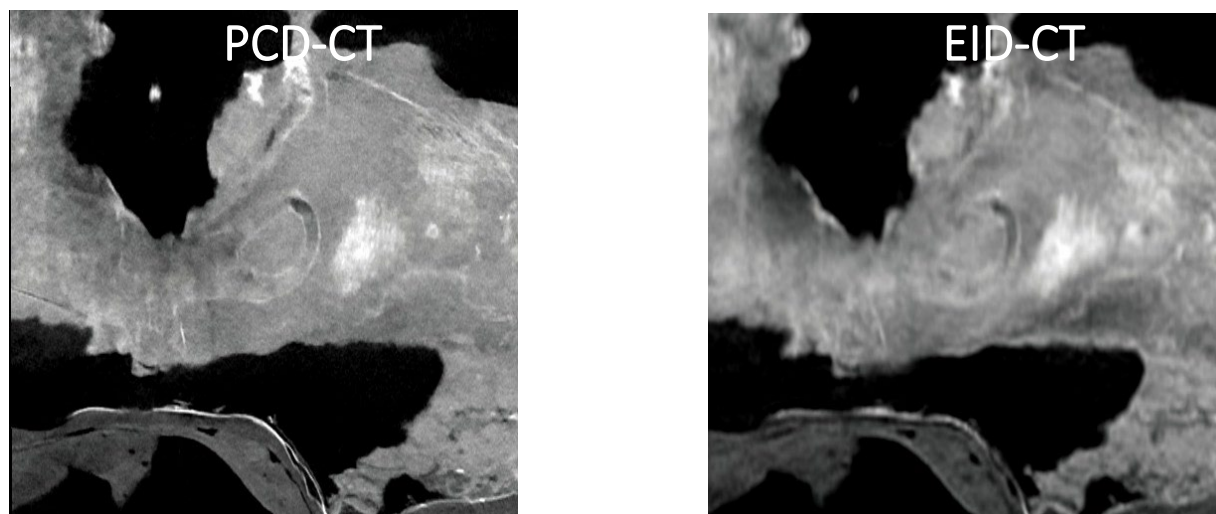


Figure 3. Cross sections of the Camarasaurus temporal bone imaged with PCD-CT and EID-CT.

4. Discussion

To the best of our knowledge, this is the first photon-counting CT imaging study of dinosaur fossils. This study demonstrates the significant advantages of PCD-CT over conventional EID-CT in imaging dinosaur fossils. The superior spatial resolution and contrast-to-noise ratio of PCD-CT allow for more detailed visualization of fossil internal structures such as the Tyrannosaurus mandibular canal and the semicircular canals of the Camarasaurus. Visualizing fine anatomical details with PCD-CT creates new possibilities for paleontological research. For example, detailed images of the mandibular canal in the Tyrannosaurus fossil may provide new information on the sensory capabilities and feeding behavior of this iconic dinosaur [13]. Similarly, the clear imaging of the semicircular canals in the Camarasaurus fossil may shed light on the balance and locomotion of this large sauropod.

Non-destructive PCD-CT imaging ensures that valuable fossils are studied in detail without the risk of damage. One additional benefit of PCD-CT is its ability to create effective atomic number images from spectral information, which may be used for future analysis of fossil composition (i.e., the weathering phenomenon known as pyrite disease that affects fossils). Pyrite disease occurs when fossils are extracted from rock and placed in oxygen-rich environments or exposed to rising temperatures, which accelerates oxidation [14]. As a result, crystals of pyrite or marcasite (FeS_2) grow within the fossil, causing it to deteriorate from the inside. Pyrite disease is a significant concern for the preservation of specimens, as it often affects dinosaur fossils. However, the progression of pyrite disease within fossils and the ultimate destruction it causes have not been thoroughly investigated. The ability of PCD-CT to create effective atomic number images from spectral information provides great potential for non-destructive testing and analysis in paleontology, allowing researchers to gain insights into fossil mineral composition and preservation state without damaging them.

Despite these advantages, there are some limitations for PCD-CT in paleontology. The high cost and limited availability of PCD-CT scanners may restrict their use to well-funded research institutions. Additionally, PCD-CT image interpretation requires specialized knowledge and expertise, which may not be readily available in all paleontological research settings. Thus, it is important for radiologists and paleontologists to collaborate and complement each other's knowledge to advance photon-counting CT research on dinosaur fossils.

5. Conclusions

This study highlights PCD-CT as a powerful tool for non-destructive imaging of dinosaur fossils. The superior image quality and additional spectral information provided by PCD-CT enhances our understanding of fossil internal structure and composition, and paves the way for new discoveries in paleontology. Future research should focus on expanding the use of PCD-CT and developing standardized protocols for its application as a paleontological tool of discovery.

Author Contributions: Soichiro Kawabe, Hideki Hyodoh and Tetsuya Tsujikawa contributed to the study conception and design. Material preparation, data collection and analysis were performed by Tasuku Wakabayashi, Kenji Takata, Soichiro Kawabe, Masato Shimada, Takeshi Mugitani, Takuya Yachida, Rikiya Maruyama and Toshiki Tateishi. The first draft of the manuscript was written by Wakabayashi and Kenji Takata, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the University of Fukui, Faculty of Medical Sciences (study protocol # 20220056, 29 June 2023).

Informed Consent Statement: Not applicable.

Data Availability Statement: The files/data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

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