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Image Rendering Techniques in Postmortem Computed Tomography: Evaluation of Biological Health and Profile in Stranded Cetaceans

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TITLE:

Image Rendering Techniques in Postmortem Computed Tomography: Evaluation of Biological Health and Profile in Stranded Cetaceans

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SUMMARY:

The Hong Kong cetacean stranding response program has incorporated postmortem computed tomography, which provides valuable information on the biological health and profile of the deceased animals. This study describes 8 image rendering techniques that are essential for the identification and visualization of postmortem findings in stranded cetaceans.

ABSTRACT:

With 6 years of experience in implementing virtopsy routinely into the Hong Kong cetacean stranding response program, standardized virtopsy procedures, postmortem computed tomography (PMCT) acquisition, postprocessing, and evaluation were successfully established. In this pioneer cetacean virtopsy stranding response program, PMCT was performed on 193 stranded cetaceans, providing postmortem findings to aid necropsy and shed light on the biological health and profile of the animals. This study aimed to assess 8 image rendering techniques in PMCT, including multiplanar reconstruction, curved planar reformation, maximum intensity projection, minimum intensity projection, direct volume rendering, segmentation, transfer function, and perspective volume rendering. Illustrated with practical examples, these techniques were able to identify most of the PM findings in stranded cetaceans and served as a tool to investigate their biological health and profile. This study could guide radiologists, clinicians

and veterinarians through the often difficult and complicated realm of PMCT image rendering and reviewing.

INTRODUCTION:

Virtopsy, also known as postmortem (PM) imaging, is the examination of a carcass with advanced cross-sectional imaging modalities, including postmortem computed tomography (PMCT), postmortem magnetic resonance imaging (PMMRI), and ultrasonography[1]. In humans, PMCT is useful in investigating traumatic cases of skeletal alterations[2,4], foreign bodies, gaseous findings[4-6], and pathologies of the vascular system[7-9]. Since 2014, virtopsy has been routinely implemented in the Hong Kong cetacean stranding response program. PMCT and PMMRI are able to depict patho-morphological findings on carcasses that are too decomposed to be evaluated by conventional dissection. The non-invasive radiological assessment is objective and digitally storable, allowing second opinion or retrospective studies years later[1,10-11]. Virtopsy has become a valuable alternative technique to provide new insights of PM findings in stranded marine animals[12-16]. Combined with necropsy, which is the gold standard to explain the pathophysiological reconstruction and cause of death[17], the biological health and profile of the animals can be addressed. Virtopsy has been gradually recognized and implemented into stranding response programs worldwide, including but not limited to Costa Rica, Japan, Mainland China, New Zealand, Taiwan, Thailand and USA[12].

Image rendering techniques in radiology use computer algorithms to transform numbers into information about the tissue. For example, radiological density is expressed in conventional X-rays and CT. The vast quantity of volumetric data is stored in the Digital Imaging and Communications in Medicine (DICOM) format. CT images can be used to produce isotropic voxel data using two-dimensional (2D) and three-dimensional (3D) image rendering in a postprocessing 3D workstation for high resolution visualization[18-19]. Quantitative data and results are mapped to transform serially acquired axial images into 3D images with gray-scale or color parameters[19-21]. Choosing an appropriate data visualization method from diverse rendering techniques is an essential technical determinant of the visualization quality, which significantly affects the analysis and interpretation of radiological findings[21]. This is particularly critical for stranding work that involves personnel without any radiology background, who need to understand the results in different circumstances[17]. The goal of implementing these image rendering techniques is to enhance the quality on the visualization of anatomical details, relationships and clinical findings, which boosts the diagnostic value of imaging and allows an effective rendition of the defined regions of interest[17,19,22-25].

Although the primary axial CT/MRI images contain most information, they may limit accurate diagnosis or documentation of pathologies as structures cannot be viewed in various orthogonal planes. Image reformation at other anatomically aligned planes permits visualization of structural relationships from another perspective without having to reposition the body[26]. As medical anatomy and forensic pathology data are predominantly 3D in nature, color-coded PMCT images and 3D reconstructed images are preferred to gray-scale images and 2D slice images in view of improved understandability and suitability for courtroom adjudications[27-28]. With the advances in PMCT technology, a concern of visualization exploration (i.e., the creation and interpretation of 2D and 3D image) in cetacean PM investigation has been raised[12,29]. Various volumetric rendering techniques in the radiology workstation allow radiologists, technicians, referring clinicians (e.g., veterinarians and marine mammal scientists), and even laymen (e.g., stranding response personnel, government officers and general public) to visualize and study the regions of interest. Yet, the choice of a suitable technique and confusion of terminology remain a major issue. It is necessary to understand the basic concept, strengths and limitations of the common techniques, since it would significantly influence the diagnostic value and interpretation of radiological findings. Misuse of techniques may generate misleading images (e.g., images that have distortions, rendering errors, reconstruction noises or artefacts) and lead to an incorrect diagnosis[30].

The present study aims to assess 8 essential image rendering techniques in PMCT that were used to identify most of the PM findings in stranded cetaceans in Hong Kong waters. Descriptions and practical examples of each technique are provided to guide radiologists, clinicians, and veterinarians worldwide through the often difficult and complicated realm of PMCT image rendering and review for the evaluation of biological health and profile.

PROTOCOL:

NOTE: In the framework of the Hong Kong cetacean virtopsy stranding response program, stranded cetaceans were routinely examined by PMCT. The authors were in charge of virtopsy scanning, data postprocessing (e.g., image reconstruction and rendering), data interpretation, and virtopsy reporting[1]. This advanced technology emphasizes attentive findings and gives insights on the initial investigation of PM findings prior to conventional necropsy (https://www.facebook.com/aquanimallab).

1. Data preparation

1.1 Export the acquired CT datasets in DICOM 3.0 format. Copy the DICOM folder to computer (e.g., desktop).

1.2 Open a free or commercial DICOM viewer. The following steps are based on the TeraRecon Aquarius iNtuition Workstation (version 4.4.12).

1.3 Double-click the icon of **Aquarius iNtuition Client Viewer (AQi) icon**. Enter user name, password, and server name in the appropriate fields. Click the **Login** button.

NOTE: Make sure that the server name field has the correct server IP address.

1.4 Click **Import** under the data management tool buttons and select the DICOM folder to import. Click the **Update** icon to renew the study list after the import status reaches 100%.

1.5 View the datasets by selecting 1 or multiple CT series from the Patient List by double-left-clicking the series.

1.6 After loading the designated series, click the **Window Layout Button** for the **2x2** display interface, showing a 2x2 default layout, a 3D volume rendered image (upper-right panel) and 3 MPR images in axial view (upper-left panel), coronal view (lower-left panel), sagittal view (lower-right panel), giving different orientations.

1.7 Evaluate the virtopsy datasets thoroughly using different image rendering techniques provided.

2. Multiplanar reconstruction (MPR)

2.1 Display the default MPR from axial view (upper-left panel), coronal view (lower-left panel), and sagittal view (lower-right panel) after loading the series. Change the rendering mode to MPR by either right-clicking the image and select **MPR** or click **MPR** in the **Rendering Mode Mini-Toolbar**.

2.2 Evaluate the virtopsy datasets from the first image to the last image using the axial view, followed by coronal and sagittal views, with the assistance of the following functions: Click **Slice**, left-click-hold mouse button and drag the mouse to view and adjust the CT image slice by slice.

2.3 Click **Pan**, left-click-hold mouse button and drag the mouse to adjust the location of the image inside the panel.

2.4 Click **Zoom**, left-click-hold mouse button and drag the mouse to magnify or minify the image.

2.5 Select the appropriate pre-set window/levels by clicking **Abd 1** (window width: 350, window level: 75), **Abd 2** (window width: 250, window level: 40), **Head** (window width: 100, window level: 45), **Lung** (window width: 1500, window level: -700), **Bone** (window width: 2200, window level: 200) in the **Window/Level Mini-Toolbar**, depending on the regions of interest.

2.6 Click **Window/Level (W/L)**, left-click-hold mouse button and drag the mouse to manually adjust the window width and window level of the CT slice.

2.7 Click **Rotate**, left-click-hold mouse button and drag the mouse to rotate the MPR images.

2.8 Left-click-hold mouse button on the center of **MPR Crosshairs** to concurrently adjust the regions of interest and slices in 3 MPR images.

NOTE: There are mouse modes for the 4 main functions of rotations, panning, zooming and window/level changes provided by AQi to facilitate the viewing process. For keyboard shortcuts, see Table 1.

3. Curved planar reformation (CPR)

3.1 Decide the region of anatomical interest. Left-click-hold mouse button on the center of **MPR crosshairs** to the particular region of interest.

3.2 View the MPR from 3 different views. Ensure the **MPR crosshairs** is placed in a correct location. Adjust the **MPR crosshairs** if it is not.

3.3 Select 1 display panel from axial, coronal, and sagittal views as study panel, e.g., aiming to view the flipper from an axial view.

3.4 Depending on the study panel, adjust the **extended line of MPR crosshairs** (e.g., blue color) from coronal view perpendicularly to the region of interest by left-click-hold mouse button on the **rotation point of extended line**.

3.5 Adjust another **extended line** (e.g., red color) **of MPR crosshairs** from sagittal view parallel to the region of interest by left-click-hold mouse button on the **rotation point of extended line**.

3.6 Look at the axial view to check whether the region of interest is adjusted correctly. Adjust the extended lines if it is not. Evaluate the virtopsy datasets using the 4 main functions of rotation, panning, zooming and window/level changes.

NOTE: There are 3 colored **extended lines of MPR crosshairs** (green, red, and blue), representing different alignments of the MPR plane (Figure 2).

4. Maximum intensity projection (MIP)

4.1 Change the rendering mode to MIP by either right-clicking the image and selecting **MIP** or by clicking **MIP** in the **Rendering Mode Mini-Toolbar**.

4.2 Adjust the **slab thickness** on the right upper corner (minimum: 1 mm, maximum: 500 mm) by clicking the green annotation and select a new thickness to visualize the regions of interest, e.g., the bronchial tree in the lung.

4.3 Evaluate the virtopsy datasets using the 4 main functions of rotation, panning, zooming, and window/level changes.

5. Minimum intensity projection (MinIP)

5.1 Change the rendering mode to MIP by either right-clicking the image and selecting **MinIP** or by clicking **MinIP** in the **Rendering Mode Mini-Toolbar**.

5.2 Adjust the **slab thickness** on the right upper corner (minimum: 1 mm, maximum: 500 mm) by clicking the green annotation and select a new thickness to visualize the regions of interest (e.g., the bronchial tree in the lung).

5.3 Evaluate the virtopsy datasets using the 4 main functions of rotation, panning, zooming, and window/level changes.

6. Direct volume rendering (DVR)

NOTE: As 1 of the default display 2x2 interfaces, DVR (upper-right panel) shows the 3D rendered images of the carcass. The default DVR template setting is **AAA** (abdominal aortic aneurysm; window width: 530, window level: 385), giving a gross skeletal structure of the carcass.

6.1 Automatically adjust the windowing setting by clicking **Template** under the **Viewer** and select the appropriate DVR template, e.g., **Gray 10%** (window width: 442, window level: 115), **Fracture** (window width: 2228, window level: 1414) if needed.

6.2 Click **Window/Level (W/L)**, left-click-hold mouse button and drag the mouse to adjust the window width and window level of the CT slice manually, giving an outer layer (e.g., epidermal surface) to inner layer *(*e.g., internal structure).

6.3 Use the 4 main functions of rotation, panning, zooming, and window/level changes for further corrections.

NOTE: All DVR templates provided by AQi are human clinical oriented, not designated for PM imaging of cetaceans.

7. Segmentation and Region-of-Interest (ROI) Editing

7.1 Segment the CT image slice using 3 different tools, **Slab and Cube View tool**, **Free ROI tool**, and **Dynamic region growing tool**.

7.2 For **Slab and Cube View tool**, click **Slab** under **Tool**, giving a parallel display line. Adjust the slab location by relocating the **MPR crosshairs** from the corresponding MPR views. Change the slab thickness (minimum: 1 mm, maximum: 500 mm) via the **slab thickness bar**, resulting a segmentation of 3D rendered images of the carcass.

7.3 For **Free ROI tool**, click **FreeRO** under **Tool**. Hold on the **Shift** key on the keyboard, and use either **Draw Free Curve on MPR**, **Draw Circle on MPR,** or **Draw Sphere on MPR** to exclude/include the region of interest from the MPR views and DVR.

7.4 For **Dynamic region growing tool**, click **Region** under **Tool**. Hold on the **Shift** key on keyboard, left-click-hold mouse button and scroll the middle button of the mouse (scroll-up: increase the selecting region, scroll-down: decrease the selecting region), giving a highlighted region. Click **Exclude** to delete the region. Click **Include** to keep the region.

8. Transfer Functions (TF)

8.1 Click **3D Setting** under **Viewer**, select **Copy** to create a new 3D reconstructed model.

8.2 In the new 3D reconstructed model, click **FreeRO** or **Region** under **Tool**. Hold on the **Shift** key on the keyboard, use **3D VR** to include the region of interest and then click **Select**.

8.3 Configure the 3D settings, including **W/L Slider**, **W/L Text-input Boxes**, **VR Pull-down Menu**, **Opacity Slider** (minimum: 0, maximum: 1), **Opacity Text-input Box**, and **HU Range Color Slider** under **3D Setting**.

8.4 Right-click 1 of the sliders in the color slider bar to change the color of the DVR. Select **Change Color** and define a custom color from the color palette if needed.

9. Perspective Volume Rendering (PVR)

9.1 To launch the Flythrough Module, right-click on the selected series and select **Flythrough** from the right-click menu.

9.2 Choose the **Primary 3D** of **Reading Style Preference Wizard** for primary view selection. Click the **2x2 screen layout** and **OK**, resulting in an automatically RVR, e.g., colon. Make sure the region of interest is selected.

9.3 Build a flight path by placing the start and end of **control points** by drawing a path. Correct the path by clicking the **Edit Connection**/**Edit Path** radio button in the tool panel if there is a broken path or missing structure, editing the **control points** for smoother sections of the curve or correcting problems. Create new **control points** by clicking on the flight path. Once the flight path is correct, click **OK**.

9.4 View the Flythrough window displayed, showing a **Main flythrough window**, **MPR views** and **Flat view**.

9.5 Use **Cine Tools** by clicking the Tool Panel located on the right side of the screen to evaluate the luminal structure. Adjust the speed and direction of the flythrough using **Fly backward**, **Pause**, **Fly Forward**, **Slow down flythrough,** and **Speed up flythrough** under the Cine tools.

10. Data evaluation

10.1 Conduct virtopsy evaluation systematically from head to tail. It is generally within 30 minutes, acting as a reference to guide veterinarians for subsequent necropsy.

10.2 After necropsy, compare virtopsy findings and necropsy findings. Based on the site report, virtopsy, necropsy, and sample analysis (e.g., histopathology and microbiology), conclude the PM investigation on the biological health and profile of the stranded cetacean.

REPRESENTATIVE RESULTS:

From January 2014 to May 2020, a total of 193 cetaceans that stranded in Hong Kong waters were examined by PMCT, including 42 Indo-Pacific humpback dolphins *(Sousa chinensis),* 130 Indo-Pacific finless porpoises (*Neophocaena phocaenoides*) and 21 other species. A whole-body scan was performed on 136 carcasses while 57 were partial scans on skulls and flippers. Anatomical features and pathologies commonly observed were illustrated with the 8-image rendering techniques for the evaluation of the stranded cetaceans' biological health and profile.

FIGURE AND TABLE LEGENDS:

Figure 1: MPR function displaying a deceased Indo-Pacific humpback dolphin in (A) axial, (B) reconstructed 3D, (C) reconstructed coronal, and (D) reconstructed sagittal views. Area measurements of the atlanto-occipital space are demonstrated in the axial plane. Linear measurements of the ventral tubercle to outer margins of the occipital condyle (coronal), basion-dorsal arch and opisthion-ventral arch (sagittal) for the diagnosis of atlanto-occipital dissociation are demonstrated.

Figure 2: CPR function displaying curved structures in the flipper of a deceased Indo-Pacific finless porpoise in planar view.

Figure 3: MIP function highlighting hyperattenuated pulmonary nodules (intense white dots) in both lungs of a deceased Indo-Pacific finless porpoise.

Figure 4: MinIP function highlighting hyperattenuated gas-filled structures, i.e., tracheobronchial trees in both lungs of a deceased Indo-Pacific finless porpoise.

Figure 5: DVR function displaying different components of a deceased Indo-Pacific finless porpoise. Vasculatures overlaid with the skeletal system are highlighted by **AAA**. The respiratory system is highlighted by **Lung**. The skeletal system including the vertebral physeal plates is highlighted by **Bone plus Plate**. Hyperattenuated ear bones and fish hooks are highlighted by **Hardware**.

Figure 6: ROI editing function displaying a deceased Indo-Pacific finless porpoise (A) with the CT couch and (B) with the CT couch removed.

Figure 7: TF function displaying different components of a deceased Indo-Pacific finless porpoise. Sand in an air sac is highlighted in cyan. Stomach content is highlighted in green. A parasitic granulomatous mastitis lesion is highlighted in red.

Figure 8: PVR function demonstrating a virtual bronchoscopy of a deceased Indo-Pacific humpback dolphin with the Flythrough function.

Table 1: Keyboard shortcuts of the software for different image postprocessing functions.

DISCUSSION:

For the clear visualization of virtopsy datasets, 8-image rendering techniques, consisting of both 2D and 3D rendering, were routinely applied to each stranded carcass for the PM investigation of their biological health and profile. These rendering techniques included MPR, CPR, MIP, MinIP, DVR, segmentation, TF, and PVR. Diverse rendering techniques are complementarily used together with windowing adjustment. The concepts of each image reformation technique and advantages are also described.

Multiplanar reconstruction (MPR)

MPR is the process of creating non-axial 2D images, including the coronal, sagittal, and any anatomically aligned oblique plane image[24,30], which is not acquired directly during the acquisition in an axial plane. This dominant 2D rendering technique is especially helpful in assessing any intact anatomical structure or pathology in the required plane with high quality images[31-32]. With the help of MRP, cetacean PM investigations of the entire body, orthopedic, and neurological/spine were routinely performed in 3 directions simultaneously, which significantly improved the accuracy of findings (**Figure 1**). Through comprehensive observation from the 3 planes, the error rate of misidentifying minute pathologies is reduced. In addition, MPR also supports linear and area measurement at the axial, coronal, and sagittal plane. However, it is operator-dependent, and requires sufficient anatomical knowledge to identify both normal structures and pathological conditions, which avoid misinterpretation of the rendered images.

Curved planar reformation (CPR)

CPR is also called curved MPR. Despite being treated as MRP in some peer-viewed literatures, CPR is a distinct 2D rendering technique. Using isotropic imaging that aligns the long axis of the image plane with a selected anatomic structure, 2D images are reformatted with no loss of image quality[18,24]. This allows the operator to manually define a centerline path for a curved reconstruction within the volumetric dataset. This is particularly crucial when the subject cannot be placed in a true or relatively true anatomical position in reference to the PMCT detectors (i.e., true reconstructed coronal/sagittal/axial image), especially for frozen or mummified carcasses. The alignment of complicated, tortuous or calcified structures is needed to obtain a more symmetrical image for diagnosis. Due to its flexible flattening and distortion characteristics, misinterpretation can be easily induced. The operator must clearly remember the position and shape of the anatomical structures of interest. Flippers are 1 of the most difficult body parts to obtain a true anatomical position as they are curved towards the body flanks, unless resected before the PMCT scan. With the utilization of CPR, most of the anatomical features in the flippers were demonstrated at 1 plane and for skeletal age estimation (**Figure 2**).

Maximum intensity projection (MIP)

MIP projects only the highest attenuation value in each pixel of the volumetric datasets within the viewer' sight[32] and selects the voxel with the maximum intensity as the value of the corresponding display pixel[18]. Originally, this technique is recognized to evaluate the osteological material, metallic implants, and contrast-filled structures for CT angiography in clinical radiology antemortem[17,33]. Due to decomposition of internal structures and organs, and the absence of blood perfusion in stranded carcasses, the adoption of MIP in evaluating the contrast-filled structures for CT angiography become very difficult in virtopsy. However, MIP still takes a dominant character in examining osteological materials, foreign bodies (e.g., food bolus, fish remains, stone, metallic entanglement) and calcifications within soft tissues, as well as highly attenuated, narrow, and blood- or water-filled structures such as the major arteries and veins. Through the adjustment of slab thickness (i.e., image thickness for data reconstruction) subjective to the size of the evaluated target, the visualization of lesions could be emphasized. For instance, using different sliding thin-slab[34], the identification of small pulmonary nodules in collapsed lungs of a stranded carcass was intensively improved, as MIP emphasized these minutes of hyperattenuated speckles, which evidenced the presence of lung consolidation and parasitic pneumonia (**Figure 3**).

Minimum intensity projection (MinIP)

In contrast to MIP, MinIP projects only the lowest attenuation value encountered along a ray pass through a volume toward the viewer' sight within a volume[18,24]. Although MinIP is not commonly used in clinical radiology[24], this technique still served as an excellent visualization tool on hypoattenuated structures and gas-filled structures, such as the respiratory and gastrointestinal tract. The examination of the morphology and pulmonary parenchymal abnormalities, started from the blowhole down to the tracheobronchial tree, in the stranded cetaceans were significantly enhanced (**Figure 4**). Similar to MIP, additional control should be taken on the slab thickness, subject to the examined pathologies, to generate a more distinguishable image[35], as the slab thickness is critical to determine the distinction of presented structures on the studied structures.

Direct volume rendering (DVR)

DVR is an algorithm that converts an entire 3D image set into 2D images directly without discarding any information[18]. The final displayed 2D image is created based on its Hounsfield units by assigning each voxel in the image a specific color and opacity value along with other voxels in the same projection ray. As the opposition of creating an intermediate representation (e.g., an extracted surface model by soft-tissue removal tool), the internal and external conditions of a stranded carcass at all depths with the 3D method can be examined at once, without obscuring each other. This 3D rendering technique was a quick, versatile and interactive tool for a whole-body carcass evaluation from any angle. Bony lesions, complex fractures, body fragmentation, and foreign bodies caused by human interaction (e.g., traumatic injuries caused by vessel collision and fisheries) were possible to be identified (**Figure 5**). The challenge of DVR is that the operator needs to adjust the rendering parameters, *i.e.*, the opacity and brightness, to display the vasculature more accurately [21,36].

Segmentation and Region-of-Interest (ROI) Editing

Irrelevant structures, objects (e.g., body bag and CT couch), and artefacts (e.g., metallic zippers) displayed on the DVR model may degrade the image quality and obscure radiological diagnosis. To illustrate certain areas of anatomy or pathology in a better manner, segmentation is used to include or exclude selected volumetric data on either 2D or 3D images[18,24]. Although automated segmentation programs are available, manual segmentation which requires high tissue recognition and delineation by the operator was performed in most circumstances to assist the identification of radiological findings on the DVR of stranded carcasses. ROI editing was the most common segmentation tool used in the present study, which allowed the operator to include or exclude a region of interest manually by drawing a rectangular, elliptical or other shape to define the precise spatial boundary of the target (**Figure 6**). Similar to DVR templates provided in the 3D workstation, automated segmentation is based on the rules of connectedness and thresholding, and subjected to clinical radiology, which was mostly unsuitable for this study, except for the automatic body bone removal function.

Transfer Functions (TF)

TF is an algorithm to control the threshold of opacity, brightness, and color of the selected volume[18,24]. This tool allows the operator to selectively reveal the relevant structures on the DVR model, by selecting the threshold value, range, and shape, to serve different purposes at the defined region. For instance, choosing a lower opacity threshold removes the external low-opacity soft tissues (skin and fat) and obscures the abdominal content, while a high opacity threshold keeps high opaque objects (e.g., bone, calcium, and excreted contrast materials); changing the color, brightness, and contrast scale highlights the region of interest, and makes the appearance of the DVR model to look different. These controls give a better elucidation and quicker differentiation of structures based on their attenuation. However, these are vulnerable to interobserver variability and dependent on operator mastery in optimization of rendering parameters[21]. With the contribution of segmentation and TF, the relationship of displayed tissues, organs, and foreign bodies in scanned carcasses were well-classified (**Figure 7**). Fast and clear preliminary findings on stranded cetaceans were demonstrated on the edited DVR model, which gave veterinarians and stranding response personnel an overview on the internal and external condition, as well as the initial PM investigation findings, and facilitated subsequent conventional necropsy.

Perspective Volume Rendering (PVR)

PVR, also called endoluminal imaging or immersive rendering, is mainly applied to air-containing structures such as trachea, colon, esophagus, and arteries. It allows the operator to visualize the internal conditions of the lumen by virtual navigation[35]. The operator designates the start point, end point, and a centerline path to fly through. By displaying an animation of flying through the structure, the relationships between anatomic structures and endoluminal abnormalities such as polyps or cancerous growths on the walls can be identified as in a non-invasive virtual endoscopy[19]. The corresponding MPR images displayed alongside allow concurrent reviewing of particular lesions[37,38]. By extending PVR beyond the lumen, adjacent extraluminal structures can also be visualized[24]. In the present study, PVR was only applicable on fresh carcasses with uncollapsed structures, which permitted the reconstruction of the endoluminal view (**Figure 8**).

In the present overview of rendering techniques, only 8 techniques commonly used in the routine virtopsy of stranded cetaceans were described, while others were disputed due to their limited usefulness. The techniques mentioned could also give insight and be applied to other animals in general. In clinical radiology, there are many other rendering techniques and DVR templates, built on threshold-based algorithms with preset values for opacity, brightness, lighting, heat scale, window level and window width, provided in most 3D workstations. Those are designed to emphasize the illustration of different tissue types and body parts for special examinations, for instance, vascular contrast, airways, stomach or thrombus[18,24,31]. However, in the case of stranded carcasses, there is gas accumulation caused by decomposition with no organ perfusion. Most DVR presets of clinical CT examination, especially CT angiography, require contrast injection and thus could not be applied in the present study. The self-designed DVR templates combined with single or multiple DVR models for cetacean PM investigation could be established after standardization of the threshold-based algorithms in terms of species and their level of decomposition. Nevertheless, based on our experience, the 8 rendering techniques listed were able to identify most of the PM findings in stranded cetaceans, and were sufficient to investigate their biological health and profile.

Preparation and scanning of carcasses is critical for subsequent postprocessing and visualization of virtopsy data. Operation of a CT machine, an ionizing radiological unit, must be performed by a certificated radiological technician or clinician in compliance with the law. Although the scanned subjects were carcasses, the radiation dose should be kept to as low as reasonably achievable. The control of scanning parameters, especially slice thickness, would highly influence the accuracy of the reconstructed coronal and sagittal planes. Moreover, reduction in CT slice thickness permits more precise diagnosis. For instance, acquiring PMCT images at 3 mm thickness may neglect a 1×1×1 mm parasitic granuloma, commonly observed in the mammary glands of stranded cetaceans. To avoid missing any finding and improve the resolution of 2D and 3D rendering, a standardized scanning protocol was used. The slice thickness was controlled at 1 mm, and down to 0.625 mm whenever possible, which is the minimum slice thickness available for the CT machine used.

A proper postprocessing visualization and manipulation of virtopsy datasets requires clear understanding of the principles and pitfalls of the common rendering techniques used for cetacean PM investigation, e.g., the identification of strength and weakness between the techniques[21]. The choice of rendering techniques depends on the anatomical structures and the underlying pathologies to be illustrated, there is no single technique that can comprehensively recognize all the PM findings. Knowing the pros and cons and choosing the appropriate rendering techniques can boost image quality and interpretability of virtopsy datasets, which aid to obtain a correct diagnosis. Carefully reviewing virtopsy datasets and correlating them with other techniques can avoid potential rendering and segmentation error[18]. Still, the final judgement and diagnosis should be made by veterinary radiologists or radiological clinicians who are certificated and experienced to report virtopsy findings.

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The authors have nothing to disclose.

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Figure 1

Click here to access/download;Figure;Figure 1.tif

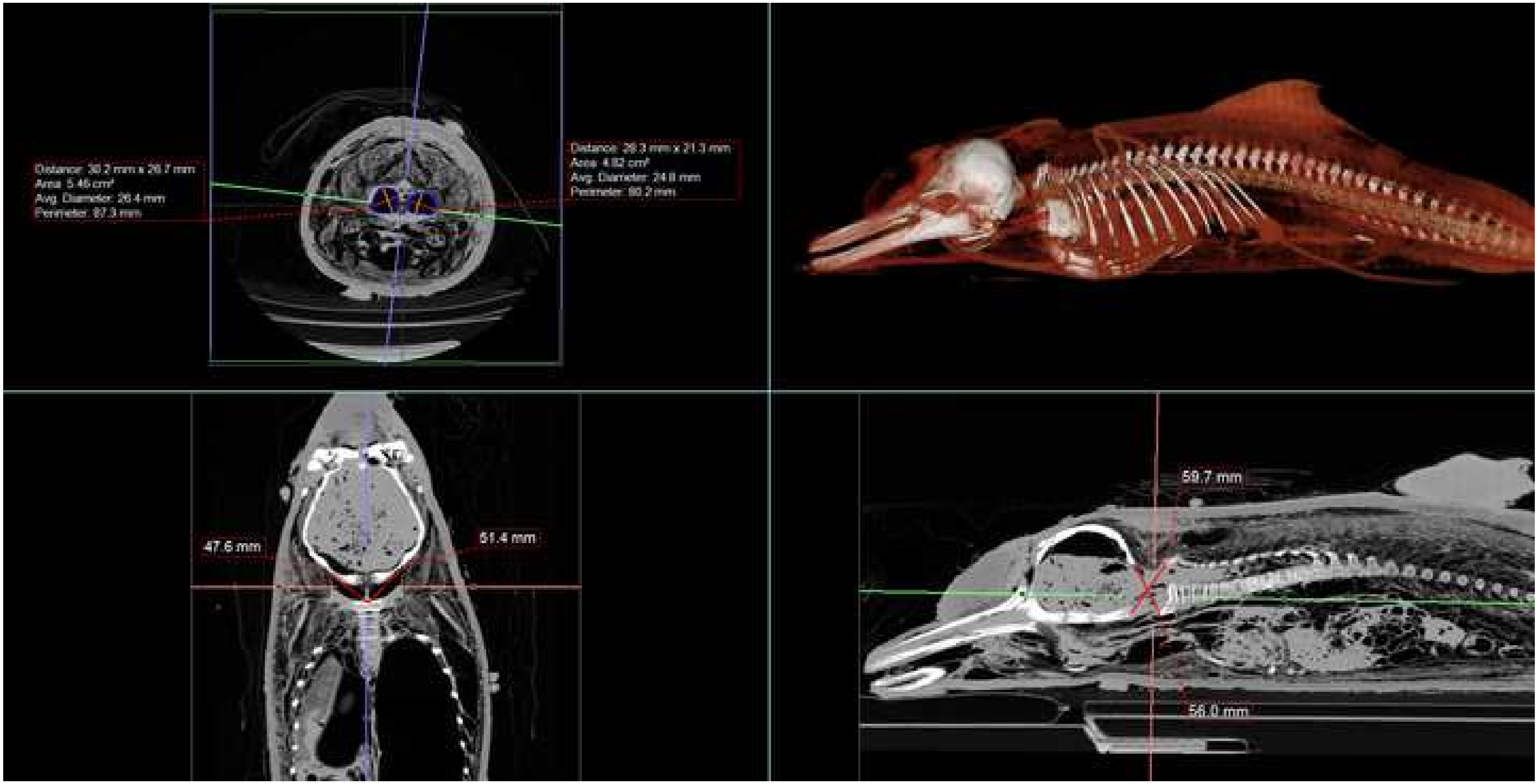

Figure 2

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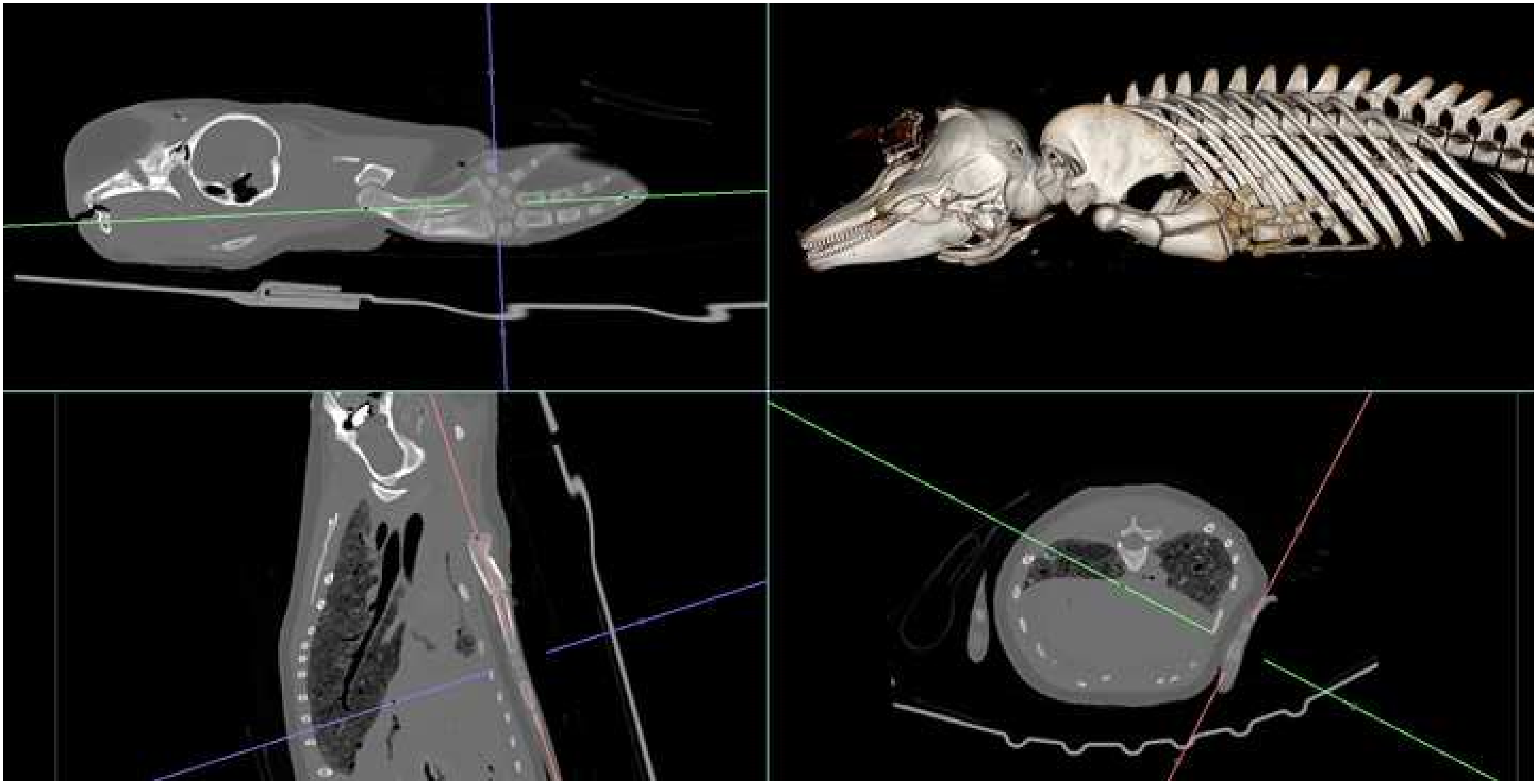

Figure 3

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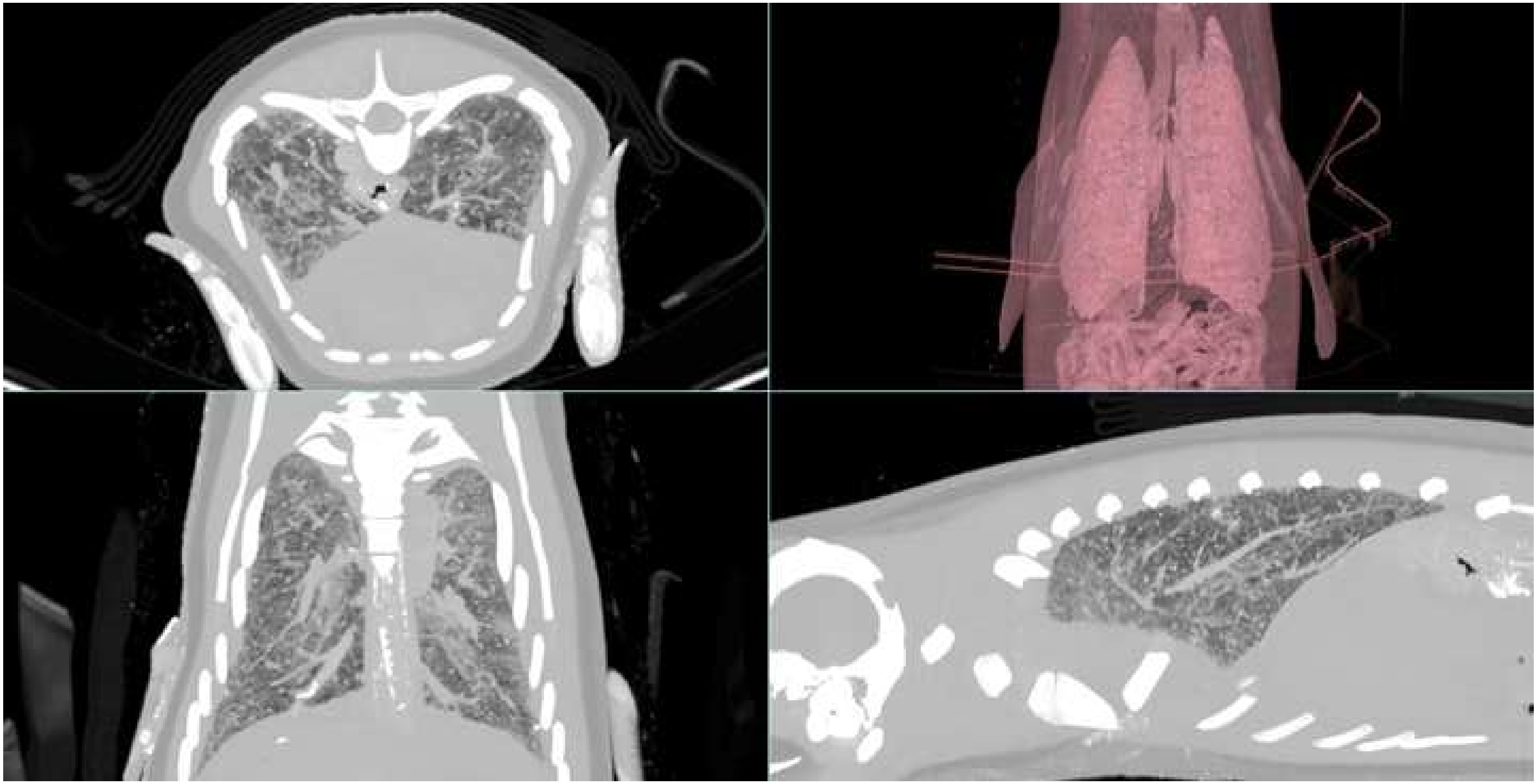

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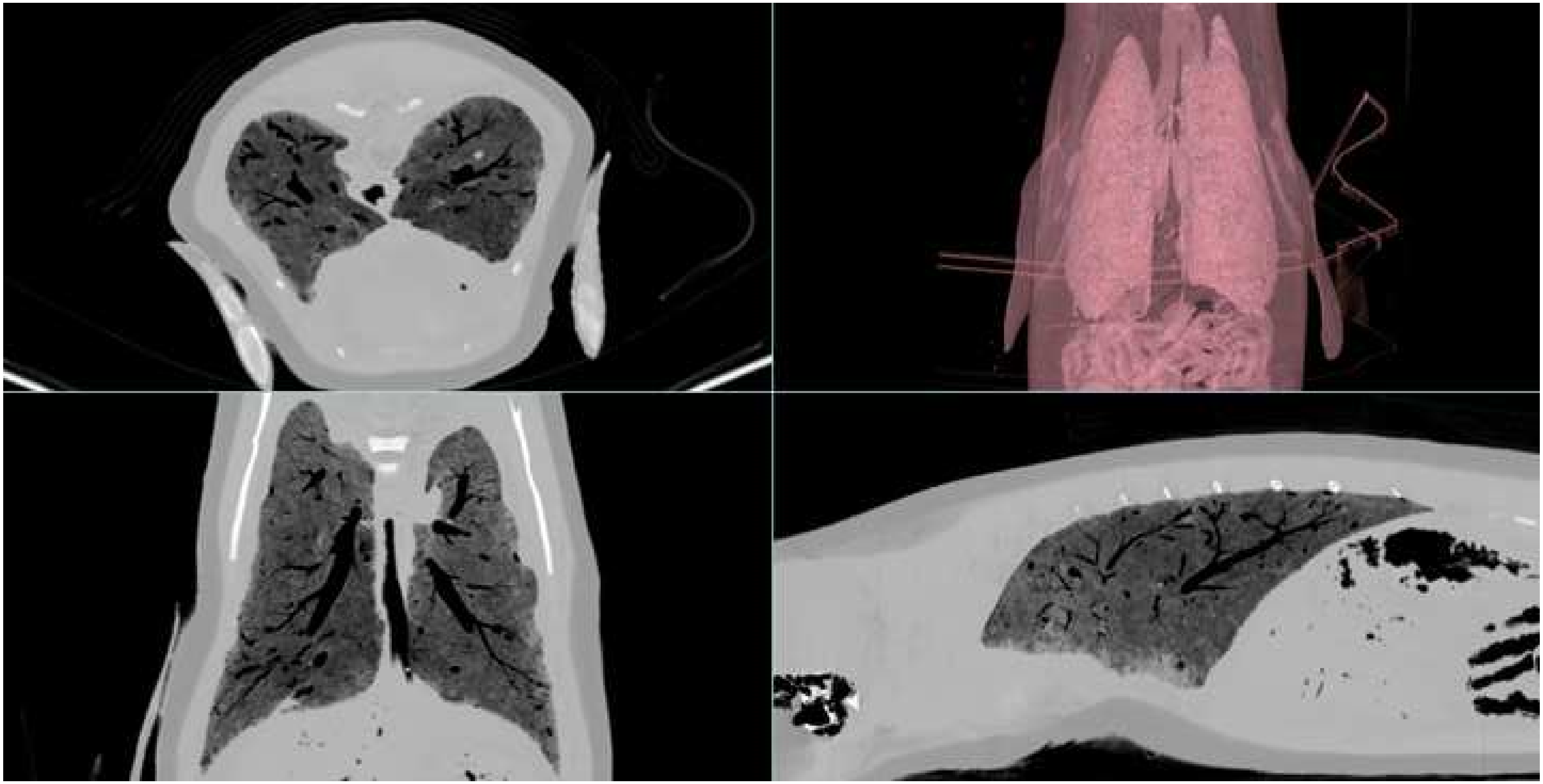
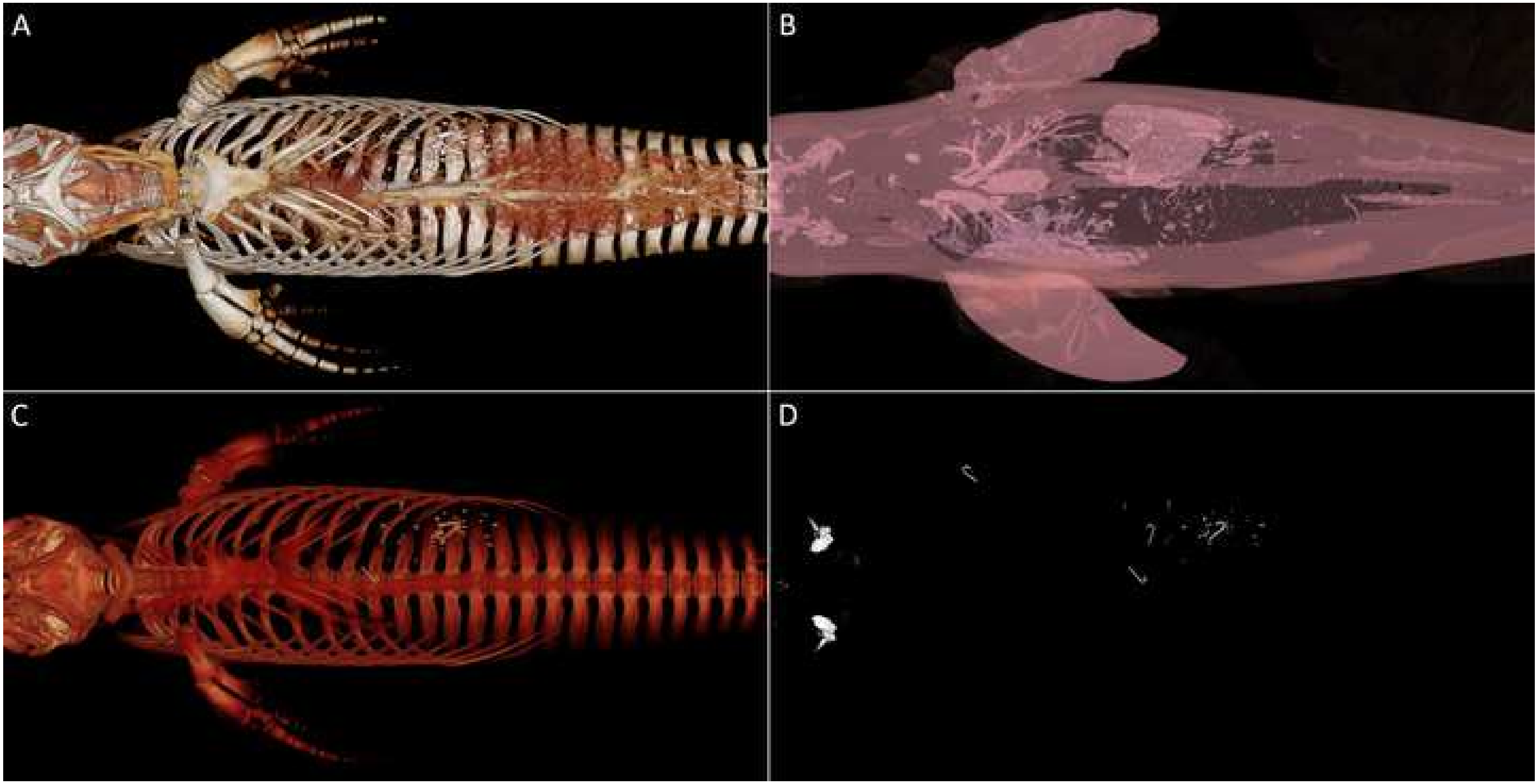


Figure 5



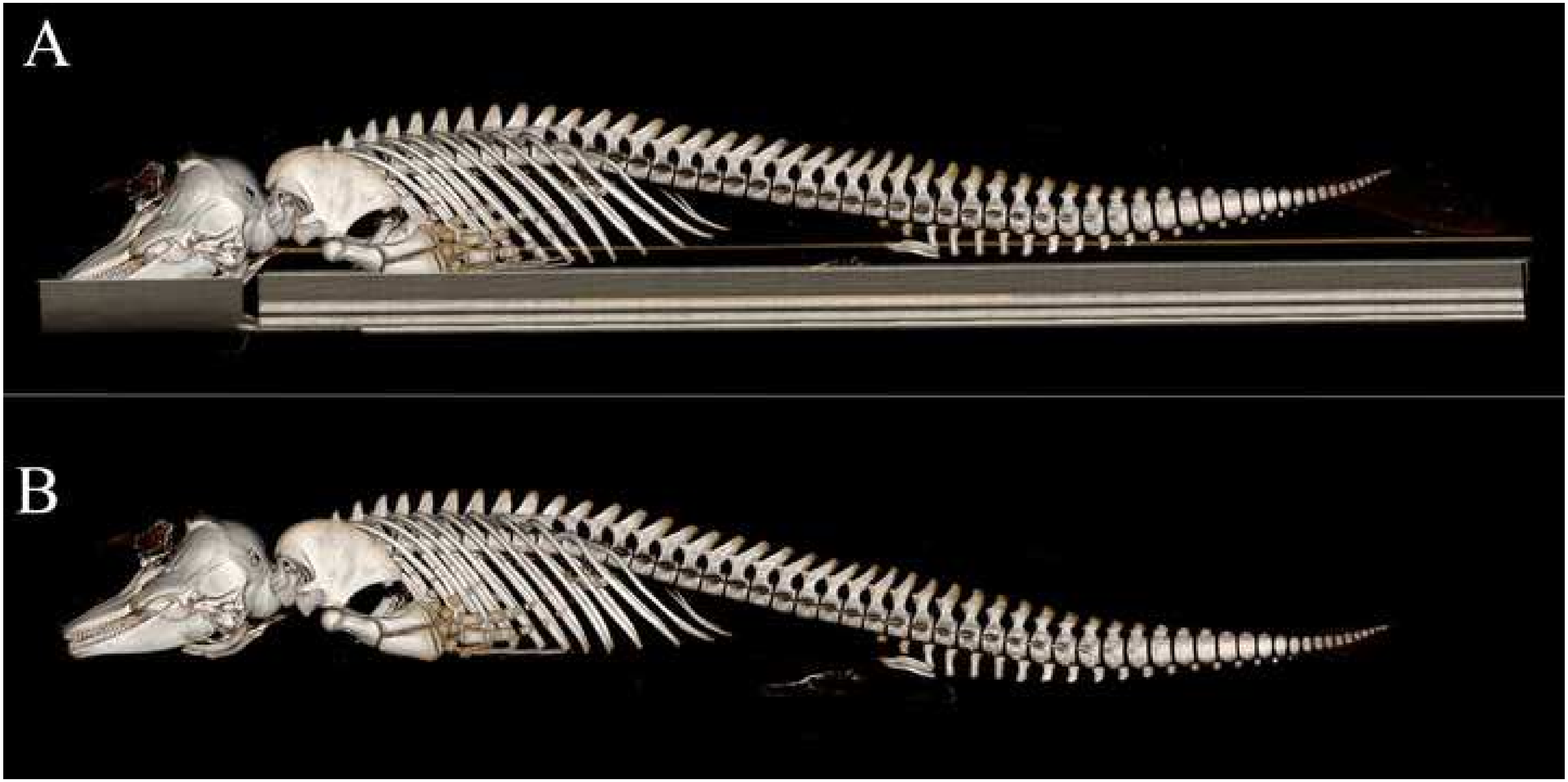

A
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Figure 7

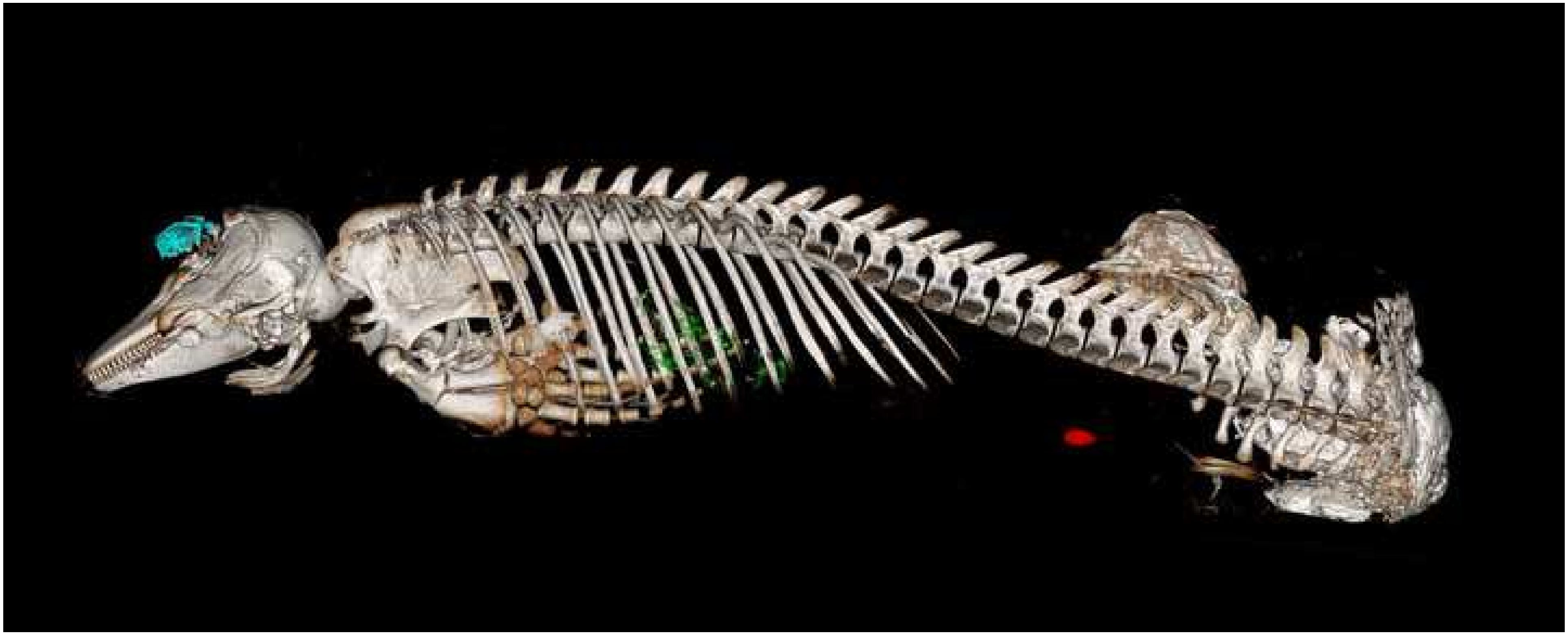
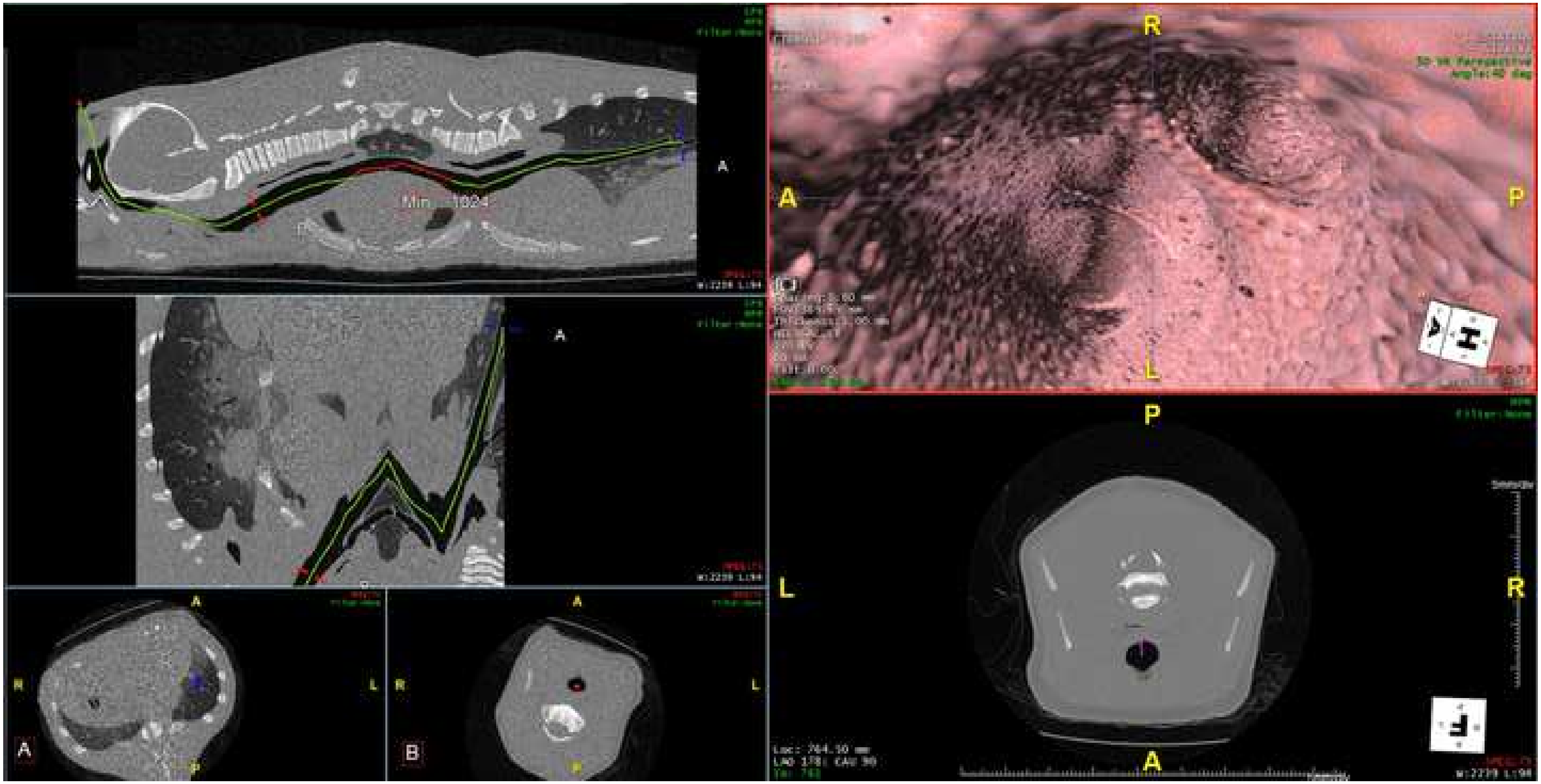


Figure 8

Click here to access/download;Figure;Figure 8.tif



Name of Material/ Equipment	Company	Catalog Number	Comments/Description
Aquarius iNtuition workstation	TeraRecon Inc	NA	
Siemens 64-row multi-slice spiral CT scanner Somatom go.Up	Siemens Healthineers	NA	

Responses to Editor's and Reviewers' comments

Editorial and production comments:
Changes to be made by the Author(s) regarding the written manuscript:
1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues.
We agree with the editor's comment. The manuscript was edited by an English native speaker timely and its use of English wording and grammar were revised throughout the manuscript content.

2. Unfortunately, there are sections of the manuscript that show overlap with previously published work. Please use original language throughout the manuscript. Please revise lines: 60-63,
We agree with the editor's comment. The lines were rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 58-72).

3. Please provide a protocol section header to help divide the protocol.
We agree with the editor's comment. Protocol section headers were added in the revised manuscript as suggested.

Changes to be made by the Author(s) regarding the video:
1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues.
We agree with the editor's comment. The manuscript was edited by an English native speaker timely and its use of English wording and grammar were revised throughout the manuscript content.

2. • 02:29 This section is called "CPR" which is shown as distinct from "MPR" in the previous section. The narration refers the crosshairs as "MPR crosshairs" as did in the previous section. Should these be "CPR crosshairs" instead?
The feature itself is called "MPR crosshairs", which is universally named in DICOM viewer. This feature allows users to visualize and review complex internal structures and pathology, with reference to the corresponding axial, coronal and sagittal planes in the basic MPR mode.

3. • 02:30 "interest studies of regions". Consider rephrasing as, "studied regions of interest". The original syntax is confusing in American English.
We agree with the editor's comment. The phrase was changed to "regions of interest" in the revised video.

4. • 02:35 "the MPR from 3 different views" Did he mean CPR? He repeatedly says MPR in this section but that was for the last section. I feel this may be in error.
The feature itself is called "MPR crosshairs", which is universally named in DICOM viewer. This feature allows users to visualize and review complex internal structures and pathology, with reference to the corresponding axial, coronal and sagittal planes in the basic MPR mode.

5. • 03:17 "Studies of regions" See note for 02:30, is this the same instance?
We agree with the editor's comment. The phrase was changed to "regions of interest" in the revised video.

6. • 03:26 "Studies of regions". See previous note. Consider call this "regions of interest" or "regions of study".
We agree with the editor's comment. The phrase was changed to "regions of interest" in the revised video.

Please upload a revised high-resolution video here:
https://www.dropbox.com/request/HXeNB2CMtMa1eP5qplc2?oref=e
The revised video with editor's and reviewers' comments taken, has been uploaded to the dropbox.

Reviewers' comments:
Reviewer #1:

Manuscript Summary:
The article describes 8 image rendering techniques that can be applied to post mortem cetaceans during CT scans to evaluate their tissue and organ health. These techniques were applied to 193 post mortem cetacean in Hong Kong. The paper aims to provide detailed techniques how to use the image rendering techniques, with applications for radiologists, clinicians, and veterinarians.

Major Concerns:
1) Conceptually an interesting idea, by unclear why these techniques are so important in their application to cetaceans as opposed to any dead animal. It is also unclear early on why these 8 techniques are presented and not others- why are these the optimal ones. This is addressed at the very end of the discussion but should be in your introduction
The rendering techniques are part of the methodology used in virtopsy, which is part of the big umbrella under the cetacean PM investigation. We used our experience in HK and adjacent waters as an example to assess the biological health of the endangered cetacean populations in these waters, which is the first virtopsy-driven stranding response program worldwide. The techniques mentioned in this manuscript could also give insight and be applied to other animals in general, yet practical examples listed were based on the authors' >6-year experience on cetaceans. The 8 techniques presented were able to identify most of the PM findings in stranded cetaceans. The statement was added in the revised manuscript as suggested (revised manuscript, page 3, line 109-110).

2) Overall, sentences need to be broken down as several are run-ons and grammatically incorrect ones. The paper needs substantial edits to conform to grammatically correct English. I stopped implementing grammar corrections after the introduction.
We agree with the editor's comment. The manuscript was edited by an English native speaker timely and its use of English wording and grammar were revised throughout the manuscript content.

3) CT scans are very expensive and it seems unlikely that the general public/medical laymen would have regular access to them instead of trained clinicians. While the educational value of virtopsy in veterinary schools is clear although not explicitly mentioned in this paper, the conceptual framework that the general public will have access to and be trusted to interpret the results of CT scans is unrealistic.
The study aimed to assess 8 rendering techniques in PMCT as a tool to investigate the biological health and profile of stranded cetaceans. Although virtopsy may increase the running cost for PM investigation, partnership with local human and veterinary hospitals could minimise such cost. Virtopsy has also been recognized and implemented into stranding response programmes worldwide, including but not limited to Costa Rica, Japan, Mainland China, New Zealand, Taiwan, Thailand and USA. This study could guide not only radiologists, clinicians and veterinarians, but also stranding response personnel who could be actively involved in the data collection and analysis, particularly on carcass with advanced decomposition status, to master the rendering and reviewing process of virtopsy for probing PM findings that conventional necropsy may be missed. Still, as mentioned at the end of the manuscript, the official reporting still rely on the certified and experienced radiological clinicians and assignation of cause of death rely on all collective data from the field, virtopsy, as well as conventional necropsy conclusively.

4) Much of the introduction is presented in disjunct paragraphs that need restructuring so that the progression of ideas flows together seamlessly.

We agree with the editor's comment. The paragraphs were restructured in the revised manuscript as suggested.

5) For the study to be effective, it should present data collected by virtopsy that is then compared to standardized necropsy techniques to determine if consistent causes of deaths are found. In cetaceans, causes of death are often pathological, and it is unclear how virtopsy techniques compare with histological analysis and microanatomical assessment.

The study aimed to assess the rendering techniques on their strengths in identifying different PM findings in stranded cetaceans. The actual findings on causes of death of the studied animals were not the scope of this study. Assignation of cause of death in our virtopsy-driven stranding response program rely on all collective data from the field, virtopsy, as well as conventional necropsy conclusively.

6) The results are a series of pictures with no accompanying in-text explanation.

The presented figures were pictorial descriptions, which demonstrated the strength of each rendering technique. Detailed explanation of each was provided in the Discussion section.

7) Most of the discussion is a description of the techniques. You assessed 193 carcasses. Provide specific data in the results and discussion about what patterns were found. How did the virtopsy results compare with necropsies on the same animals? Were these virtopsies used to determine cause of death? This should be emphasized to show their utility.

The study aimed to assess the rendering techniques on their strengths in identifying different PM findings in stranded cetaceans. The actual findings on causes of death of the studied animals were not the scope of this study. Assignation of cause of death in our virtopsy-driven stranding response program rely on all collective data from the field, virtopsy, as well as conventional necropsy conclusively.

Stranded cetacean carcasses, particularly their cranial cavity, were often badly decomposed, which made conventional necropsy and histological analysis inoperable. With its superior ability in depicting internal findings without invasively opening the decomposed carcasses, virtopsy could reveal biological information of the stranded animals when conventional necropsy could not offer the answers.

Minor Concerns:

Abstract:

- There are many acronyms that are not necessary as they are not repeated in the abstract.

We agree with the reviewer's comment. The unnecessary acronyms were deleted in the revised manuscript as suggested.

- It is unclear why these 8 techniques specifically are described and not others as there are multiple for PMCT. Be more explicit for your reader why these 8 techniques are of value over others.

We agree with the reviewer's comment. The 8 rendering techniques were able to identify most of the PM findings in stranded cetaceans. The statement was added in the revised manuscript as suggested (revised manuscript, page 2, line 50-52).

- Why were the techniques only applied to 75% of stranded cetaceans? Unless it is because the techniques failed on 25% of the animals, then instead report only how many animals the techniques were applied on. Eg, PMCT was performed on 193 recovered local stranded cetaceans

The 25% unscanned cases were non-retrievable from the stranding site due to logistic difficulties, which was not related to the virtopsy techniques. We agree with the reviewer's comment and the percentage was deleted in the revised manuscript as suggested (revised manuscript, page 2, line 45-46).

Summary should not be a copy paste of a sentence in the abstract. Rearticulate the point in different words.
We agree with the reviewer's comment. The summary was rewritten in the revised manuscript as suggested (revised manuscript, page 1, line 33-38).

Introduction:

Line 60: Define what vitropsy is for your reader
We agree with the reviewer's comment. The concept of virtopsy was explained in the revised manuscript as suggested (revised manuscript, page 2, line 58-72).

Lines 64-67: Remove the words "through the employment of"
We agree with the reviewer's comment. The words were removed in the revised manuscript as suggested.

Line 67: Remove the word "the"
We agree with the reviewer's comment. The word was removed in the revised manuscript as suggested.

Line 69. Replace wording with "might be solvable".
We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 68-70).

Line 71: useful in investigating traumatic cases
We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 60-62).

Line 72-76: clinicians utilize… format. Additionally, PMCT can be used to produce…
We agree with the reviewer's comment. The sentences were rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 76-79).

Line 78-79: Image rendering techniques in radiology use computer 3D algorithms to transform numbers into information about the tissue.
We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 74-75).

Line 79: For example, radiological density is expressed in conventional X-rays and CT.
We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 75-76).

Lines 80-82: Grammar incorrect and sentence is not comprehensible as is.
We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 79-80).

Lines 83-84: is an essential technical determinant of the quality of visualization, which significantly affects the analysis and interpretation of radiological findings.

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 81-83).

Lines 85-87: This is particularly critical for strandings involving people unfamiliar with radiology who need to understand results in different circumstance.

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 2, line 83-85).

Line 89: "lucid" is an awkward word choice

We agree with the reviewer's comment. The word was changed to "effective" in the revised manuscript as suggested (revised manuscript, page 2, line 87).

Lines 90-93: "written reports were preferred to gray-scale images and 2D slice images, with improved understandability, cost effectiveness, and suitability for courtroom adjudications.

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 3, line 93-96).

Lines 95-98: As medical anatomy and forensic pathology data are predominantly 3D in nature (e.g. bony fractures and foreign bodies), 3D reconstructed images are less cluttered, less visually contaminated, and more relevant in presenting a specific observation compared to conventional necropsy.

In addition to my edits to grammar, it is unclear what is meant by visually contaminated.

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 3, line 93-96)

Line 98: images contain

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 3, line 90).

Line 99: they may limit accurate diagnosis… due to their

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 3, line 90-92).

Line 100: of the head,

Unclear why you would need to dissemble the body to do a CT scan or MRI. Add citation as not clear who it is not preferred by

We agree with the reviewer's comment. The idea was that certain body parts (e.g. the flippers) do not fall into the axial, coronal or sagittal plane as the rest of the body unless dissembled, and this is where the image rendering techniques come into use for the visualization of such body parts. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 3, line 90-92).

Line 104: Unclear what is meant by prospective one

We agree with the reviewer's comment. The word should be "perspective". The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 3, line 90-92).

Line 108: Raised by whom? Citation needed

We agree with the reviewer's comment. Citation 24 was added in the revised manuscript as suggested (revised manuscript, page 3, line 96-98).

Line 109: Nowadays is not formal English

We agree with the reviewer's comment. The word was removed in the revised manuscript as suggested (revised manuscript, page 3, line 98).

Line 109: Remove the word 'provided'

We agree with the reviewer's comment. The word was removed in the revised manuscript as suggested (revised manuscript, page 3, line 99).

Line 111: The definition of medical laymen does not seem appropriate. The general public and government officials are not medical at all

We agree with the reviewer's comment. The word medical was removed in the revised manuscript as suggested (revised manuscript, page 3, line 100).

Line 112: Interests is the incorrect word choice

We agree with the reviewer's comment. The word was changed to "regions of interest" in the revised manuscript as suggested (revised manuscript, page 3, line 101-102).

Lines 117-121: Grammar issue with tenses

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 3, line 102-107).

Discussion:

Line 344: Again "lucid" is an awkward word choice

We agree with the reviewer's comment. The word was changed to "clear" in the revised manuscript as suggested (revised manuscript, page 8, line 321).

Line 344-346: consisting of both 2D and 3D rendering, were routinely applied to each stranded carcass for the biological health and profile investigation. These rendering techniques included…

We agree with the reviewer's comment. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 8, line 321-324).

Line 346: Not clear what is meant by "profile investigation"

It refers to the cetacean PM investigation of biological health and profile. The sentence was rewritten in the revised manuscript as suggested (revised manuscript, page 8, line 321-323).

Lines 346-347: Remove the following words "Upon the whole of cetacean PM investigation,"

We agree with the reviewer's comment. The words were removed in the revised manuscript as suggested (revised manuscript, page 8, line 324).

Line 480: why was it important to have low doses of radiation if they were dead?

Radiation dose should be kept to as low as reasonably achievable if higher radiation has no direct benefit. It is also important for the maintenance of the CT machine as excessive dose would exhaust the tungsten filaments in the X-ray tubes faster and shorten the life expectancy of the apparatus.

Reviewer #2:

Manuscript Summary:
This manuscript provides a much needed guide to performing various CT processing techniques for primarily diagnostic purposes in cetaceans. The descriptions of various processing functions will be especially helpful for those beginning to work with CT processing and who have access to the TeraRecon workstation.

Major concerns:
1. The primary CT processing software utilized for the 8 imaging processing techniques is first mentioned in the "protocol" section as TeraRecon Aquarius iNtuition workstation. While the 8 processing techniques may be found in other programs as well, the steps themselves refer to specific functions and screens found in this workstation and not others. Therefore, there needs to be statement earlier on in the manuscript (in the abstract and the introduction) that the specific details of the techniques described within apply to the TeraRecon Aquarius iNtuition workstation, and not necessarily other workstations/programs. Other software may have similar functions, but executing those functions may be very different than the steps mentioned here.
The TeraRecon Aquarius iNtuition Workstation is one of the most equipped DICOM viewers, which commonly used in the radiology field. It offers a wide collection of useful features in a user-friendly interface as recognized by vast medical professionals from thousands of institutions worldwide. It also runs on a web-based server, which allows flexible data access among radiologists, clinicians, veterinarians and researchers from different institutes. Other programs are available but with less features or less manageable controls. The 8 imaging rendering techniques we used were named in with most universal and commonly known radiological terminology, which allowed readers to follow easily in other DICOM viewers, other than the TeraRecon Aquarius iNtuition Workstation.

2. Please add the species being imaged to the figure legends.
We agree with the reviewer's comment. The species was added to the figure legends in the revised manuscript as suggested (revised manuscript, page 7-8, line 284-314).

Minor Concerns:
There are many grammatical errors/sentence structure errors throughout the manuscript that will need to be resolved throughout the document to be consistent with American English; This sometimes makes it difficult to understand the content of the manuscript. This may be resolved however by the proofing department.
We agree with the editor's comment. The manuscript was edited by an English native speaker timely and its use of English wording and grammar were revised throughout the manuscript content.

Reviewer #3:

- The techniques described are not novel, but rather are standard and fundamental to general diagnostic imaging (both antemortem and postmortem). Nonetheless, their use in post-mortem imaging of marine mammal species is a novel and powerful application which warrants communication to the scientific and conservation community.

- My major criticism of this work is not using an open source pacs. There are many open source pacs solutions capable of the majority of the techniques described herein. Consequently I could not reproduce their methods.
The TeraRecon Aquarius iNtuition Workstation is one of the most equipped DICOM viewers, which commonly used in the radiology field. It offers a wide collection of useful features in a user-friendly interface as recognized by vast medical professionals from thousands of institutions worldwide. It also runs on a web-based server, which allows flexible data access among radiologists, clinicians, veterinarians and researchers from different institutes. Other programs are available but with less features or less manageable controls. The 8 imaging rendering techniques we used were named in with most universal and commonly known radiological terminology, which allowed readers to follow easily in other DICOM viewers, other than the TeraRecon Aquarius iNtuition Workstation.

- Many opportunities to improve grammar and style throughout the manuscript. I believe Jove does this independently.
We agree with the editor's comment. The manuscript was edited by an English native speaker timely and its use of English wording and grammar were revised throughout the manuscript content.

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Table 1: Keyboard shortcuts of Aquarius iNtuition Client Viewer for different image postprocessing functions

Group	Function	Keyboard Shortcut
3D VR General		
3D Mouse Operation	Rotate	Left button click and drag
	Re-center	Click Middle button
2D Mouse Operation	Paging	Scroll wheel
		Left button click and drag
		Middle and Right buttons click and drag
	Paging with Slow Speed	Left button click and drag, then Shift
		Middle and Right buttons click and drag, then Shift
	Link to 3D ON/OFF	Middle button double click
3D / 2D Mouse Operation	Window Level	Left and Right buttons click and drag
		Move mouse cursor over W/L and Left button click
		Key: 1-9. 0 is for reset.
	Pan	Right button click and drag
	Zoom	Middle button click and drag
	Re-center	Alt + Left button click
	Move Scale Bar	Left button double click on the scale bar. Left button click on it and drag.
Capture	Capture	C
	Capture All	Ctrl + Shift + C
	Capture All in One	Ctrl + Alt + C
	Capture to Folder	Ctrl + S
Measurement	Distance	D
	Ellipse	E
	Profile	I
	Angle	Shift + comma (,) / Less than (<)
	Distance Pair	Ctrl + D
	Polygon	Ctrl + P
	Fat Analysis	Ctrl + O
	Select Previous Result	Ctrl + Open Brackets ([)
	Select Next Result	Ctrl + Close Brackets (])
	Mouse Escape	Esc
	Delete Measurement	Delete
Measurement Protocol	Export AIM xml file	Shift + E

	Move to Next Step	B
Finding	New Finding	N
	Show Measurement Result	Semicolon (;)
Arrow / Text	Arrow/Text	M
	Landmark Arrow	Ctrl + M
	Text	T
Orientation	Anterior	A
	Posterior	P
	Head	H
	Feet	F
	Right	R
	Left	L
	Rotate to Up	Up(↑)
	Rotate to Down	Down(↓)
	Rotate to Left	Left (←)
	Rotate to Right	Right(→)
	Angle Setting (LAO, RAO)	O
Batch 2D	Wizard	F8
G-Bar	Show G-Bar	G
CPR	Enter CPR Mode	V, F7
	Show / Hide Centerline	Ctrl + T
CPR – Edit Centerline	Quick Edit Mode	Shift + Move mouse over CPR window
	Add / Delete Point	Shift + Left button click
	Smooth Centerline	Ctrl + Left button click and drag
CPR – Edit Contour	Redraw	Shift + Left button and draw
	Nudge	Alt + Left button and draw
Region Growing	Region Growing	F5
	Select Visible Region	Shift + Left button hold
	Select Visible and Invisible Region	Shift + Ctrl + Left button hold
Free ROI	Free Curve	F6
Free ROI – 3D	Exclude	Shift + Left button drag
	Edit	Shift + Left button click to draw region, then click button from Free ROI tool
	Add Back Previously Removed Region	Shift + Right button click and drag
Free ROI – 2D	Edit	Shift + Left button click to draw region, then click button from Free ROI tool

Mask	Smooth Mask	Ctrl + E
Crosshairs	Re-center MPR Crosshairs	Alt + X
	Show / Hide Crosshairs	X
Cutplane	Slab	W
	MPR Map ON/OFF	Alt + W
	Modify Thickness	Ctrl + Middle button click and drag
Cube view	Cube View	Q
		Space + Left button click
	Change Cube Size	Middle button click and drag
	Zoom	Ctrl + Middle button click and drag
Render Mode	3D VR	F2
	3D Perspective	Alt + F2
	MPR	F2
	MIP	F3
	Draft/Fine ON/OFF	Ctrl + F
4D Cine	Backward	Page Down
	Forward	Page Up
	Play Forward	Period (.)
	Speed Control	Comma (,)
Layout	1x1	Ctrl + F2
	2x2	Ctrl + F3
	2x2 Vessel Track	Ctrl + F4
	2x2 CPR Vertical	Ctrl + F5
	2x2 CPR Horizontal	Ctrl + F6
	Back to Previous Layout	Double click
Other	Undo	Ctrl + Z, Z
	Redo	Ctrl + Y
	Control Panel ON/OFF	Ctrl + R
	Multidata Sync	Space bar
	Full Screen Mode	F11
	AQi Online Help	F1
Patient List Preview		
Mouse Operation	Open Quick View Panel	Left button double click
	Paging with Slow Speed	Shift + Left buttons click and drag
Paging	Move Forward	Up(↑)
	Move Backward	Down(↓)
	Go First Slice	Home
	Go Last Slice	End
	4D Phase Forward	Right(→), Page Up

	4D phase Backward	Left (←), Page Down
Output Panel		
	Drag and Drop an Image in Format	Left button click + drag and drop
		Ctrl + Left button click and drag
	Open Edit Window	Left button double click
TDA		
Paging	Backward	Left (←)
	Forward	Right(→)
	Level Down	Down(↓)
	Level Up	Up(↑)
Rendering Mode	MPR	F3
	MIP	F4
	BF	F5
	BV	F6
	MTT	F7
	Penumbra	F8
	Permeability	F9
TVA		
Colored Motion	Colored Motion	K
Flythrough		
User Annotation	Landmark Arrow	M
Candidate Marker	Candidate Marker On/Off	Pipe (|)
	Previous Maker	Open Bracket ([)
	Next Marker	Close Bracket (])
	Flat View Forward / Backward in the Path	Left button click
		Alt + Left button click
	Tilt Camera Angle between Left and Right	Left button click and drag horizontally
Cube View	Change Cube Size	Shift + Middle button click and drag
Perspective View	Orbit	Ctrl + Left button click and drag