Application of Non-Destructive Inspection of Endangered Animals using Soft X-ray Radiography, Computed Tomography and Magnetic Resonance Imaging: Case Study of a Northern Smooth-tailed Tree Shrew (Dendrogale murina)

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稀少動物に対する不破壊検査、computed tomography およびmagnetic resonance imaging を用いた非破壊検査の応用：キタノソオツバイ

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ABSTRACT. This research demonstrates the application of diagnostic imaging techniques using soft X-ray radiography, computed tomography (CT) and magnetic resonance imaging (MRI) for non-destructive inspection of the northern smooth-tailed tree shrew (Dendrogale murina). A non-invasive morphological observation is possible in each method. Soft X-ray radiography reveals the excellent skeletal system, but the soft tissue structures are projected with superimposition of morphological structures. However, 3-dimensional renderings of CT images can be manipulated to provide images of the skin surface and skeletal system from any view, though spatial resolution was limited. Although MRI provides sectional morphological images in any plane, magnetic susceptibility artifacts from metallic foreign bodies were seen. Findings from this study suggest that medical imaging techniques can be successfully used for non-destructive interrogation of endangered animals. Yet it is important to remember that the selection of the imaging modality depends on its purpose.

Key words：computed tomography (CT), magnetic resonance imaging (MRI), northern smooth-tailed tree shrew (Dendrogale murina)

Because the populations of endangered animals are small, samples and specimens for collecting biological data are rare, and there are very few opportunities for invasive morphological observation. This study demonstrates the application of non-destructive medical imaging techniques for morphological characterization of endangered animals. The
northern smooth-tailed tree shrew (*Dendrogale murina*) used in this investigation, one of the arboreal species of Scandentia, was captured in Thailand [1-4]. The specimen had a body length of 11.0 cm, and was fixed in 10% formalin solution and preserved in 70% ethanol.

Soft X-ray radiographs were acquired using SOFTEX-CSM-2 (Softex, Tokyo, Japan), industrial X-ray film (Fuji Photo Film, Tokyo, Japan) and X-ray Film Cassette (JK 10 by 12, Okamoto Manufacturing, Tokyo, Japan). Dorsoventral and lateral projection radiographs (Fig.1) were taken using an exposure technique of 50 kVp, 5 mA and 50 seconds exposure time. Images provided excellent anatomical detail of the skeletal system and, to a lesser extent, the abdominal and thoracic viscera. Excellent discrimination between compact and spongy substance was possible. In this specimen, a transitional 13th vertebra was also detected at the level of the thoracolumbar junction (Fig.1B, arrow). Due to superimposition of viscera, similarity density of the abdominal and thoracic viscera and incomplete aeration of the lungs, topographical details of the soft tissues were not clearly defined. Metal dense radiopaque debris was detected in the digestive tract as an incidental finding. The computed tomography (CT) images were acquired using a conventional helical CT scanner (X vision/Real, Toshiba Medical Systems, Tokyo, Japan). Images were

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Fig. 1  Soft X-ray radiographs (A: lateral view, B: dorsoventral view) reveal both skeletal and soft tissues. Anatomical detail of the skeletal system is particularly good owing to the density of bone and the inherent spatial resolution of the radiographic system. Note the definition between the Ulna and Radius, the Tibia and Fibula and the bones of the digits. A transitional vertebra (B, arrow) and atelectasis were also depicted.
acquired in the sagittal plane in helical mode using 0.6 mm slice collimation and exposure parameters of 130 kVp and 100 mAs. Imaging data was 3-dimensionally surface-rendered using image processing software included as a part of the CT operating system. Representative images are shown in Fig. 2. By rotating the surface renderings using an interactive image processing workstation, it is possible to observe anatomical structure in three dimensions. For the specimen described in this paper, skin surface and skeletal renderings were generated using image segmentation methods to isolate tissues of specific density. Although the in-plane spatial resolution of the CT images is excellent, it is not as good as that of conventional, high-detail radiography. In the imaged specimen for instance, the transitional vertebra and the definition between the Ulna and Radius seen on radiographs is not evident on CT. Also, surface rendering, as the name implies, provides only an image of the object surface limiting its use when internal anatomical detail is of interest. Magnetic resonance (MR) images were obtained with a 1.5 tesla magnetic field strength unit (VISART™, Toshiba Medical Systems) consisting of a superconducting magnet equipped with quadrature radio frequency human head originated coil. T1 weighted images (Fig. 3) were acquired using a spin echo pulse sequence (repetition time 500 msec [sagittal plane] or 400 msec [dorsal plane], echo time 15 msec, 2 mm slice thickness, field-of-view [FOV] = 18cm, 512 × 512 matrix, 10 numbers of excitation). On MR images, the cerebrum, cerebellum and spinal cord were visible, and soft tissue such as the heart, liver, kidneys and digestive tract were observed. Metallic foreign bodies were also incidentally identified in the digestive tract due to the production of a magnetic susceptibility artifact (arrows) [5].

MR relies on tissue differences in the response of hydrogen ions to radiofrequency wave pulses to produce image contrast. Because of the paucity of mobile hydrogen protons in dense cortical bone, skeletal structure is not well depicted. In addition, the pattern of the muscular system reported in the previous anatomical studies [1] was not observed due to the spatial resolution limits of the study. Small organs such as the adrenal gland (4-5 mm) are therefore not observed even when thin cross-sectional slices are acquired using a conventional clinical MR scanner. In general, image quality and spatial resolution can be improved, up to the system limitations of the scanner, by increasing such parameters as matrix size and number of excitations and by decreasing the FOV and slice thickness. However, this comes at a cost of increased time for image acquisition, which can increase rapidly with only slight improvements in resolution. This time constraint can be prohibitive when scanning live, anesthetized animals, but is a lesser consideration when scanning specimens. The acquisition time for MR images described in this investigation was 40 minutes using a conventional human clinical scanner, and resulting in-plane spatial resolution was 0.35 mm. Spatial resolution can be markedly improved by using a small-bore, high magnetic field strength, high-resolution MRI unit. Resolutions of under 20 micrometers can be attained using such MR microscopy systems [6].

The application of non-destructive interrogation techniques has progressed dramatically in recent years. The term of ‘non-destructive inspection’ was originally from inspecting an atomic power station, architecture and dockyard by means of visual, acoustic emission, ultrasonic and radiographic testing. Non-destructive methods of interrogation have also been
Fig. 3  Magnetic resonance images (A: sagittal plane, B: dorsal plane) reveal the cerebrum (a), cerebellum (b), spinal cord (c), heart (d), liver (e), kidney (f) and digestive tract. Magnetic susceptibility artifacts (arrows) produced by foreign bodies can be seen in the digestive tract.

used for analyzing such specimens as Egyptian mummies [7] and ancient manuscripts [8]; and have more recently been employed as screening methods to non-invasively examine mail for explosives and other dangerous materials. In this investigation, we used non-destructive diagnostic imaging methods for morphological observation of an endangered species specimen. These results suggest that the application of imaging diagnosis is a new option for endangered animals as a non-destructive inspection method. Yet it is important to remember that the selection of the imaging modality depends on its purpose.

要 約
キタホソオツバイ northern smooth-tailed tree shrew （Dendrogale murina）に対する非破壊検査として、軟エックス線、computed tomography (CT) および magnetic resonance imaging (MRI) を応用した。いずれの画像診断法も非侵襲的な形態観察が可能であった。軟エックス線像は骨格系の観察に優れたが、透過像であるため軟部組織が重複した。三次元CTは骨格および皮膚面の多方向からの観察が可能であったが、解像度には限界があった。MRIは多方向からの断層画像による形態観察が可能であったが、金属異物による磁化率アーチファクトが出現した。以上、画像診断法は稀少動物の非破壊検査として利用できることが示唆された。なお、画像診断手法は観察の目的により選択することが重要である。

REFERENCES
Application of Non-Destructive Inspection


