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Four-dimensional computed tomography evaluation of condylar movement in a patient with temporomandibular joint osteoarthritis

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Abstract

Temporomandibular joint osteoarthritis (TMJ-OA) is a disease of the bone, cartilage, and supporting tissues of the joint. Patients with advanced TMJ-OA often suffer from symptoms such as pain, swelling, and joint dysfunction, and sometimes required surgical intervention when conservative treatment is not effective. The etiology of TMJ-OA remains elusive. The usefulness of four-dimensional computed tomography (4DCT) in motion analyses of various joints has been recently reported. This article introduces a novel imaging technique of 4DCT which aims to identify kinematic features that may be associated with the etiology of TMJ-OA. In a 69-year-old female patient with severe TMJ-OA, 4DCT evaluation of the condylar movement was performed. During the scan, she was instructed to masticate cookie normally and her natural condylar movement during mastication was evaluated. The coronal 4DCT motion images revealed that the synovial cavity was narrower on the affected side than on the non-affected side. Repeated friction between the articular surface of the condyle and the caudal surface of the articular eminence was observed during natural mastication. Although friction between the condyle and the articular eminence has been considered as a factor in the initiation and progression of TMJ-OA in previous experimental studies using animals, this is the first study to directly visualize the friction between the atrophic and flattened condylar surface and the articular eminence. 4DCT is a novel imaging technique with the potential to assess kinematic features that cannot be visualized with other imaging modalities in patients with TMJ disease.

Introduction

The temporomandibular joint (TMJ) is a complex synovial joint with an articular disc and mechanical features.[1] Osteoarthritis (OA) is a chronic, progressive, and debilitating disease that causes the gradual deterioration (degeneration) of the cartilage in joints.[2] Temporomandibular joint osteoarthritis (TMJ-OA) is a disease of the bone, cartilage, and supporting tissues of the TMJ. In principle, the treatment of TMJ-OA is conservative and aims to relieve symptoms, and mostly includes physical therapy, occlusal splints, non-steroidal anti-inflammatory drugs, and arthrocentesis.[3,4] Surgical intervention is performed only for severe TMJ-OA in patients with impaired joint function and intractable pain.[3,5,6] However, there are no definite criteria governing which TMJ-OA cases should be considered for surgical intervention.

The etiology of most TMJ-OA is complex and multifocal, or unknown.[3] OA may be a final common pathway for several joint conditions, including inflammatory, endocrine, metabolic developmental, and biomedical disorders.[7] Degenerative change in TMJ-OA results from dysfunctional articular remodeling caused by two possible mechanisms: (1) a decrease in the adaptive capacity of the articulating structures of the joint; or (2) excessive or sustained physical stress of the TMJ articular structure that exceeds the normal adaptive capacity.[7] The host-adaptive capacity may decrease as a result of age, systemic illness, or hormone factors.[7] Mechanical factors that overload the articular tissues and result in the onset and development of TMJ-OA include trauma, parafunction, unstable occlusion, functional overloading, and increased joint function.[7] Macrotrauma in the condylar area causes degeneration of the articular cartilage and production of inflammatory mediators.[7] Parafunction produces abnormal forces that lead to the onset of disc displacement and degenerative changes in the condyle and articular eminence.[7,8] Parafunctional hyperactivity of the lateral pterygoid muscle leads to masticatory muscle pain.[7,9] There is a possibility that dysfunction of the lateral pterygoid muscle results in TMJ-OA.[7,9] Functional overloading and increases in joint friction may act together as etiological events for TMJ -OA.[7]

The usefulness of four-dimensional (4D) (three spatial dimensions plus a time axis) computed tomography (CT) was first introduced for preoperative evaluation of the parathyroid and for localizing parathyroid adenoma.[10,11] The fourth dimension refers to the radiographic changes in the perfusion quality of hyperfunctioning glands observed over time.[11] The potential of 4DCT as a visualization and clinical tool for assessing dynamic movement in various joints, such as the wrist, has been recently noted.[12,13] 4DCT has also been useful in determining the size of the pharyngeal flap in patients with persistent velopharyngeal insufficiency, providing a detailed morphological and kinematic analysis of velopharyngeal closure.[14] We recently conducted a novel pilot study using 4DCT to analyze jaw movement during normal mastication in patients who underwent mandibular reconstruction with free fibula flaps.[15] In the present case study, we used our novel 4DCT imaging technique to analyze condylar movement in a patient with severe TMJ-OA, with the aim of identifying the morphological and kinematic features that may be associated with the etiology of TMJ-OA.

Case report

A 69-year-old female who had been diagnosed with TMJ-OA was referred to our department. She had experienced a TMJ dislocation around the age of 20, but had no other history of trauma or otitis media. She had no systemic illnesses such as rheumatoid arthritis. One year before her first visit to our department, she visited another hospital complaining of severe pain around the left TMJ and severe trismus (maximum mouth opening < 10 mm). Blood tests showed slightly high levels of neutrophils (79.3%) and C-reactive protein (1.35 mg/dL), and the previous doctors diagnosed an infectious lesion and administered antibiotics intravenously. The patient’s symptoms of pain, swelling, and severe trismus gradually improved over the next few days (blood test results 3 days after the initial administration of antibiotics were neutrophils 50.8%, C-reactive protein 2.01 mg/dL). The patient subsequently experienced similar symptoms repeatedly, and was referred to our department.

Panoramic x-ray and CT images taken in the previous hospital before referral to our department showed evidence of osseous changes in the left TMJ. The left condyle was obviously smaller and more flattened than the right condyle. The axial CT image revealed condylar atrophy with severe sclerosis and internal resorption. The coronal short-tau inversion recovery image (STIR) of the magnetic resonance imaging (MRI) showed a focal area of high signal intensity in the left synovial cavity, indicating joint effusion. The coronal T1-weighted images showed obvious atrophic changes in the left condyle, and the bone marrow signal intensity of the left condyle was obviously lower than the right. The sagittal STIR image showed anterior disc displacement (Fig. 1).

We diagnosed the patient's condition as TMJ-OA. The differential diagnoses included osteomyelitis of the condyle with unknown cause, and synovial chondromatosis without loose body formation. The patient had repeated symptoms of severe pain and swelling that were refractory with conservative treatment. Our pilot study using 4DCT was approved by the Medical Ethics Committee of Kobe University, and the patient gave written informed consent to participate.

CT examination was performed with an Aquilion ONE (Toshiba Medical Systems Corporation, Otawara, Japan). The imaging protocols were as follows: rotation time 0.35 s/rotation; slice thickness 0.5 mm; field of view 220 mm; tube current 20 mA; tube voltage 120 kV; scanning time 5 s. All images were acquired axially with a 320-detector row CT to allow for multiple phases of unenhanced 3D volume acquisition with 10 cm coverage. The patient's forehead was fixed with tape to prevent bodily movement, and she was instructed to chew a cookie during the scan to assess normal masticatory movement. The gantry was angled to limit radiation to the eyes, and the inferior aspect of the field of view was tailored to minimize radiation to the thyroid. The exposure dose was within the notification values recommended by the AAPM Working Group on Standardization of CT Nomenclature and Protocols for 4DCT (https://www.aapm.org/pubs/CTProtocols/documents/Notification). For image post-processing, volume rendering (VR) and multiplanar reconstruction (MPR) images were generated using

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commercial software (Ziostation2, AMIN Inc., Tokyo, Japan). The radiation dose for image acquisition in this patient was as follows: computed tomography dose index (CTDI) 18.8 mGy and dose length product (DLP) 263.4 mGy × cm.

Figure 2 shows the sagittal VR and MPR images, and the coronal MPR images. As shown in video clip 1 (particularly in the coronal MPR motion images), the left synovial cavity appeared to be narrower than the right. The superior surface of the left condyle and the articular surface of the temporal bone seemed to be rubbing together during condylar protrusion (Video 1). In contrast, the right synovial cavity was wide, and no contact was observed between the articular surfaces of the right condyle and articular eminence (Video 1).

A surgical intervention to relieve symptoms was proposed and accepted by the patient. A condylectomy was performed under general anesthesia. Histopathological examination ruled out possible diagnoses of osteomyelitis and synovial chondromatosis. The final diagnosis was TMJ-OA. One year postoperatively, the recurrent symptoms (severe pain and swelling) had completely resolved. Although the mandible shifts to the left side during mouth opening, there is no trismus and the occlusion is acceptable. The patient is satisfied with the procedural outcome (Fig. 3).

Discussion

The potential causative mechanisms of TMJ-OA are: (1) a decrease in the adaptive capacity of the TMJ tissues; and (2) sustained stress on the TMJ tissues that exceeds the normal adaptive capacity.[7] The patient in this case report had no systemic lesions that could cause a decrease in her host-adaptive capacity. She also had no history of macrotrauma, except for dislocation of the TMJ when she was young. We observed repeated friction between the articular surfaces of the diseased condyle and the articular eminence during normal mastication when assessing the 4DCT image of coronal motion. Increased joint friction is an etiological event for internal derangement of the TMJ and TMJ-OA.[7] Experimental studies of the porcine TMJ have found that surface friction in the TMJ may be an important factor in compromised lubrication and the development of OA.[16,17] To our knowledge, this is the first report that has directly visualized repeated friction between the diseased condyle and the articular eminence during natural mastication in a patient with severe TMJ-OA.

Although the precise cause of TMJ-OA remains elusive, functional overload with subsequent microtrauma may be a crucial event.[18] Mechanical overload may be an initiation factor for degenerative changes in the TMJ, resulting in condylar resorption and deformity.[18] Unilateral mechanical overloading of the joint may be caused by an imbalance of the masseter muscle between the right and left sides.[18] Patients with TMJ-OA have a smaller and significantly more posteriorly rotated mandible compared with normal subjects.[18] The condyle on the midline-shifted side is smaller and has a higher incidence of disc displacement than the condyle on the non-shifted side.[19] In our patient, the imbalance of the masseter muscle was not investigated with electromyography. There was no evidence of a midline shift in the mandible.

Henderson et al.[20] hypothesized that the altered joint movement or travel path (kinematics) caused by trauma or parafunctional habits is one of the underlying mechanisms involved in progressive TMJ-OA. They conducted an experimental study in which altered occlusion was mechanically induced in rabbits wearing unilateral molar dental splints, and suggested that fibrocartilage degeneration of the condyle, but not the TMJ disc, might be the initial source of TMJ degeneration, and that the decrease in anteroposterior displacement of the working condyle might be indicative of condylar degeneration and early-stage TMJ-OA.[20,21] If the joint kinematics do not return to normal, the altered kinematics may be a primary driver for additional joint and end-stage TMJ-OA.[20] In our patient, severe anterior disc displacement without reduction was observed in the sagittal MRI.

In the healthy TMJ, the frictional coefficient between the cartilage surfaces is considered to be almost zero because of the presence of synovial fluid.[7,16] When synovial fluid degrades and its viscosity decreases, boundary lubrication between the articular surfaces becomes impaired, leading to an increase in the frictional cofficient.[16] Additionally, the frictional coefficient increases during comprehensive loading.[16] The principal role of the TMJ disc is to reduce surface friction. Friction on the surface of the condyle is at least three times greater without the aid of the TMJ disc than when the disc is in place.[17] Interestingly, there was a small effect of static sustained loading on the frictional coefficient in the intact porcine TMJ model that analyzed the frictional coefficient after constant loading.[16] When the frictional coefficient increases, the shear stresses within the TMJ structure become greater, resulting in the fatigue, damage, and irreversible deformation of the TMJ tissues that initiate TMJ-OA.[7] Importantly, 4DCT motion images shown in this report revealed that the friction between the articular surfaces of the condyle and the eminence seemed to be intermittent, not static and sustained. Even in non-TMJ-OA patients with disc displacement without reduction, pathological friction between the articular surfaces of the condyle and the eminence may occur. 4DCT motion analysis may be useful for early detection of sings of TMJ-OA in patients with disc displacement.

Management of TMJ-OA can be non-invasive, minimally invasive, or surgical.[7] Our patient had clinical symptoms such as recurrent severe pain around the TMJ on the affected side and visible swelling, and her condyle was flattened and atrophic on CT images. We treated our patient with condylectomy only, without joint replacement, and the procedural outcome was acceptable (no pain, no restriction of mouth opening, and restoration of occlusion). As shown in this report, if the synovial joint space has narrowed and intermittent friction between the condyle and the articular eminence during normal mastication is detected with 4DCT motion analysis, conservative treatment to relieve pain may have little effect, so invasive management options may have to be considered.

The most significant problem of 4DCT is radiation exposure. The radiation dose for 4DCT image acquisition can be reduced to a level approximately 1.38 times higher than the dose applied for general facial CT in our hospital (CTDI 13.6 mGy and DLP 190.4 mGy × cm). Another limitation of 4DCT is that motion visualization of the TMJ disc is impossible. A previous study using cinematographic (CINE) MRI reported the usefulness of CINE MRI to assess disc mobility and reduction at various stages of mouth opening, compared with static MRI.[22] However, CINE MRI can be configured to focus only on one arbitrarily selected sagittal slice. 4DCT seems to be superior to CINE MRI in three-dimensional evaluation of mandibular kinematics in every slice from every direction. Metal artifacts are also problematic in 4DCT analysis. We predicted that we would be able to identify the habitual chewing side of the study subject by assessing movement during normal mastication of a cookie containing contrast agent in the 4DCT motion images. However, it was difficult to assess the movement of the cookie during mastication in patients have metal artifacts. Despite these problems and limitations of 4DCT, this form of imaging is the only means currently available for obtaining critical information about the etiology of TMJ-OA.

Conflict of interests

We have no conflict of interests.

Ethics statement/confirmation that permission of patients was given

The pilot study using 4DCT was approved by the Medical Ethics Committee of Kobe University. The patient gave written informed consent to participate in the pilot study.

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Figure Legends

FIGURE 1. *A*, Initial panoramic x-ray image. *B*, Initial three-dimensional computed tomography (CT) image. *C*, Initial axial CT image. *D–G*, Initial magnetic resonance image. *D*, Coronal short-tau inversion recovery image (STIR). *E*, Coronal T1-weighted image of the right condyle. *F*, Coronal T1-weighted image of the left condyle. *G*, Sagittal STIR image.

FIGURE 2. Still images of four-dimensional computed tomographic images. *A*, Right sagittal volume rendering (VR) image. *B*, Left sagittal VR image. *C*, Right sagittal multiplanar reconstruction (MPR) image. *D*, Left sagittal MPR image. *E*, Right coronal MPR image. *F*, Left coronal MPR image.

FIGURE 3. *A*, Occlusion 1 year after surgery. *B*, Mouth opening 1 year after surgery.

VIDEO CLIP 1. Videos of four-dimensional computed tomographic images. *A*, Right sagittal volume rendering (VR) image. *B*, Left sagittal VR image. *C*, Right sagittal multiplanar reconstruction (MPR) image. *D*, Left sagittal MPR image. *E*, Right coronal MPR image. *F*, Left coronal MPR image.

Figure

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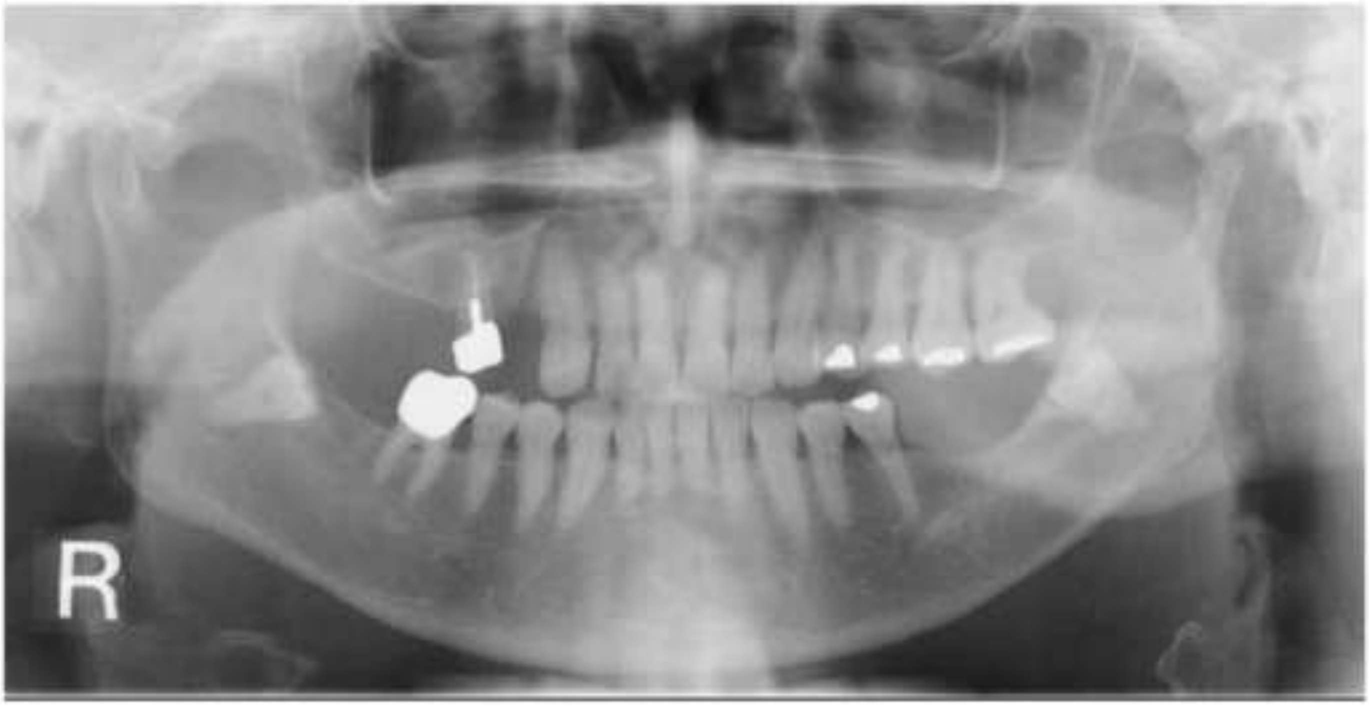

FIGURE 1A.

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FIGURE 1B.

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FIGURE 1C.

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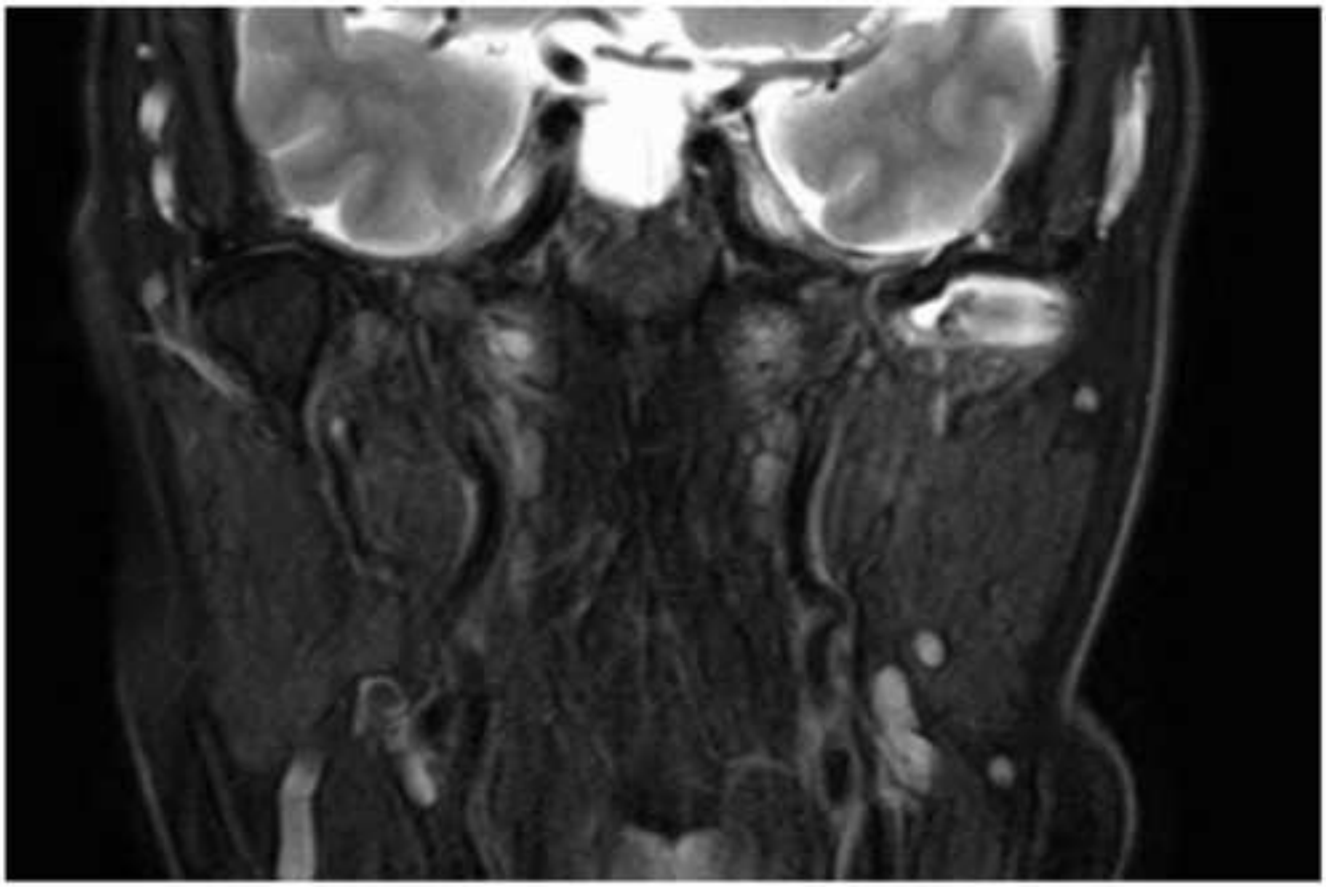

FIGURE 1D.

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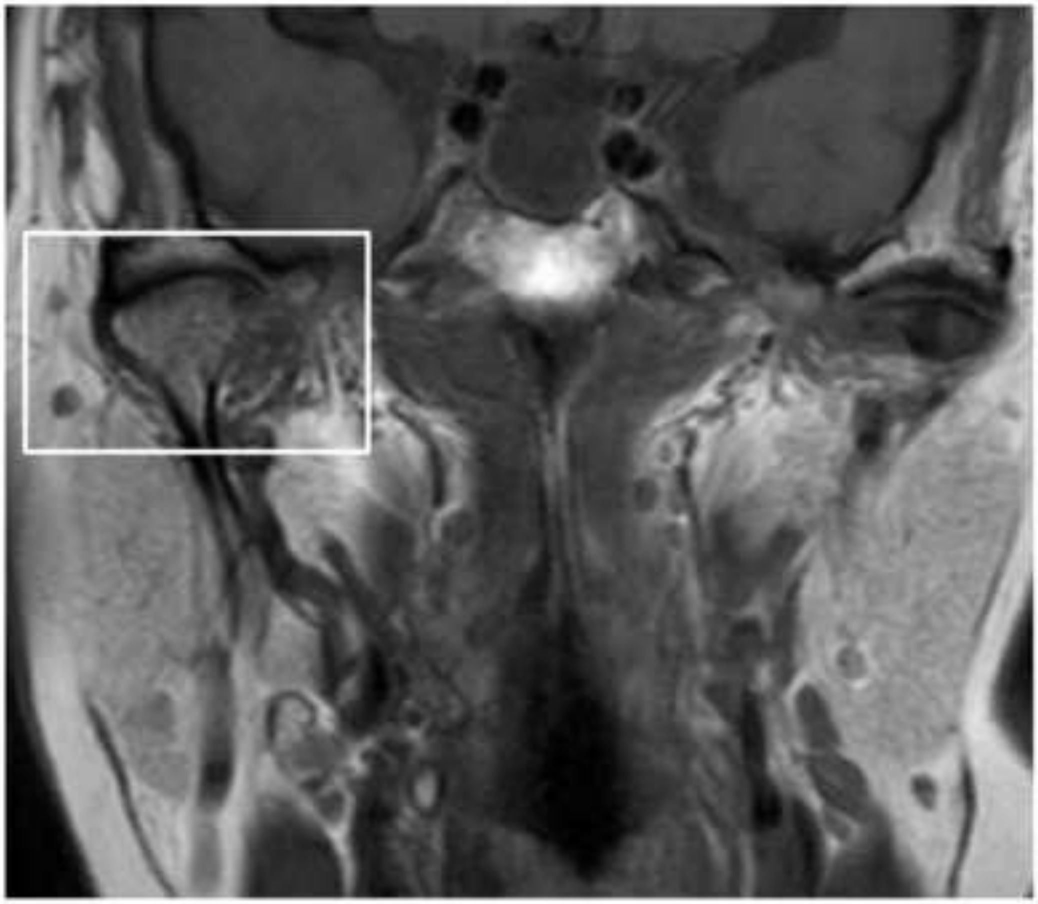

FIGURE 1E.

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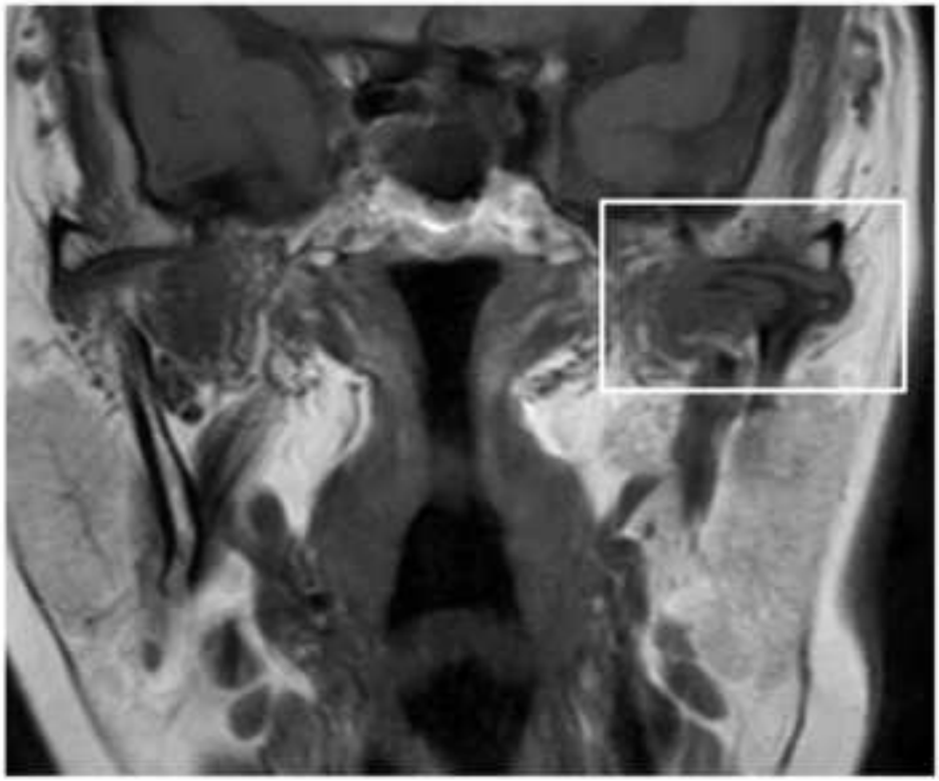

FIGURE 1F.

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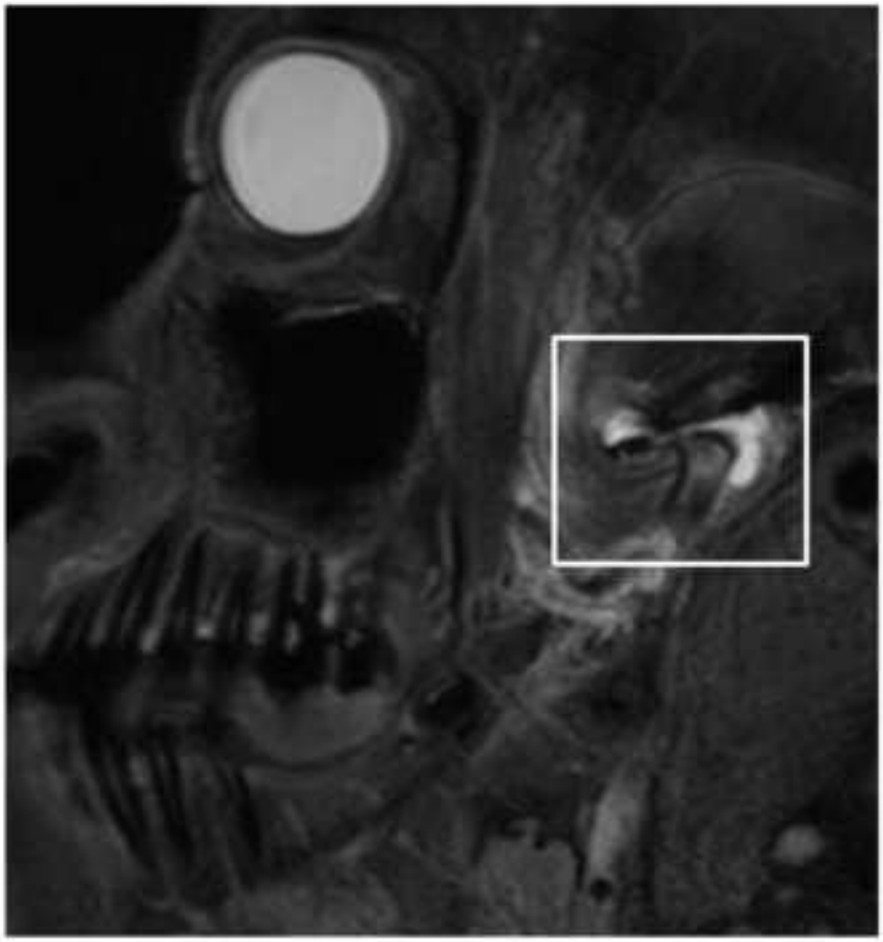

FIGURE 1G.

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FIGURE 2A.

Figure
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FIGURE 2B.

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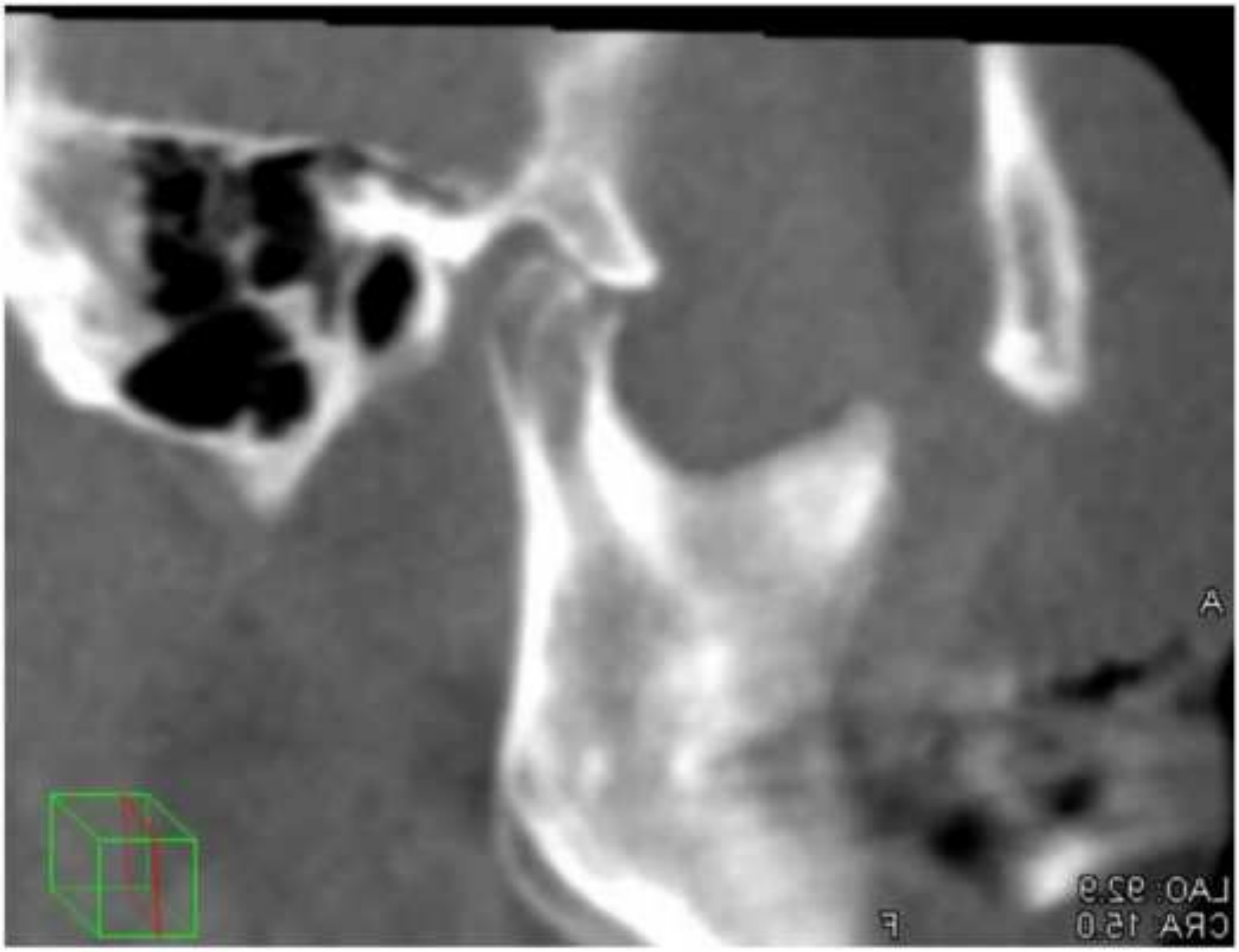

FIGURE 2C.

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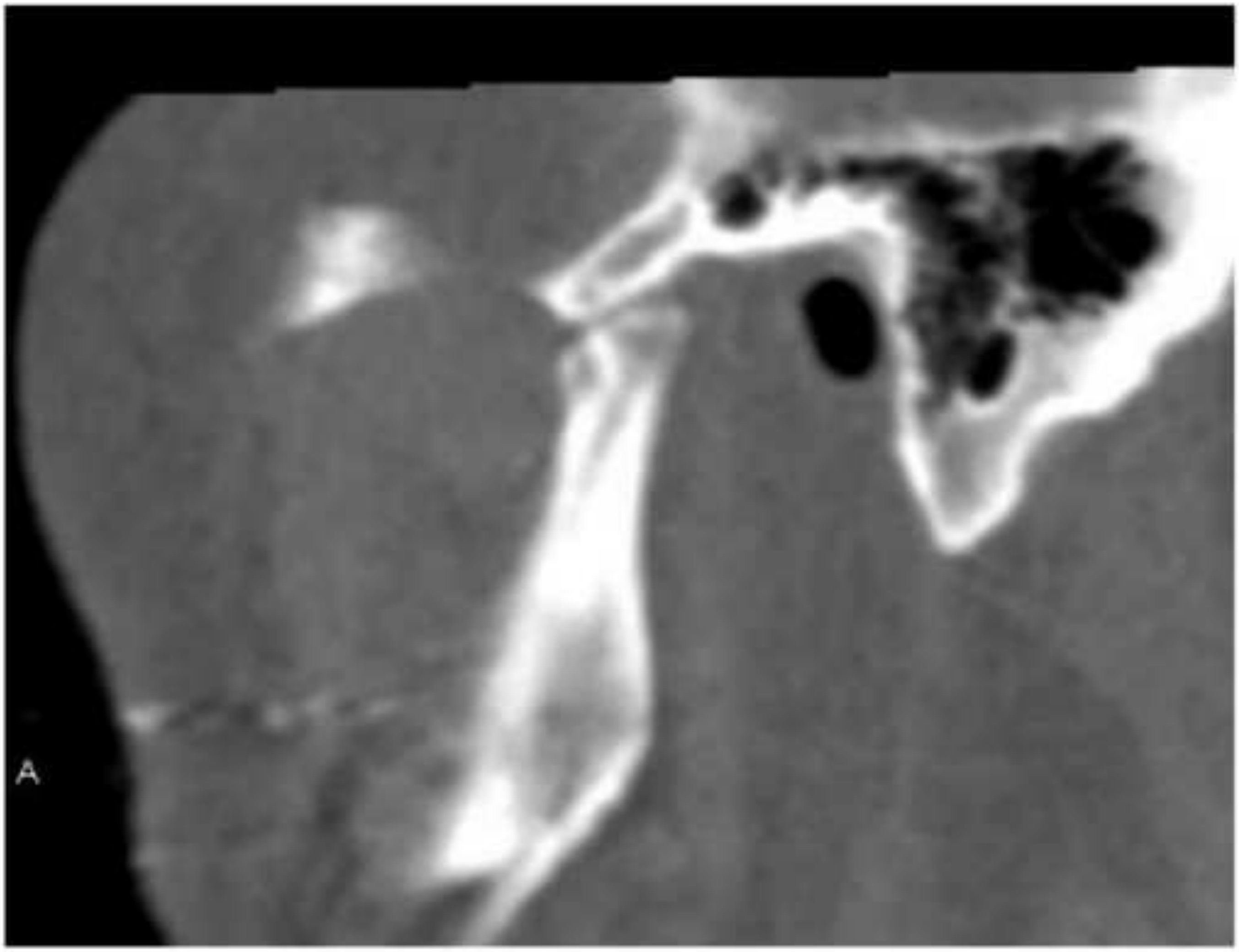

FIGURE 2D.

Figure

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FIGURE 2E.

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FIGURE 2F.

Figure
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FIGURE 3A.

Figure
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FIGURE 3B.