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CASE REPORT

Zoo animals

Orthognathic surgery to improve malocclusion in a chimpanzee (*Pan troglodytes*)

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Abstract

Malocclusion is a common finding in both companion animals and humans due to dental or maxillofacial discrepancies. Treatment depends on the complications and the species it presents in. In humans, orthognathic surgery is commonly performed to address skeletal malocclusions. A male chimpanzee born in 2002 and orphaned due to the bush meat pet trade was rescued in 2010 by Chimp Eden, a chimpanzee sanctuary. In 2017, it presented with inappetence and weight loss of 6-month duration. After a computed tomography scan was performed and full mouth impressions were made, a diagnosis of asymmetry of the mandible with the left side markedly shorter and rotated along its long axis was made (malocclusion class IV in a side-to-side direction). A bilateral sagittal split operation was performed to correct the malocclusion and improve its feeding. At the time of writing this report, it was eating freely and no complications were seen on multiple post-operative radiographs.

BACKGROUND

Malocclusions in dogs, cats and horses are well described in veterinary literature.[1–3] These malocclusions can be hereditary, a consequence of maxillofacial trauma or even delayed exfoliation of teeth.[4–6] Malocclusions that lead to trauma of the soft or hard tissues of the oral cavity are called traumatic malocclusions. In dogs and cats, these are often treated by the movement (orthodontics),[2] shortening of the teeth[7] or extraction (exodontics)[8] of the offending tooth or teeth. Orthognathic surgery (surgery to lengthen or shorten the maxillofacial skeleton) in horses with mandibular brachygnathia is advocated, but very few cases have been reported in the literature.[9]

In humans, malocclusions have a similar suite of aetiologies compared to animals,[10,11] but a much larger variety of treatment techniques have been developed. These range from exodontics[12] and orthodontics[13] to orthognathic surgery.[14] Malocclusion corrections are performed to improve masticatory function, reduce stress and pain on the temporomandibular joints, help alleviate obstructive sleep apnoea, correct dentofacial deformities as well as airway collapse patterns and for aesthetic reasons.[14–16]

Delayed eruption of teeth has been reported in a hand-raised orangutan (*Pongo* sp.),[17] but malocclusions in any of the great apes have not been documented in the literature. As the anatomy of the masticatory apparatus in great apes is similar to humans, it stands to reason that, should a malocclusion be diagnosed in a great ape, many of these advanced treatment modalities could be applicable.

By March 2021, there were an estimated 1115 chimpanzees (*Pan troglodytes*) in 16 Pan African Sanctuary Alliance (PASA) sanctuaries in Africa (J. Swart, personal communication, 2022). A further 150 chimpanzees are cared for in non-PASA sanctuaries (J. Swart, personal communication, 2022). These chimpanzees are often orphans injured by poachers of the bush meat trade in central and Western Africa. When adult chimpanzees are killed by poachers, the young will often cling to the dead females, and their removal by the poachers can be violent, resulting in injury.[18]

We report on a traumatic malocclusion in a male chimpanzee treated by a bilateral sagittal split osteotomy (BSSO), with radiological and clinical follow-up examinations up to 48 months post-operatively. This is the first case report of orthognathic surgery in a great ape.

CASE PRESENTATION

The patient is a male chimpanzee born in the Central African Republic in 2002. It was orphaned when its mother was killed by poachers and later sold into the pet trade. In 2010, it was rescued from the steel cage it lived in and brought to Chimp Eden, a chimpanzee sanctuary in South Africa belonging to the Jane Goodall Foundation. Initially, it was introduced to a group of 11 chimpanzees, but was later moved to a different group after one of the males in that group died. A total of 33 chimpanzees are living in three different hierarchical groups in this sanctuary.

In March 2017, concerns were raised that the patient had lost weight over the previous 6 months, and was reluctant to eat hard foods. During the initial assessment of the chimpanzee from a distance, the only abnormality noticed was a class IV malocclusion in a side-to-side direction. A decision was made to immobilise it and perform a full clinical evaluation as well as a detailed oral examination.

INVESTIGATIONS

The chimpanzee was initially premedicated with midazolam (Dormicum, Roche; 15 mg, orally [PO]), and anaesthetised with 1 mg of medetomidine (Wildlife Pharmaceuticals; 0.022 mg/kg, intramuscularly [IM]) and 100 mg of tiletamine-zolazepam (Zoletil, Virbac Centurion; 2.3 mg/kg, IM) via hand injection. A complete oral and dental examination was performed, followed by a head computed tomography (CT) scan. The following abnormalities were noticed (Figure 1):

- malocclusion class IV in a side-to-side direction;
- the mandibular head of the left condylar process was hypoplastic/atrophied (Figure 2);
- absence of the left mandibular second premolar tooth (35), as well as the first and second molar teeth (36,37);
- the left mandibular third molar tooth was lingually deviated and made no contact with the maxillary arcade (confirmed on oral evaluation).

One month later, it was again immobilised for a full clinical examination, including an echocardiogram that is routinely performed in all older male chimpanzees due to their high risk of cardiac disease using above-mentioned drug protocol.[19] During the same anaesthetic episode, full mouth impressions and bite registration were done using a polyvinyl siloxane impression material (President regular putty, Coltene), whereafter a polyvinyl siloxane wash (President light body, Coltene) was used to record more precise details. This stone model together with the CT scan was presented to a human maxillofacial surgeon to discuss the presentation of the chimpanzee and to plan the surgical treatment. The patient was diagnosed with ventricular subcompaction, and treatment with pimobendan (20 mg PO once a day; Vetmedin, Boehringer Ingelheim) and a nutraceutical (CardioFocus supplement, Vetbrands) was initiated. Apart from the malocclusion and the cardiac pathology, no other abnormalities were detected.

While its progress on its new cardiac therapy was monitored, its diet was also changed to boiled vegetables, eggs and soft fruits to improve feeding. During this time, we evaluated all of its data with a human maxillofacial surgeon (Christiaan Fritz Hoogendijk), and the decision was made to perform a BSSO on the mandible.

In November 2018 (14 months post-operative), follow-up radiographs of the chimpanzee's head were taken to assess post-operative healing. Follow-up radiographs were also done in November 2019 (26 months post-operative) and April 2021 (43 months post-operative) as part of routine health checks and tuberculosis screening.

LEARNING POINTS/TAKE-HOME MESSAGES

- Malocclusions do occur in great apes and may be a reason for poor appetite or painful mastication.
- Malocclusions can result in increased stress on the temporomandibular joints causing oral pain of non-odontogenic origin.
- Trauma to a mandible, depending on the severity, location and age of the patient, can also affect the temporomandibular joints.
- Bilateral sagittal split osteotomy is possible in chimpanzees and may benefit them if they suffer from skeletal malocclusions affecting mastication.
- Considering greater biting forces in chimpanzee for orthognathic surgery, the use of two 2.5 mm or preferably 2.7 mm titanium mandibular reconstruction plates should be the minimum size used. Future surgeries and outcome will determine optimal plate size to be used in chimpanzee maxillofacial surgery.
- Post-operative care in great apes can be arguably more difficult compared to companion animals and humans in general, made more complicated when in a group setting.
- Further research is needed to establish the incidence of malocclusions in great apes and the effects it has on them.

DIFFERENTIAL DIAGNOSIS

Malocclusion class IV in a side-to-side direction, with the absence of the second premolar tooth (35), as well as the first and second molar teeth (36,37).

The mandibular head of the left condylar process was hypoplastic/atrophied.

Our hypothesis is that this individual suffered trauma to its left mandible and temporomandibular joint during the development phase. This trauma was severe enough to cause the loss of the left mandibular second premolar tooth (35), as well as the first and second molar teeth (36,37), as well as rotation of the remaining third molar tooth (38). A healed mandibular fracture is the most likely event that could explain this presentation.

TREATMENT

A BSSO is performed by making a series of cuts through the lateral and lingual cortices of the mandible to split the two surfaces without damage to the inferior alveolar nerve, artery or vein. Once split, the mandible can be moved into an improved physiological occlusion, after which it is stabilised by wires to

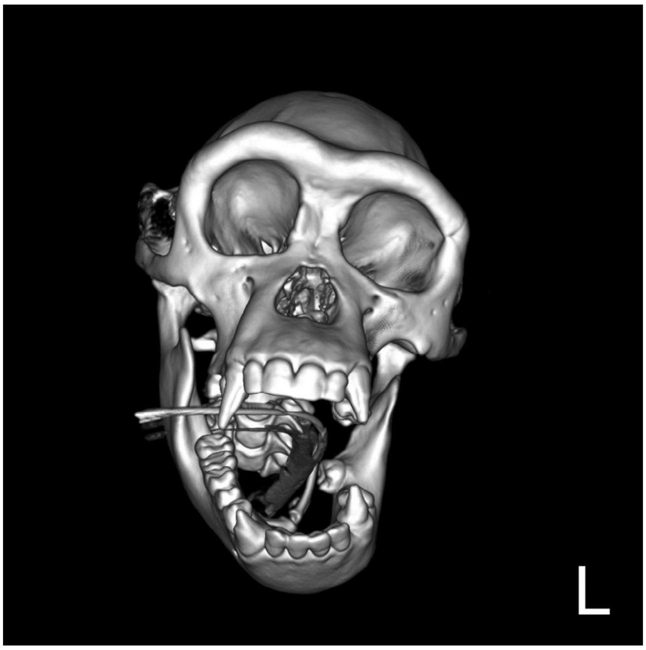

FIGURE 1 Three-dimensional volume rendering image of the chimpanzee's skull. The lingual inclination of the third left mandibular molar tooth, absence of the left mandibular second premolar tooth, as well as the first and second molar teeth and general asymmetry of the mandible are visible.

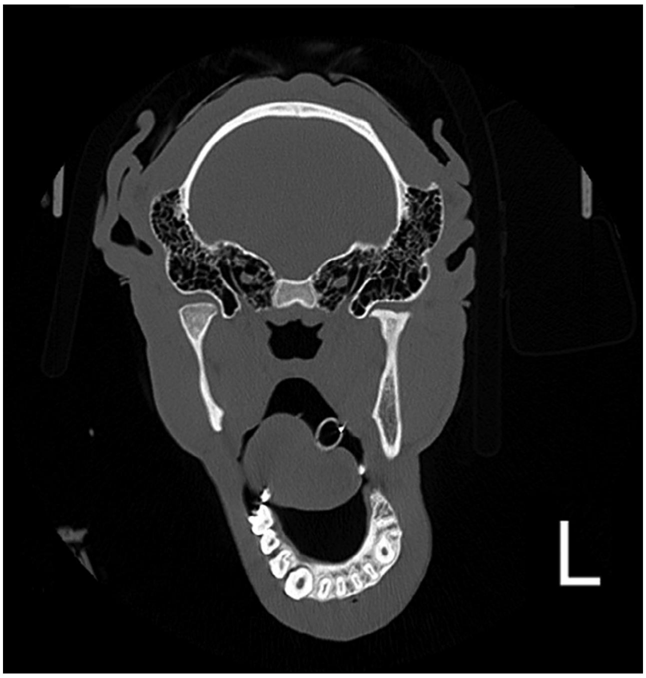

FIGURE 2 A transverse computed tomography image in a bone window of the chimpanzee's mandible illustrating both TMJs. The left mandibular head of the condylar process is smaller and irregular compared to the right. This may indicate either atrophy, hypoplasia or dysplasia, possibly as a result of the suspected trauma the chimpanzee suffered to its left mandible.

the maxilla around pre-placed intermaxillary fixation screws (IMF). The lateral mandibular cortices are then rigidly stabilised using 1.5 mm titanium maxillofacial locking plates.[20] This surgery aimed to improve the chimpanzee's occlusion and thereby improve its mastication. With the improvement in its occlusion, we hoped to reduce any further stress and

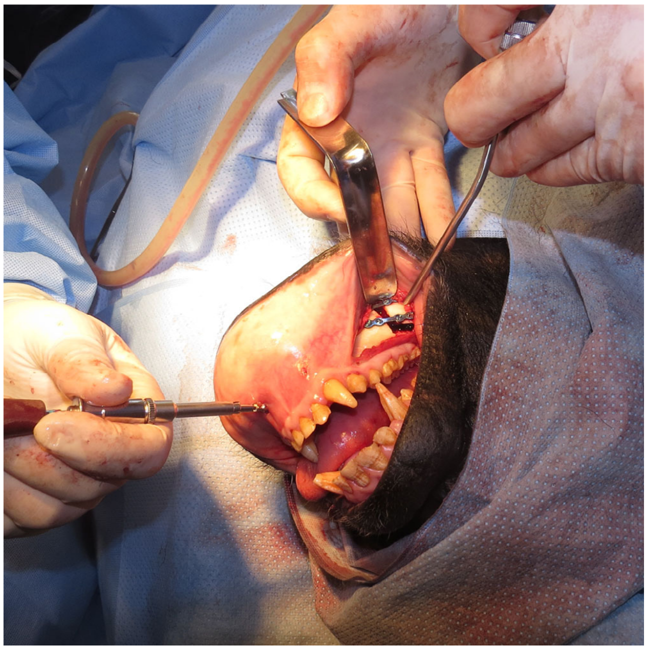

FIGURE 3 Intraoperative photo of the completed stabilisation of the right mandible with two 2 mm maxillofacial locking plates. The surgeon is currently removing one of the 2 mm intermaxillary fixation screws.

degeneration of the mandibular head of its left condylar process.

In September 2017, the chimpanzee was moved to a veterinary practice near the sanctuary where the surgery was performed. It was premedicated with 15 mg midazolam orally in grape juice (Dormicum 15 mg), and hand injected with zolazepam/tiletamine and medetomidine at the same dose as previously described. A second injection of 40 mg of zolazepam/tiletamine was given 56 minutes after the initial injection due to the insufficient effect of the previous dose. Orotracheal intubation was performed and anaesthesia was maintained by the administration of isoflurane (Isofor, Safeline Pharmaceuticals) carried in oxygen, delivered through a semi-closed circle system. Initially, the linguoverted left mandibular third molar tooth was extracted using a closed technique with extraction forceps. The BSSO was then performed as described, advancing the left side by 17 mm and the right by 5 mm. Once mobilised, the mandible was fixed to the maxilla by placing four 2 mm intermaxilliary fixation screws (IMF screws, DePuy Synthes) in pairs in the rostral maxilla and mandible. The mandible was moved into position, and secured to the maxilla by threading 0.5 mm (24 gauge) orthopaedic wire (Diag Import and Export) through each screw pair and tightened. Both sides were then stabilised with two 2 mm titanium maxillofacial locking plates (Narang Medical, Vindmed medical supplies) and 5 mm monocortical self-drilling, self-tapping screws on each side (Figure 3). The soft tissue was closed by a submucosal single interrupted layer of sutures, followed by a single continuous suture to close the oral mucosa using 4/0 polyglecaprone 25 (Monocryl, Johnson & Johnson). Post-operatively, the malocclusion approximated a class II malocclusion.

It was treated with amoxicillin clavulanic acid 390 mg (Augmentin 0.6 g per 20 mL; Aspen Pharmacare), buprenorphine 0.3 mg (Temgesic 0.3 mg/mL IM; Schering-Plough) and meloxicam 9 mg (Petcam 20 mg/mL IM; Ciplavet)

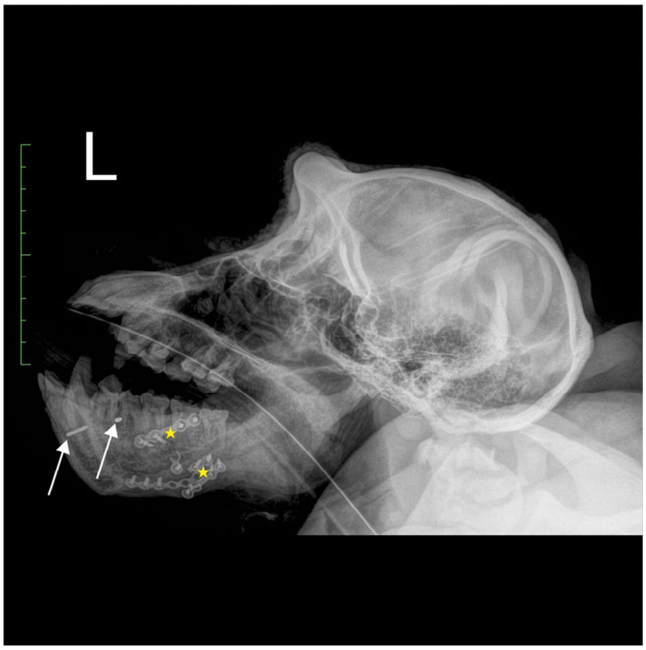

FIGURE 4 A left lateral radiograph of the chimpanzee's skull, 7 months post-operative. Two of the plates have fractured (yellow stars) and one section of one plate is absent. Dorsal and rostral to the plates, the remnants of two intermaxillary fixation screws can be seen (white arrows). There are no bone defects visible caudal to the molar teeth, indicating healing of the osteotomy sites.

FIGURE 5 A left lateral radiograph of the chimpanzee's skull, 14 months post-operative. All plates and plate fragments that were not removed are in place and no abnormalities can be detected. The rostral intermaxillary fixation screw that could not be removed previously is still in place, with no abnormalities around it.

intraoperatively, and reversed with 5 mg of atipamezole (Antisedan 5 mg/mL IM; Pfitzer).

It received 10 mL of paracetamol syrup (120 mg/5 mL twice a day [BID] PO; Panado, Aspen Pharmacare), amoxicillin clavulanic acid syrup 300 mg (Augmentin, 125 mg amoxicillin and 31.25 mg clavuanic acid per 5 mL, BID) and midazolam 7.5 mg (dormicum 7.5 mg tablets OID PO) for 7 days post-operatively.

The chimpanzee was returned to its enclosure for recovery from the anaesthesia.

OUTCOME AND FOLLOW-UP

The chimpanzee was kept in its night room separated from the other chimpanzees, but visual to the group. For the next 21 days, it was only allowed soft food and medications as described.

One week after surgery, the animal keepers reported it was eating hard foods again and consumed its first entire pineapple in years. This was unfortunately contrary to the post-operative instructions given. However, it continued to improve and during the April 2018 health examinations (7 months after surgery), it was once again immobilised for a follow-up echocardiography and to obtain skull radiographs to monitor the healing of the surgical site. Radiography revealed that two of the four plates broke (Figure 4). None of the BSSO lines were visible on lateral and dorsoventral skull radiographs. The surgical wounds healed and the mandible was stable in the new occlusion. The plates and screws showing implant failure were removed during this anaesthetic procedure. Due to the non-availability of an orthopaedic surgical set in this remote sanctuary, the mobile implants were removed with a soft tissue surgical kit. As it was under constant supervision and would be subjected to serial follow-up radiographs, no attempt was made to remove all the implants.

In November 2018 (14 months after surgery), the chimpanzee, together with the other chimpanzees, was anaesthetised for tuberculosis testing, as one individual showed clinical signs of the disease. During this evaluation, skull radiographs were performed, and all surgical sites were recorded as healed. The remaining two plates were intact without further complications (Figure 5). Further radiographic evaluations took place in November 2019 (26 months post-operative) and April 2021 (43 months post-operative) as part of routine health checks and tuberculosis screening. During all of these assessments, the remaining implants remained unchanged.

DISCUSSION

Malocclusion is commonly seen in domestic animals as well as humans.[1–3,10,11] Most malocclusions in animals do not cause any masticatory issues for the animals,[1] but when the malocclusion causes trauma to the hard and soft tissue structures of the oral cavity, it is classified as a traumatic malocclusion. Malocclusion can lead to local discomfort (traumatic malocclusion) or may even cause temporomandibular joint disease, as seen in humans.[21] Various treatment options are available for domestic animals when trauma is caused by the mandibular canine teeth on the hard palate, such as crown shortening, extraction of the offending teeth or orthodontic movement of the canine teeth.[2,7,8,22]

Malocclusions in great apes have not been reported in the literature. As their maxillofacial anatomy is similar to humans, the different treatment options available to human patients should, in theory, be applicable to great apes. In humans, however, certain treatment options are for aesthetic reasons, whereas in chimpanzee treatment is aimed at reducing discomfort and pain.

This case report highlights the difficulty a 15-year-old male chimpanzee experienced with a suspected, acquired malocclusion, probably the consequence of craniomaxillofacial trauma at a young age. Skull radiographs are not adequate to assess dental or temporomandibular joint disease, due to superimposition with other structures.[23] The diagnostic modality of choice should depend on structure to evaluate, for skeletal and dental abnormalities (CT) and for the temporomandibular joint and its associated soft tissues (magnetic resonance imaging).[24] The authors decided to use the CT as the advance imaging of choice for its proximity to the sanctuary, the need for a much shorter anaesthesia, could be used for planning of the surgery, and gave enough detail of the temporomandibular joint (TMJ) osseous structures.

The pathology presented in this chimpanzee is very consistent with trauma (fracture) of the left caudal mandible. The smaller mandibular head of the left condylar process could represent atrophy, hypoplasia or dysplasia. We believed the malocclusion type IV in a side-to-side direction increased the pressure on this abnormal head, leading to temporomandibular joint pain. Malocclusion is a known cause of temporomandibular disease in humans.[25] In humans, improving the occlusion of the patient reduces this stress on the TMJ with patients consequently experiencing less pain.[21] As this chimpanzee had a malocclusion and we suspected also TMJ pain, we decided to perform a BSSO.

Follow-up radiographs 7 months post-operative showed failure of two of the titanium plates used. It is estimated that humans have a bite force less than 50% of that of a chimpanzee.[26] Therefore, the use of 2 mm titanium plates, even though were used in pairs, was an error. In future, we would consider using at least two 2.5 or 2.7 mm titanium mandibular reconstruction plates. This complication is a known occurrence in humans receiving biodegradable or titanium plates after BSSO procedures.[27]

Post-operative care and behaviour in wild animals is very unpredictable. Due to this, strict instructions should always be given to carers, as was done in this case. The fact that animals (especially intelligent ones like great apes) may feed each other objects that can be detrimental to the operated individual is another layer of complexity in caring for these animals. In this case, we do believe the addition of hard foods to the chimpanzees' diet shortly after the surgery played a role in implant failure. Care should be taken to avoid any food or toys in a whole group, if it may negatively affect one individual. In humans, post-operative management revolves around good pain control, control of post-operative swelling and a diet with minimal hard consistency food (Hoogendijk, personal communication, 2023)

Radiographic follow-up of mandibular fractures in humans is recommended at 5 weeks post-operative (less than 18 years old) or 9 weeks post-operative (adults),[28] with complete healing taking place at approximately 3 months post-operative.[28] Due to the fact that the chimpanzee appeared to be eating well and had no problem integrating back into the group, it was decided to only anaesthetise it at the next biannual assessment; in this case, a 7-month post-operative radiographic study that revealed failed implants and healed bone. Continued radiographic follow-up was conducted to assess the implants left, and by 43 weeks post-operative all implants were unchanged. The sanctuary is located far from the nearest CT facilities and as it was recovering well, no attempt was made to repeat the CT scan.

In human patients, recovery after orthognathic surgery usually takes 6–8 weeks, and the signs used to judge this is the return to normal functions excluding recreational activities.[29] The surgery on this chimpanzee is considered a success as it is eating hard foods with ease, it is not showing any signs of discomfort and is functioning within its family group as normal. It will be monitored for any signs of temporomandibular joint disease manifesting as eating discomfort, and the remaining implants monitored biannually by means of skull radiographs during the health examinations.

AUTHOR CONTRIBUTIONS

Gerhard Steenkamp, Katja Koeppel and Christiaan Fritz Hoogendijk discussed and decided on the best treatment plan and performed the surgery. Gerhard Steenkamp, Katja Koeppel and Jose Carlos Almansa Ruiz collected follow-up data and re-operated on the patient to remove the plates. Gerhard Steenkamp, Christiaan Fritz Hoogendijk, Jose Carlos Almansa Ruiz and Katja Koeppel wrote and edited the paper.

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CONFLICT OF INTEREST STATEMENT

The authors declare they have no conflicts of interest.

FUNDING INFORMATION

No outside funding was received for this project.

ETHICS STATEMENT

The publication of this case report was approved by the Faculty of Veterinary Science's Animal Ethics Committee (REC 43-21).

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IMAGE QUIZ

Figure 5. This figure is a left lateral radiograph of a chimpanzee's skull that had orthognathic surgery 14 months before the radiograph being obtained. Post-operative some of the plates and intermaxilliary screws broke.

MULTIPLE-CHOICE QUESTION

Apart from clinical features like plate/screw exposure or plate/screw migration, how can a radiograph like this assist in deciding if the metal implants should be removed?

POSSIBLE ANSWERS TO MULTIPLE-CHOICE QUESTION

The angle of the plate is not the same as intraoperative
The loss of a locking screw from the plate
Plate appears thinner than intraoperative
Radiolucencies present around any of the screws
Periosteal reaction of the ventral cortex

CORRECT ANSWER

Radiolucencies present around any of the screws.

The presence of infection around implants is a clear sign that the implant is not performing the function it was intended to do. These radiolucencies could indicate heat necrosis around the implants or osteomyelitis. In these instances, the screw/s should be removed and sent for culture in order to identify the organism present, which together with an antibiogram would assist the clinician in clearing up the infection.