Introduction

Acquiring high quality diagnostic radiographs of the equine skull can be a challenging task. While most equine practitioners are comfortable obtaining radiographs of the distal limb and do so on a regular basis, many practitioners do not routinely acquire skull radiographs. This lack of regular practice, in conjunction with inherent challenges of skull radiography, can be intimidating and limit the diagnostic quality of the study. Inherent challenges of skull radiography include the large size and complexity of the structure being examined and the variation of x-ray attenuating materials within the skull. Of course, horse compliance is also key to a diagnostic study. After the radiographs have been obtained comes the hurdle of interpreting the radiographs. The complex anatomy and superimposition of structures presents a challenge for everyone, including experienced practitioners and radiologists. However, interpretation can be made easier by dividing the skull into separate anatomic parts and applying general principles of radiographic interpretation. Having a good sense of normal anatomy and understanding the typical radiographic appearance of common pathological processes helps decrease the sometimes daunting task of evaluating skull radiographs.

Radiographic technique

Radiographic technique will vary depending on the imaging system. The large degree of x-ray attenuation of enamel is in stark contrast to the air in the sinuses, requiring fineness with exposure technique. Traditionally, using screen film radiography, it was often necessary to obtain several exposures for a single area, one to highlight the teeth and a different technique for evaluation of the paranasal sinuses. Digital radiography has helped in this regard, as often a single exposure is sufficient with the appropriate algorithm settings. However, the quality of the image will depend largely on the quality of the system being used, as not all digital systems are created equal.

Portable units are generally sufficient for obtaining most skull radiographs. The smaller, lighter 80 kVp and 15 mA units can be used to obtain adequate radiographs of the paranasal sinuses, although they are more limited for the dorsoventral images because the necessary increased time for adequate exposure increases the likelihood of motion artefact. When available, in-house x-ray generators are also helpful because the overhead crane decreases the physical challenge of hoisting a heavy portable unit high in the air, and the higher mA capabilities are useful for denser structures in the caudal skull. Overhead crane systems are not as flexible in regards to placement around a stationary object and often limit the lesion-specific views that can be obtained. Standard plates are acceptable, although larger plates can greatly improve the ease of interpretation because more structures are included, providing a better overall impression of the skull. Often people have a tendency to shoot very close to the plate, which can decrease image sharpness and requires many images to be pieced together like a puzzle for complete skull evaluation. Stepping back and including more anatomy on the image, even when limited by a standard plate, can improve image quality.

Proper head positioning is vital to obtaining a diagnostic radiograph. Unless there is a medical contraindication, sedation is recommended. The use of sedation minimises the number of retake radiographs required due to motion, and also helps lower the patient’s head, which makes acquiring the images easier. Alpha-2 agonists such as xylazine, detomidine or romifidine are commonly used in combination with butorphanol. While butorphanol can cause some patients to twitch or flip their heads, the authors find it helpful when an appropriate combination with an α2 agonist is administered. Sedation also generally allows the horse handler to step further away from the head during image acquisition, decreasing radiographic exposure. A headstand is helpful to stabilise the head. All personnel should wear lead aprons and the person holding the plate should use lead gloves and/or a long plate handle. Lateral radiographs can easily and safely be performed by simply placing the horse’s head on a headstand or resting the muzzle on a flat solid structure. A large plate can be strapped to the horse’s head using bungee type elastic cords to allow radiographs to be taken without a plate holder. However, a bungee device should be used with caution, as there is increased risk of damage to equipment and it may not be tolerated by some cases. The horse’s halter should be replaced with a rope halter or placed around the neck as the knot on a rope halter can create artefact.

One of the most common faults in equine skull radiography is a lack of labelling. Not only is it essential to have proper labelling in order to interpret the findings accurately, but it also is important for the medical record. In the days of digital radiography, many people have moved away from using a radiopaque label placed on the plate, because there is an...
TABLE 1: Radiographic view of the equine skull by anatomic region

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<td>Intraoral an excellent tool to eliminate overlap of mandibular and maxillary incisors</td>
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<td></td>
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<td>Intraoral ventrodorsal (mandibular incisors)</td>
<td>Both obliques should be obtained for comparison purposes</td>
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<td>Dorsoventral</td>
<td>Right dorsal 15° lateral left ventral oblique (RD15-LVO; maxillary sinus and cheek teeth)</td>
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<td>Nasal cavity, maxillary cheek teeth, paranasal sinuses</td>
<td>Lateral</td>
<td>Left dorso 15° lateral right ventral oblique (LD15-RVO; maxillary sinus and cheek teeth)</td>
<td>RD60-LVO projects left side dorsally. Left marker placed on top of plate</td>
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<td>Caudal skull (cranial vault, temporomandibular joint, tympanohyoid articulation)</td>
<td>Lateral</td>
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<td>R45°V30°L-CdDLO allows greater individual evaluation of temporomandibular joints and avoids the need for anaesthetised dorsoventral views</td>
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<td></td>
<td>Dorsoventral</td>
<td>Rostral 60° lateral-left ventral oblique (RD60-LVO)</td>
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An expectation of digital labelling, however, using digital labelling still requires attention to detail and proper naming of the radiograph, and there are times when traditional labels are needed.

A common labelling shortcut is to name a radiograph as right oblique or left oblique. Unfortunately, this does not actually indicate the area of the anatomy that is highlighted, because the name does not include whether a projection was made from dorsal to ventral or vice versa. Using the full name, such as right dorsal-left ventral oblique (RDLO), allows the reader to know that the right ventral and left dorsal portions of the skull are being highlighted. For example, on a maxillary study, an RDLO will highlight the left paranasal sinuses and left maxillary arcade. Digital systems can be updated so that the correctly named image can be selected prior to acquisition. Even when correct digital labels are in place, it is often helpful to still include a real marker, and, for film, it is essential. From the previous example, a left marker should be placed on the top of the plate, and right marker on the bottom. The converse applies to the opposite oblique.

While not essential, Mitchell markers are a helpful additional labelling option. Mitchell markers contain several small beads that align on the bottom of the marker. The beads indicate how the plate was positioned relative to the ground, and fluid lines in the sinuses should align with the plane of the Mitchell marker.

Holding the horse’s mouth open wide is a very useful technique to detect or rule out dental disease. This can be achieved by placing a small section of 7.5–10 cm diameter PVC pipe between the upper and lower dental arcades and decreases superimposition of the right and left arcades. This technique is recommended for evaluation of occlusal wear abnormalities, exposed crown pathology and periodontal changes associated with diastemata or abnormal spaces between teeth (Barakzai and Dixon 2003).

Generally, in terms of pathological conditions and radiographic regions, the skull can be divided into 4 sections: 1) incisive region (rostral skull); 2) maxillary studies (nasal cavity, maxillary cheek teeth and paranasal sinuses); 3) mandibular studies; and 4) caudal skull and cranial vault, which includes temporomandibular joint and tympanohyoid articulation. A brief summary of the radiographic views recommended for each anatomic section is provided in Table 1.

Incisive region
Fractures of the rostral mandible are the most common jaw fracture and are typically seen in young horses, often as a result of biting onto a fixed object, such as stall door, and then becoming startled and pulling back, fracturing the alveolar bone (Wyn-Jones 1985; Greet and Ramzan 2010). Rostral maxilla fractures are less common. Fractures can extend into
Fractures of the incisive bone, maxillary bone, or incisive portion of mandibular bone. Generally, these types of fractures are best visualised with intraoral radiographs. A special plate is usually not needed for this type of intraoral radiograph. However, equine dental radiography does make use of dental-specific smaller vinyl plates for other types of intraoral studies. If the fracture is complete, the fracture portion is usually displaced preventing occlusion of the incisors, so the risk to the plate is minimal. If this is not the case, a mouth gag can be used to keep the mouth open and reduce the risk of damage to the plate. The affected incisors are generally displaced rostrally and/or laterally. Fractures of the rostral mandible can extend into mandibular diastemata, sometimes as far caudally as the mandibular premolars. Incomplete fractures that extend caudally can be difficult to fully visualise radiographically (Pease 2007). Apical abscesses can also be sequelae to trauma and fractures to the alveolar bone (Dacre 2005) (Fig 1).

Infections of the incisor teeth are less common than of the cheek teeth, but do occur. Intraoral radiographs are useful for evaluation of periapical tooth root abscesses. The changes are most commonly characterised by lucencies, sometimes surrounded by a rim of sclerosis, adjacent to the tooth root. Clubbing of the tooth root structure or widening of the periodontal space may also be noted. These changes are best visualised using a bisecting angle technique by placing the cassette in the mouth and dorsoventral views of the upper and Ventrodorsal views of the lower incisors (Klugh 2003).

Equine odontoclastic tooth resorption and hypercementosis is a recently described disorder of the incisor and canine teeth in aged horses (Staszyk et al. 2008). This disorder causes periodontitis, with resorptive or proliferative changes of the calcified dental tissues usually affecting the lateral incisors initially and progressing medially. Radiographically, there is widened periodontal ligament space and marked hypercementosis of the reserve crowns (Fig 2).

While uncommon, the rostral skull, can be affected by neoplasia. True neoplastic lesions of the skull are often categorised into 3 categories: 1) soft tissue neoplastic lesions; 2) osteogenic (bone origin) neoplastic lesions; and 3) odontogenic (dental tissue origin) neoplastic lesions. An accurate diagnosis of neoplasia with radiographs alone is nearly impossible. However, based on radiographic findings, neoplastic lesions can often be placed within one of the 3 categories.

Ossifying fibroma is the most common benign neoplasia of the equine skull often located in the mandibular region. This is an expansile lesion that eventually results in loosening of the incisors or even pathological fracture of the mandible. Radiographically, lesions are less radiodense than bone, but may contain calcification and radiolucent centres. Osteomas are rare, slow-growing benign tumours found on the mandible and maxilla. They are characterised as a well-defined, expansile, mineral opaque mass with a distinctive radiodense outline (Wyn-Jones 1985; Park 1993; Knottenbelt and Kelly 2010).

Malignant osseous tumours of the rostral skull such as osteosarcomas are very uncommon, and are generally accompanied by osteolysis, irregular proliferative new bone and/or soft tissue swelling.

Maxillary study
The maxillary study is likely to be the most common of the skull studies, due to the common clinical signs such as nasal...
discharge, epistaxis, decreased airflow, or foul smell often pointing in the direction of sinonasal disease. Often maxillary dental disease and sinusitis go hand in hand, but there are also multiple other afflictions of the paranasal sinuses that are not associated with dental disease, thus it is important to try to adequately determine the underlying source of the problem.

Dental disease
Detecting infection of the maxillary cheek teeth can be challenging. Because of the frequent association of maxillary dental disease and sinusitis, the already complex anatomy is often further challenged by the superimposition of soft tissue opacities within the paranasal sinuses. In particular, this can make detection of alveolar bone sclerosis, one of the signs of dental disease, particularly difficult to determine accurately. Radiography for the accurate diagnosis of dental disorders has been shown to have 52–69% specificity and 70–95% sensitivity (Weller et al. 2001; Barakzai 2006). Townsend et al. (2011) reported that the most reliable indicators of periapical infection include periapical sclerosis, periapical lucency, and clubbing of the tooth roots. Loss of the lamina dura denta was found to have low sensitivity, but very high specificity (Townsend et al. 2011). Other reported indicators are widening of the periodontal space, changes in the shape or an indistinct appearance of the tooth root (Wyn-Jones 1985; Gibbs and Lane 1987) (Fig 3). Occasionally small root fragments can be visualised. Crown fractures can be identified as an area of lucency within the normally markedly opaque teeth. Sometimes this is manifested only as a subtle, linear lucency, in other cases, when parts of the crown have fractured off, the entire tooth will be more lucent than the surrounding teeth. Diastemata and fractures can lead to feed impactions, which may appear as an area of mixed soft-tissue and gas opacity.

Dental conditions other than infection that can be appreciated include brachygnathia, prognathia, malocclusions, oligodontia and polydontia.

Sinusitis
As mentioned above, sinusitis often is associated with dental disease; however, primary sinusitis is not an uncommon condition. A study by Dixon et al. (2012) evaluating paranasal sinus disease in 200 horses found 45% to be primary in origin. Of those horses diagnosed with primary sinusitis, there were 82% with intrasinus fluid lines, 61% with intrasinus radiopacity, 21% with apical changes and 15 with bony changes noted with radiography. Primary sinusitis can result from bacterial or fungal infections and often occurs secondary to an upper respiratory infection (Park 1993; Tremaine and Dixon 2001). Free fluid in the maxillary and/or conchofrontal sinuses will typically result in well-defined air-fluid interfaces (Fig 4), although with chronic sinusitis, thick or inspissated fluid may not create well-demarcated flat fluid lines. Other radiographic signs of primary sinusitis include intrasinus radiopacity diffusely throughout the paranasal sinuses, secondary to increased fluid and/or mucosal thickening, septal deviations and bony expansion (Gibbs and Lane 1987; O’Leary and Dixon 2011). However, septal deviations can be insignificant radiographic findings in clinically normal horses. When possible, repeating radiographs after removal of fluid from the sinuses can aid in identifying periapical disease, polyps or other soft tissue abnormalities associated with chronic sinusitis.

It is important to evaluate the ventral concha sinus (VCS) and corresponding ventral conchal bulla (VCB) appropriately in cases of sinusitis. Involvement of the VCS is considered an important diagnostic and prognostic indicator due to its poor drainage and tendency for inspissated material to localise in the VCS (Schumacher et al. 1987; Freeman et al. 1990; Perkins et al. 2009a; Dixon et al. 2012). Dorsoventral views are helpful to examine the medial aspect of the VCS. Finnegan et al. (2011) evaluated the radiographic appearance of the caudodorsal extension of the VCS, the VCB, and its ability to
be consistently identified in normal horses on plain lateral, oblique, and dorsoventral radiographs. The plain lateral radiograph provided a correct VCB identification of 70% (Fig 5), the 30° laterodorsal lateroventral oblique radiograph had a 45% success rate, and the dorsoventral view successfully identified the VCB in 17% of cases (Finnegan et al. 2011).

Fractures

Traumatic depression fractures typically affect the frontal, nasal, maxillary and lacrimal bones. Obtaining multiple views at varying obliquity is often necessary for complete evaluation of the extent of the fractures. Fractures of the orbit may require a more steeply angled oblique (RD70-LVO or LD70-RVO) radiograph than is standardly obtained for a sinus, in order to project the rim of the orbit with minimal bone overlap. In addition, it is very helpful to obtain the opposite oblique of the nonaffected portion of the skull for comparison purposes, which can greatly improve the identification of both abnormalities and normal variants (Fig 6). Acute fractures have sharply margined fracture lines and often have associated bone fragments. With increasing chronicity, the fracture margins will become less distinct. Often acute fractures are accompanied by external soft tissue swelling. Trauma to the orbit can result in exophthalmos.

Haemorrhage resulting in increased soft tissue opacity within the paranasal sinuses is often present secondary to skull fractures. This should begin to resolve as the haemorrhage drains via the sinonasal ostium. If increased soft tissue opacity remains within the sinus several weeks after the traumatic event, a secondary sinusitis may have developed (Park 1993). A chronic draining tract in proximity to previous trauma is often an indication of an osseous sequestrum, and is characterised by an osseous fragment separated from the parent bone by a zone of osteolysis. In chronic cases and/or on re-check radiographs, osteomyelitis should be suspected in cases of delayed fracture healing in conjunction with excessive periosteal proliferation, lysis and sclerosis of the fracture site.
Non-neoplastic soft tissue masses and cysts
While once believed to be a disease primarily of young horses, the current literature suggests that there is not an age predisposition for the development of sinonasal cysts (O’Leary and Dixon 2011). Sinonasal cysts are benign, expansile lesions resulting in decreased airflow, increased respiratory noise, nasal discharge and facial deformity (Lane et al. 1987; Woodford and Lane 2006). Radiographically, sinonasal cysts are characterised by a well-defined, smoothly marginated soft tissue opacity within maxillary sinuses, nasal cavity and occasionally conchotonal sinuses (Fig 7). However, they can also be very expansive and completely fill the sinus compartments. Often the ventrodorsal image will allow for the best visualisation of the margins of the structure, whereas on the oblique images increases soft tissue opacity is seen, but often the margins of the cyst are not well defined. Increased sinus fluid and mucosal thickening in the sinuses can further obscure the margins of the cyst. Septal deviation, dental displacement and mineralisation are other reported radiographic findings associated with sinonasal cysts (Gibbs and Lane 1987; Lane et al. 1987; Tremaine and Dixon 2001). Dixon et al. (2012) reported 31% of horses with sinonasal cysts had intrasinus fluid lines; 88% had intrasinus radiopacity; 12% had apical changes and 8% had bone changes noted with radiography. Compared to primary sinusitis cases, fluid lines were far less common. However, sinus cysts were 4.3 times more likely to have generalised sinus radiopacity than primary sinusitis cases (Dixon et al. 2012). Advanced imaging such as computed tomography (CT) and magnetic resonance imaging (MRI) clearly show cysts to be fluid filled structures with a well-defined lining (Annear et al. 2008; Cissell et al. 2011; Tessier et al. 2012).

Most commonly, progressive ethmoid haematomas (PEH) are found in the region of the ethmoid turbinates, but can occasionally affect the paranasal sinuses. Of 200 cases with sinus disease, 7 horses were diagnosed with PEH (Dixon et al. 2012). When located in the sinuses, a PEH can be difficult to distinguish from a sinonasal cyst or polyp. Similar to sinonasal cysts, PEH are generally well-defined, smoothly marginated soft tissue masses, but are often more solid masses rather than fluid filled structures. However, as fluid and soft tissue have the same radiopacity, this is not a distinction that can be made radiographically. Dixon et al. (2012) found only 33% to have fluid lines present, probably as a result of haemorrhage or secondary sinusitis. However, 100% of PEH cases had intrasinus radiopacity noted on radiographs. Generally, PEH are unilateral, however, multiple masses can be found, and occasionally a large mass will expand beyond the nasal septum (Head and Dixon 1999). The most common clinical presentation is epistaxis, although nonhaemorrhagic nasal discharge can also be seen when secondary sinusitis is present (Gibbs and Lane 1987; Park 1993). PEH are less likely to result in facial deformity or osseous remodelling than sinonasal cysts (Lane et al. 1987; Tremaine and Dixon 2001). Sinonasal polyps are firm, pendunculated masses that extend from the mucosa and are often associated with chronic inflammatory conditions. Polyps are most frequently seen in middle-aged horses (Tremaine and Dixon 2001). Polyps are well defined, smooth, rounded soft tissue opacities found within the nasal cavity and can extend into the paranasal sinuses. Unlike sinonasal cysts, which can have calcified capsules, polyps do not. Polyps also generally do not cause bony erosion or facial deformity, which can aid in distinguishing polyps from sinonasal cysts radiographically.

Neoplasia
Neoplasia of the nasal cavity and paranasal sinuses is relatively rare in horses. Squamous cell carcinoma is the most common tumour type; other reported tumours include adenocarcinoma, fibrosarcoma, osteosarcoma, osteoma, dental origin tumours, haemangiosarcoma and lymphoma (Dixon and Head 1999). Clinical signs include facial swelling or distortion, nasal discharge, mandibular and retropharyngeal lymphadenopathy and, less commonly, epiphora, epistaxis and nasal obstruction (Dixon and Head 1999; Tremaine and Dixon 2001). Middle-aged to older horses are most frequently affected. Radiographic signs will vary, with the most common sign being intrasinus radiopacity (Dixon et al. 2012). Sometimes merely a well-defined soft tissue mass with or without sinus fluid is visualised, with no evidence of osseous remodelling or other soft tissue involvement. In some of these cases, there may actually be concurrent osseous lysis that is visualised with advanced imaging, but due to the superimposition of bone and oblity cannot be appreciated radiographically. Of the 10 cases diagnosed with neoplasia in a study by Dixon et al. (2012), none had radiographic signs of bony changes. However, in more advanced or aggressive cases, osseous lysis and/or proliferation, and bony expansion may be noted (Park 1993; Tremaine and Dixon 2001). Irregular bone production within soft tissue masses can be a strong indicator of neoplasia (Park 1993).

Dentigerous cysts are most commonly seen in young horses. They are a distinctive tooth-like tumour that arises as result of failure of the first branchial cleft to close. The cysts are most frequently found at the base of the ear attached to the temporal bone, but can be seen in the maxillary region as well (Gibbs and Lane 1987; Pease 2007; Easley et al. 2010; Smith...