Improving Your Equine Dentistry Mini Series

Session Two: Understanding Equine Dental Pathology

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Understanding Equine Dental Pathology

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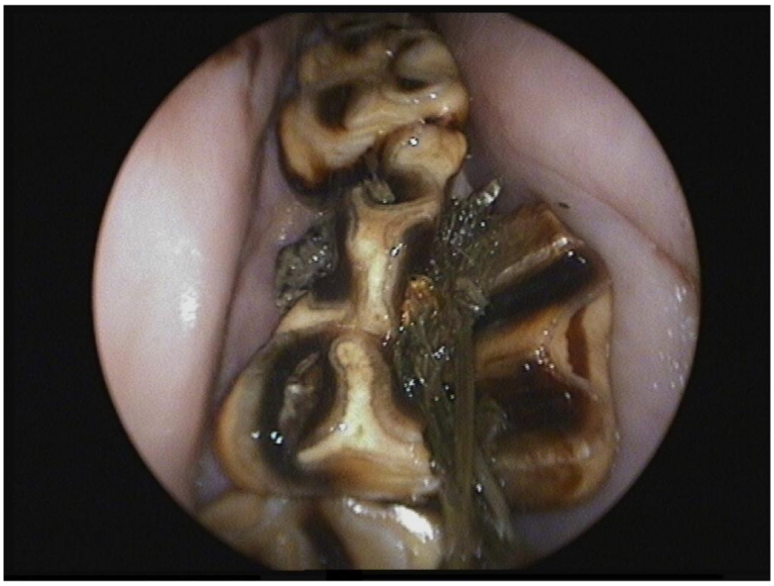
Modern veterinary dentistry
Most horse owners are aware that they need some form of regular maintenance work for their horses' teeth. Historically this has been predominantly based around the 'annual rasping', based on the fact that equine teeth develop sharp enamel points which may cause soft tissue trauma and require periodic reduction, which they often do. However, development of sharp enamel points and their reduction (or more correctly odontoplasty) is just one of the wide range of dental problems that exist, can be diagnosed – and increasingly treated. The combination of research from Edinburgh University and others, development of advanced imaging and equipment, and a willingness to put theory into practice, is leading us into a new era of veterinary dentistry for horses.

Equine veterinary medicine and surgery have developed rapidly in the past 100 years with some disciplines being close to their human counterparts – regenerative medicine, laparoscopic and arthroscopic surgery to name but a few. Early diagnosis of conditions such as joint disease, tendon injury and medical conditions such as gastric ulceration and metabolic syndromes has become the norm now through advances in knowledge, diagnostics and client education. For equine dentistry however, the first thing an owner may know about their horse's deteriorating dentition is a fractured tooth following years of undiagnosed pathological deterioration. And no, it didn't fracture because he chewed on a stone.



This tooth fractured despite the owner being unaware of the advanced state of decay

Changing the approach – a new paradigm
Equine dental pathology is slow to develop. Many cases will take years to progress to a point where clinical signs develop, and even then owners may attribute those signs to something other than the teeth e.g. head-shaking. It is likely that we are still a long way from fully understanding how horses react to dental pain, especially considering their evolutionary history and pressure to continue to eat to survive. Add to this the anatomical fact that horses dental arcades are anisognathic, necessitating mastication on one side of the mouth only at a time, and it becomes clearer how horses may disguise pain by altering their eating patterns e.g. development of 'shear mouth'. The only way we can change the approach, and advance our knowledge is to look, observe and continue to gather an evidence base. The equine oral examination, as with dentistry in other species, is of paramount importance and is the foundation of this modern approach to equine dentistry. If we look carefully, understand the anatomy and pathology that is there, appreciate that there may be no signs yet but that the horse may be compensating, then we can make informed choices about offering potential preventative care. Then the 'routine dental' becomes more about a clinical 'check-up', with the examination and diagnostics being more important than the 'rasping', but which may as well be done at the same time.

Equine Dental Nomenclature and Gross Anatomy

It is generally accepted now that the Modified Triadan system (Fig 1) is best used for equine dental nomenclature. The adult horse has between 36 and 44 teeth dependant on the presence or absence of canine teeth (Triadan 04) or the vestigial 1st premolar (Triadan 05, 'wolf teeth'). The Triadan 06-08 (second to fourth premolars) are grossly similar to the Triadan 09-11 (molars) i.e. they have become molarised and may conveniently be referred to as cheek teeth (CT). To describe the deciduous teeth using the Triadan system, an additional 4 is added to the first number. Using this system the deciduous 01's (first incisors) are 501,601, 701, and 801; the deciduous 02s are 502, 602,702, and 802 and the deciduous 03's are 503,603, 703, and 803.

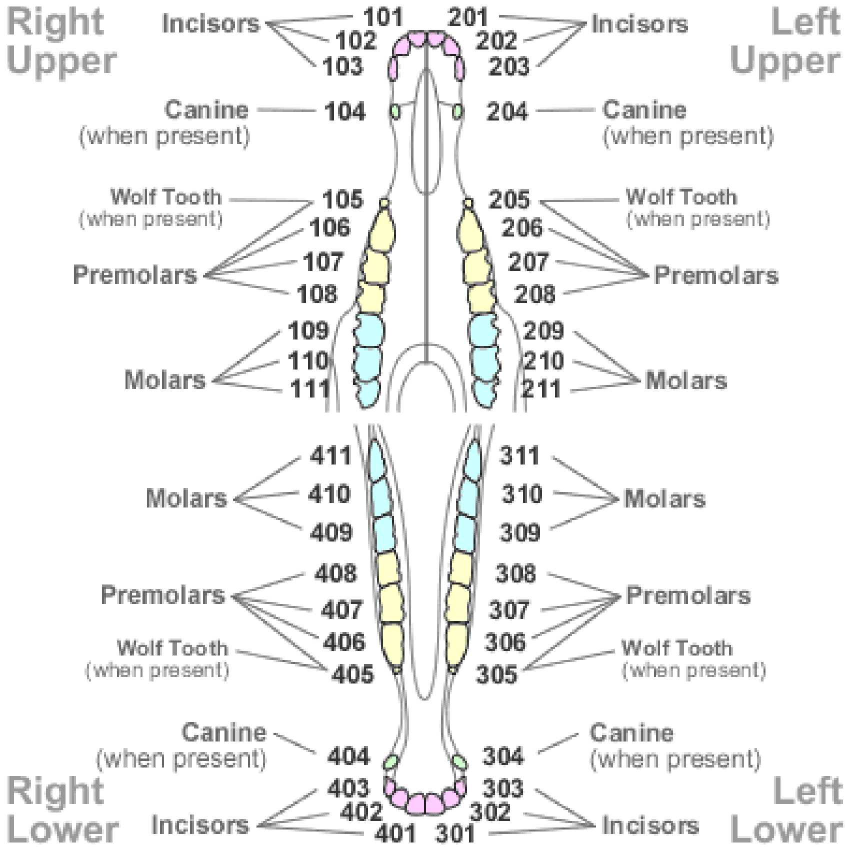


Fig 1. Modified Triadan numbering system for use in the horse (image courtesy of RVC)

The term mesial may be used for the rostral aspect of a tooth (i.e. towards the centre of the dental arch), and the term distal being caudal. Buccal refers to the lateral aspect of a CT, and lingual (mandibular) or palatal (maxillary) the medial aspect. The rostral aspect of incisor teeth is termed labial, the caudal aspect lingual. The aspect of the tooth towards the occlusal or grinding surface is termed coronal (towards the crown) and the aspect towards the root region is apical. The crown is the enamel covered part of a tooth and in horses the erupted or visible crown is termed the clinical crown, whereas the crown beneath the gingival margin is the reserve crown. The proximal aspects of the teeth are those that are normally contacting each other in a row. The terms interdental or interproximal refer to the areas between aspects of teeth that normally lie adjacent. The interdental space is the large space between the incisors (or canines) and the cheek teeth (the 'bars of the mouth'). An abnormal space between teeth is a diastema. The root is the enamel free region of the apex of a tooth.

The incisors and cheek teeth are termed hypsodont teeth, meaning 'high crowned' teeth, referring to the presence of a reserve crown containing enamel beneath the gingival margin. The presence of this reserve crown allows for slow and continued eruption to compensate for occlusal attritional wear of 2-3mm per year from prolonged grazing of a rough, silicate-containing diet. Due to the fact that enamel continues beneath the gingival margin, the term 'cemento-enamel junction' is not used in equine dentistry.

In young horses, the long reserve crowns lie deeply embedded within the supporting mandibular and maxillary bones and the paranasal sinuses (Fig 1). Consequently infections of these teeth can lead to infections of these bones or to maxillary sinusitis (O'Connor 1930, Lane 1993, Tremaine and Dixon 2001a).

There is a disparity of around 23% between the maxillary and mandibular rows, termed anisognathia, and the medial direction and great force of mastication influences the angulation of their occlusal surface, which is normally around 10-15^0 (Easley 1996).

The four rows of cheek teeth operate as single units, or batteries, and the individual teeth are in tight contact with each other at the occlusal surface in any row to prevent food accululumulating between the teeth in the interdental (interproximal) spaces. This is achieved mechanically by caudal angulation of the Triadan 06 teeth, and progressive reversal along the arcade to rostral angulation of the Triadan 10 and 11 teeth, causing continued mechanical compression during eruption. Inadequate or excessive angulation of these teeth may cause the developmental disorders such as diastema, displaced teeth and vertical impaction (Dixon 2002).

The constant eruption and surface attrition results in all layers of the laminated structure of equine teeth being exposed to the occlusal surface. Differences in the hardness of the different dental tissues, and deep infolding of enamel and presence of infundibulae (incisors and maxillary CT only) results in the enamel protruding slightly resulting in increased efficiency of mastication. At the buccal and lingual margins, these form 'enamel points' which may become excessively pronounced resulting in buccal or lingual trauma and therefore may require intermittent reduction. Areas of higher concentrations of harder dental tissues on individual teeth and the masticatory pattern result in a series of regular transverse ridges across the teeth which have been documented in fossil records and therefore are considered a normal feature of hypsodont teeth.

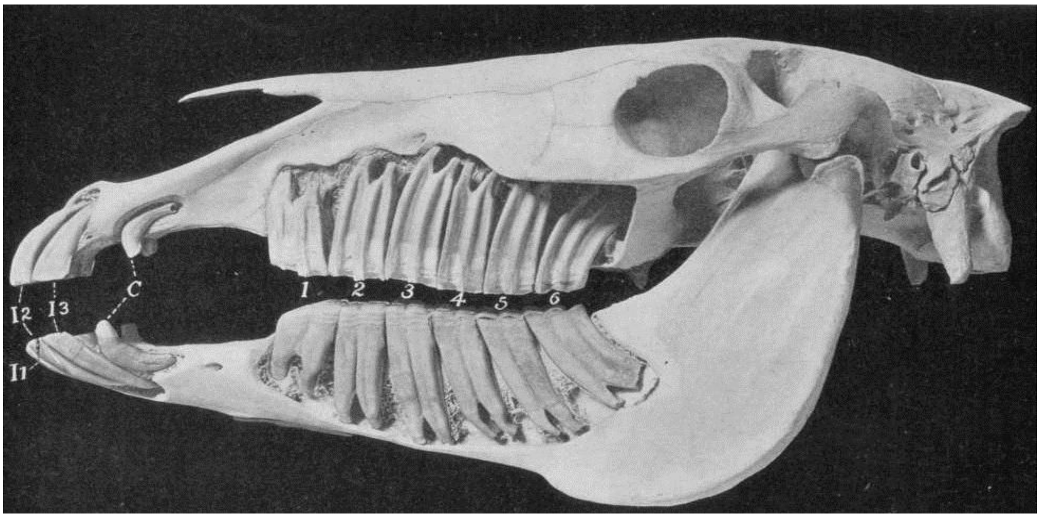


Fig 2. Skull of 5 y.o. sculpted to show reserve crowns of teeth (Sisson 1927).

Gross anatomy of teeth

Incisors

Adult horses have 12 incisors in total, 6 in each arcade. The upper incisors are embedded in the incisive bone (premaxilla) and the lower incisors in the rostral mandible. Incisors are hypsodont teeth with an initially oval cross section at the coronal aspect, which tapers uniformly towards the apex and becomes round, triangular and then oval again at the apex. These shape changes are more apparent in the central and intermediate than the corner incisors.

All incisor teeth have a single infundibulum or 'cup'. This enamel bordered conical shaped structure extends about 10mm from the occlusal surface in a young horse. It is usually incompletely filled with cement and frequently becomes filled with necrotic food material and appears dark. Following attritional wear of the infundibulum, a small enamel ring remains on the lingual aspect of the occlusal surface of the tooth, known as the 'mark'. As secondary dentine becomes exposed it becomes visible on the occlusal surface initially as a small dark yellow transverse line on the labial aspect of the cup. With further tooth wear it gradually becomes oval in shape and moves toward the centre of the occlusal surface.

Canines
Male horses normally have 4 canine teeth (2 maxillary and 2 mandibular; Triadan 1-404). They erupt at 4-6 years in the interdental space. Canines are simple brachydont type teeth, pointed in shape and curved in a caudal direction. They have one pulp horn and are not in occlusal contact or wear. Canines are usually rudimentary or absent in females.

Cheek teeth
An adult equine mouth normally contains 24 cheek teeth in four rows of 6 teeth with reserve crowns and roots embedded in the maxillary and mandibular bones. These teeth are the premolars (PM2-4) and the molars (M1-3). The cheek teeth are the 'grinding teeth' used for crushing and masticating food material in a rotary side to side movement using one mandible at a time. There is a combination of this lateral rotational movement, combined with a slight rostro-caudal movement. The occlusal surfaces of cheek teeth have interdigitating transverse ridges that increase the surface area for mastication and also help to crush the food with the rostro-caudal movements. On transverse section the cheek teeth are roughly rectangular, apart from the 1st and 6th cheek teeth that are more triangular. The caudal cheek teeth, and occasionally the rostral may be slightly curved.

Young horses possess long crowns, which mainly consist of unerupted reserve crown, deeply embedded in the alveoli sub-gingivally. When first erupted the cheek teeth have no or relatively short true roots (enamel free areas at the apex), but true roots develop some months later and then progressively elongate with age. The periodontal attachment to these true roots becomes increasingly firm. Dental eruption proceeds throughout life and normally the rate of attrition (wear) corresponds with the rate of eruption (usually around 2-3mm per year). As all teeth are in wear by 5 years of age, a 75mm tooth would be fully worn by 30-35 years of age.

Adult maxillary cheek teeth have three roots; 2 small lateral roots, and one larger medial. Mandibular cheek teeth possess two roots, one rostral and one caudal. The roots of mandibular teeth are usually longer than the maxillary roots.

The rows of both maxillary and mandibular cheek teeth form slightly curved rows, with the curvature towards the palatal and buccal aspects respectively. The rostral cheek teeth are angled slightly caudally and the caudal cheek teeth are angled slightly rostrally, meaning the teeth erupt and compress the row together allowing the teeth to function as a single 'unit'. As the teeth do not form a true arc as in other species, it is better to refer to the cheek teeth as being in a row of 6 teeth in each of the 4 quadrants.

Maxillary cheek teeth are approximately 30% wider in cross section than mandibular teeth and their positioning is anisognathic with the mandibular rows being approximately 24% closer together than the maxillary rows. The result of this is that when the mouth is closed, about one third of each maxillary cheek tooth is superimposed over about one half of a mandibular tooth. In addition, the occlusal surface of the cheek teeth are not level, but are angled at about 15-20 degrees in a bucco-lingual plane, with an increasing angle towards the caudal aspect of the row (up to 30 degrees).

Evolution of Equine Dentition

Evolution of the horse began about 50 million years ago with *Hyracotherium,* a small fox sized animal with 44 low crowned brachydont teeth. Over 20 million years dietary change from browsing to grazing diets, combined with the development of grasslands and steppes resulted in evolutionary alterations of head size and dentition. Evidence exists that much evolutionary change actually occurred before the development of grasslands in N.America, and that these were exploited by the horses with hypsodont teeth. The major evolutionary morphological change occurred 20 to 25 million years ago, resulting in a deeper skull and jaws to accommodate longer crowned hypsodont teeth, and a longer row of cheek teeth specialised for prolonged grinding. The dental formula was I3/3 C1/1 P4/4 M3/3 = 22(44). The most rostral cheek teeth, P1 became reduced to small rudimentary teeth or were absent, as is the case with modern *Equus.*

The early evolutionary species of horses became extinct in N.America with the last ice age and were re-introduced by Spanish explorers such as Hernando Cortes in the 15C. Many escaped from captivity and roamed free as *mustangs.*

Dental tissues

Pulp

Pulp is a soft tissue within the dental pulp cavities containing a variety of connective tissues, nerves, blood, lymphatic vessels, and nerves. Recently erupted teeth have a large common pulp, but with age and deposition of secondary dentine, this becomes divided into separate pulp horns. There are 6 pulp horns in the 06 and 11 teeth, and five in the other four adult cheek teeth. The additional pulp, which is termed pulp horn 6, lies on the rostral, triangular-shaped aspect of this tooth (Fig. 2). The caudal mandibular cheek teeth (311, 411) also have an additional pulp numbered 7, and mature maxillary 11 teeth have two additional pulp horns (7 and 8). Dacre et al developed a numbering system for these pulps; however, a new pulp numbering system suggested by du Toit (2009) is recommended as a simpler system with the 1st pulp always lying on the rostro-buccal aspect of the tooth and the 2nd pulp on the caudo-buccal aspect of the tooth. Pulp 3 is on the rostro-lingual aspect of the tooth (Fig. 3). All incisors have a common single pulp.

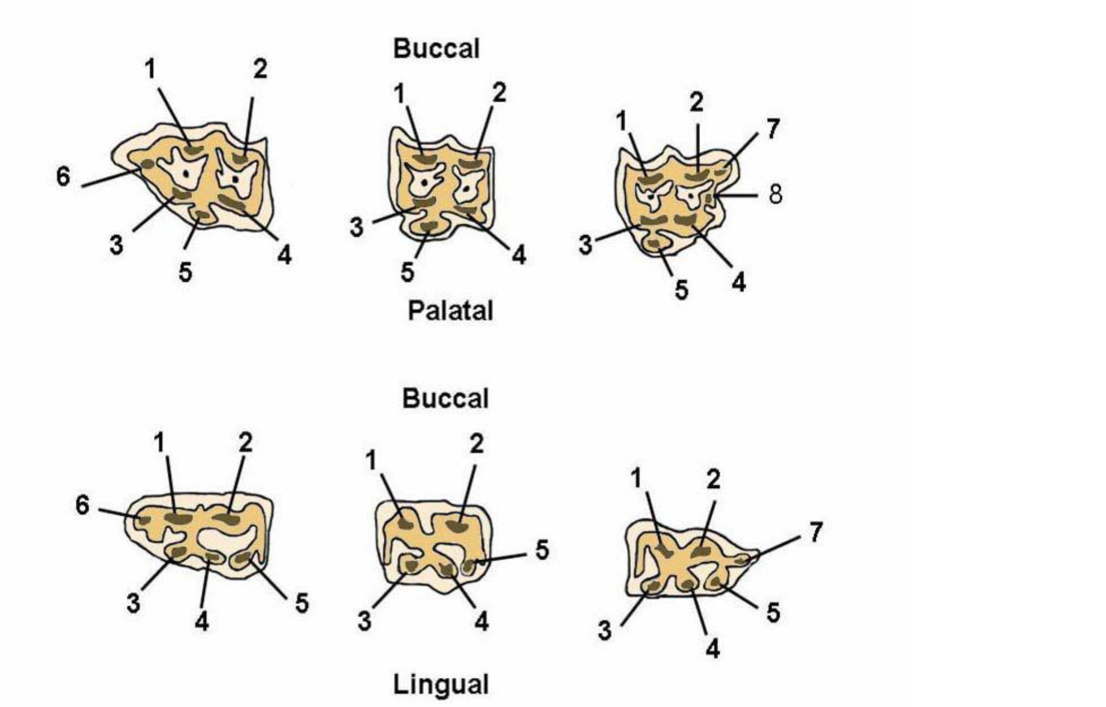


Fig 4. Pulpar anatomy (duToit et al, 2008). Top row displays maxillary teeth, lower row mandibular teeth. From left to right the teeth are Triadan 06, 07-10, 11.

Knowledge of pulp anatomy, notably whether pulp has been replaced by dentine, is important in equine dentistry as it may give an indication of how much crown may be removed during clinical crown reduction before encountering vital pulp. This is important in conditions such as step-mouth where large (>5mm) crown reductions may be necessary. Pulpal insults can be caused by heat, pressure, vibration, desiccation, chemical exposure, and bacterial infection (Shafer et al. 1983). Heating of the pulp can cause various histopathological changes, such as burn reactions at the periphery of the pulp, including formation of ‘blisters’, protoplasm coagulation, and expansion of liquid contained in the pulp and dentinal tubules with resultant increased outward liquid flow from tubules (Castelnuovo & Tjan 1997). These reactions can lead to vascular pulpar injuries with subsequent tissue necrosis (Raab 1992). The potential for thermal pulpar insult to be caused by modern motorised equine dental equipment has been studied *in vitro,* with the investigators concluding that if motorised dental equipment is used incorrectly, equine dental pulp may suffer thermal trauma (Baker & Allen 2002).

Aside from the potential risks associated with thermal pulpar insult, aggressive dental reductions that do not expose a pulp cavity, such as full ‘bit-seating’ (i.e. the fully unvalidated procedure of reducing and rounding off the rostral aspects of the 06s for allegedly better bit comfort), have the potential to expose sensitive dentine to the oral cavity (Kempson et al. 2003). In normal circumstances, dentine in contact with the oral cavity is sclerotic (i.e. the dentinal tubules have been occluded either by calcification of the odontoblast process, or by the tubule being filled by a ‘smear’ layer [ground dental dust]). Kempson et al. showed that this sclerotic layer could be removed completely with modern dental equipment, exposing sensitive odontoblast processes. To fully appreciate implications of dental interventions, a sound knowledge of ultrastructural dental anatomy is essential.

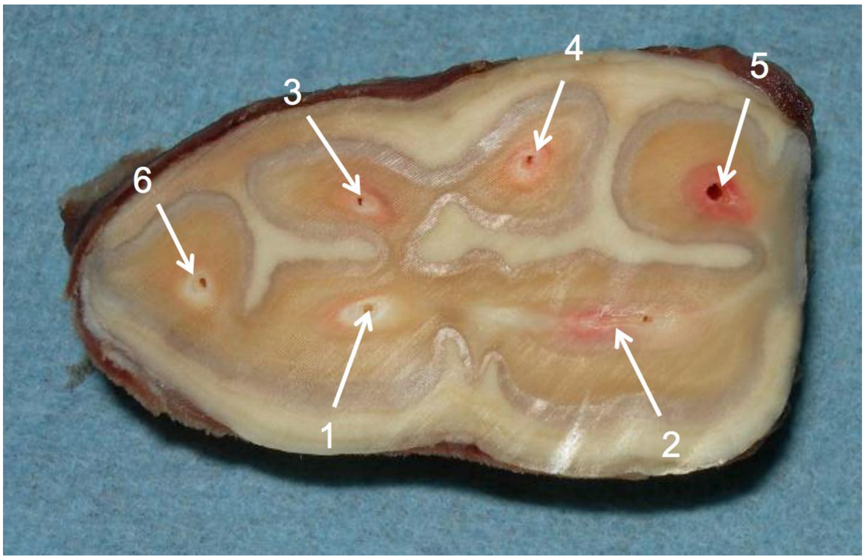


Fig 5. Transverse section of mandibular cheek tooth (306) showing six pulp horns (image courtesy of P.M.Dixon MRCVS).

Dentino-Pulpal Complex
The dentino-pulpal complex is so termed because of the intricate association between the dental pulp and surrounding dentine (Jones 1990; Torneck 1998). The outermost layer of pulp consists of odontoblast cells, responsible for continuous dentine production, which begins immediately before the formation of the enamel 'scaffolding' within the dental sac, and continues throughout the life of the equine tooth (Ferguson 1990).

Odontoblast cells leave long tubular processes within the dentine (dentinal tubules) as they retreat centrally into the pulp, with progressive deposition of dentine by these structures (Kilic et al. 1997b; Lowder & Mueller 1998; Muylle et al. 2001). These odontoblast processes extend horizontally to the amelodentinal junction and vertically to the occlusal surface of equine teeth (Kilic et al. 1997a; Kilic et al. 1997b). It is believed that odontoblast processes may transmit normal (physiological) stimuli from the occlusal or interproximal surfaces via changes in fluid pressure within the dentinal tubule and that this can regulate the rate of dentine deposition in the underlying pulp or transmit noxious stimuli (e.g. from physical, chemical or thermal trauma or caries) to initiate tertiary dentine production (Kempson et al. 2003).

The progressive attrition of equine teeth at a rate of *circa* 2-3 mm/year necessitates the continued deposition of secondary dentine to prevent pulpal exposure at the occlusal surface. This metabolically demanding process means that a significant blood supply must be prolonged to the dentinogenic zone of the pulp cavity well into a horse's life (Dixon & Copeland 1993). In contrast, the apical foramina that carry the pulpar blood supply to brachydont teeth are narrowed by dentine deposition within the pulp canal, restricting maximal blood vessel diameter at a relatively early stage of the tooth's life (Berkovitz & Moxham 1981). If appropriately stimulated, odontoblasts may produce dentine throughout their lifespan (Fawcett 1987; Ten Cate 1998a).

Dentine
Dentine is the major component of equine teeth, a cream coloured calcified tissue composed of approximately 70% minerals (hydroxyapatite crystals) and 30% organic fibres. The presence of dentine (and cement) interspersed between hard but brittle layers (of enamel) allows the structure to resemble a strong bonded laminate (like a biological 'safety glass').

Dentine may be divided into three main types, primary, secondary and tertiary (reparative). Secondary dentine is *the dentine that is deposited once a tooth is in full occlusal contact* (Kierdorf & Kierdorf 1992).

Secondary dentine is classified as being either regular or irregular, with irregular secondary dentine also being referred to as reparative, reactive or tertiary dentine (Kilic et al. 1997b). Following dental eruption, regular secondary dentine is laid down by odontoblasts throughout most of the life of the tooth, with the odontoblast cells withdrawing back towards the centre of the pulp from the previously laid down primary dentine. Secondary dentine is continuous with primary dentine, sharing the same odontoblast process within a continuation of the same dentinal tubule. Under normal circumstances, both in brachydont and hypsodont teeth, ‘regular’ secondary dentine is laid down within the pulp chamber by the odontoblasts until the pulp chamber is almost completely occluded.

Irregular secondary equine dentine (also referred to as reparative, reactive or tertiary dentine) has previously been classified as dentine that is laid down in response to noxious stimuli (Muylle et al. 2002). However, recent work has shown irregular secondary dentine to be present in all (n= 100) grossly normal equine teeth examined, with no evidence of prior exposure to noxious stimuli (Dacre 2004a). This secondary irregular dentine is laid down in the most central part of the pulp horn when this region is undergoing its final physiological stage of pulp replacement by dentine. The continued formation of both regular and irregular secondary dentine prevents pulpar exposure on the occlusal surface.

Tertiary dentine is laid down focally, in response to specific local noxious stimuli (Ten Cate 1998a). It may have some tubules that are continuous with those of secondary dentine; tubules that are sparse or distorted; or no tubules at all (Torneck 1998). Cells may be trapped within this rapidly laid down tissue, and this type of dentine is termed (tertiary) osteodentine. Tertiary dentine may be further subdivided into reactionary and reparative dentine, with the former being laid down by pre-existing odontoblasts and the latter by newly differentiated odontoblast-like cells from within the pulp.

Enamel

Enamel is the hardest and most dense substance in the body, composed of 96-98% minerals. Because it is inert and acellular once formed, it is then basically a dead calcified material and cannot repair itself. The structure of equine enamel has been described by Kilic et al (1997), who defined three types of equine enamel according to the transverse appearances of their enamel prisms and the presence, amount and appearance of their interprismatic enamel. Equine Type-1 enamel contains alternating rows of oval-shaped prisms and thick interprismatic enamel plates, and is found adjacent to the amelodentinal junction. Equine Type-2 enamel consists of ‘keyhole’ to ‘horseshoe’ shaped prisms, with little or no interprismatic enamel, and is located adjacent to the amelocemental junction. Three-dimensional prism decussation (interweaving) is present in equine Type-2 enamel, which is the main type of enamel in equine incisors. Decussation makes equine Type-2 enamel much more resistant to fracture than equine Type-1 enamel. A greater amount of equine Type-1 enamel is present in maxillary CT than in mandibular CT, with equine Type-2 enamel being the dominant form of enamel in the mandibular CT. Equine Type-3 enamel is inconsistently present as a thin layer at both the amelodentinal and amelocemental junctions, where its interprismatic enamel forms a honeycomb-like structure, with each ‘cell’ occupied by an oval shaped prism. It is less highly evolved than equine Type-1 and 2 enamel (Kilic et al. 1997a)

Fig x. Electron microscopy of Equine Type-1 enamel. (Image courtesy N.duToit MRCVS).

Enamel is produced by the ameloblasts at the apical aspect of the developing teeth and when the enamel is fully developed (usually about the time of dental eruption) the ameloblasts die off, and no further regeneration of enamel can now occur. Later on in dental development and following tooth eruption, cementum is deposited at the apical aspect of the enamel and these enamel free areas are the *true roots* of the equine teeth.

Another difference in equine as compared to brachydont teeth is the fact that the (shiny) enamel on the sides of equine clinical (erupted) crown is usually not visible because it is covered by a layer of dull, often stained cementum, an exception being the rostral/vestibular aspect of the incisors where the cementum becomes worn away while prehending food, revealing the underlying shiny, white enamel.

Enamel Infolding and Infundibular Enamel

The cheek teeth have evolved to become very efficient at grinding tough fibrous food and instead of having a single layer of enamel around the periphery of the cheek teeth (like incisor teeth) the lower cheek teeth in particular have very extensive infolding of enamel that protects the softer cementum and dentine.

Maxillary cheek teeth also have infundibular enamel that compensates for their reduced infolding. Normal infundibulae can be up to 89 mm long in 4-year-old horses to as low at 2 mm in 30-year-old horses which on average infundibular length being a mean of 82% of the total dental crown length; however, in individual cheek teeth and horses, they may be relatively much shorter.1 Thus with age either one or both infundibular can wear out (often in the 09 or 10) causing the adjacent unsupported primary and secondary dentine to wear very fast and the tooth to become hollow. Eventually this is a feature of most old teeth and this form of wear has been termed *senile excavation*. Likewise the degree of infolding present on the periphery of teeth decreases more apically and thus with age a more peripheral rim of enamel without deep enamel infolding can be present in mandibular cheek teeth that also become hollowed out.

Cementum

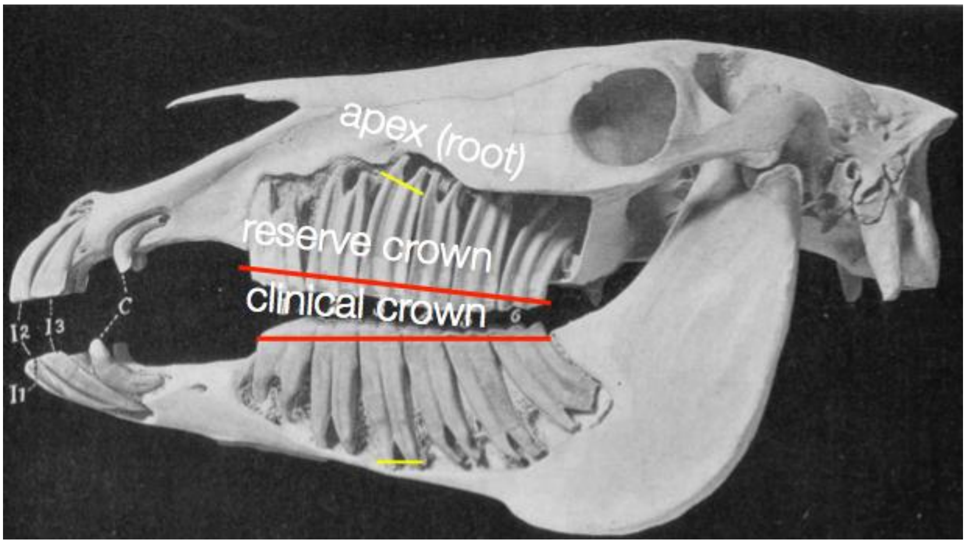
Cementum is the softest of the three calcified dental tissues, being approximately 65% mineral, 35% organic, with calcium hydroxyapatite crystals being the principle mineral present. Peripheral cement is deposited both directly and indirectly onto resorbed and unresorbed enamel, with a thin calcified layer interposed in areas of indirect mineralisation.

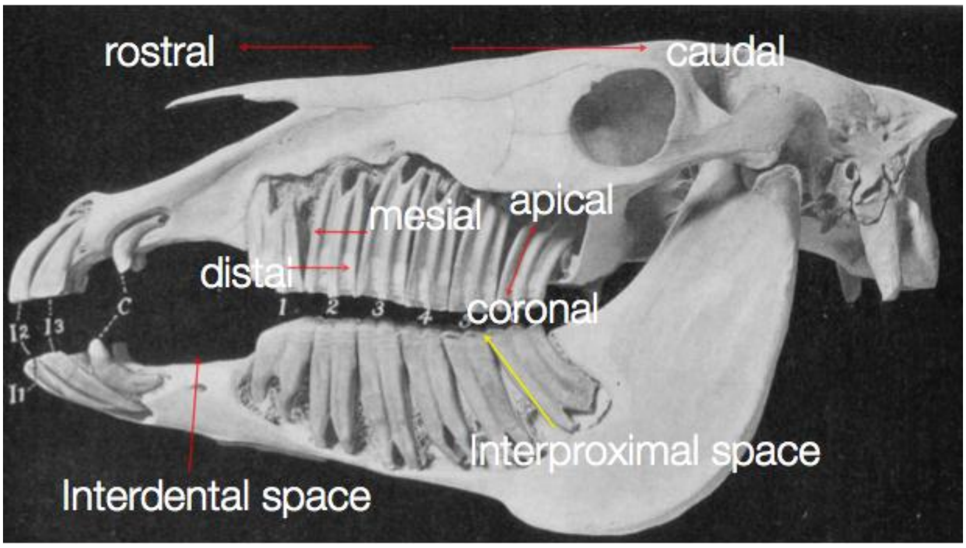
Cementum is a specialised calcified connective tissue that provides anchorage for the fibres of the periodontal ligament (Sharpey's Fibres) and also a means for dental eruption in both brachydont and hypsodont teeth. Its higher organic and water content confers some flexibility (like dentine), allowing it to give necessary support to the brittle adjacent enamel. In all horses (particularly as they become older), cementum also significantly structurally contributes to the size and strength of the crown and roots.

Subgingival cementum is nourished by the periodontium, however, this vascular supply is lost following eruption (as part of the clinical crown) by more than a few millimetres, after which cementum may be considered an inert tissue. Within the dental alveolus, and more specifically in the sub-gingival region immediately above the alveolar crest, cementum is deposited throughout the life of the tooth (Jones 1981; Mitchell 2004). Cementoblasts can also respond quickly to harmful stimuli by further rapid deposition of cementum.

Cementum formed around the periphery of a tooth including that following the infoldings of enamel is termed peripheral cementum. Infundibular cementum refers to distinct islands of cementum formed within the infundibulae (single infundibulum in incisor teeth and double in cheek teeth). Defects in cemental filling are termed infundibular cemental hypoplasia and a high proportion of cheek teeth have their infundibulae incompletely filled with cementum. Inexplicably the 09 positions have much more infundibular cemental hypoplasia than any other Triadan position. These infundibular cemental defects are so common in equine cheek teeth (especially the 09's) that they could almost be termed a physiological feature. However, these cemental defects can later get filled with food and subsequently develop caries that can cause clinical disease.

Dental terminology
When describing equine dental pathology it is customary to use terminology commonly used in human and small animal dentistry; some examples are shown in the images below:





The importance of a good examination
The horse's mouth is not well suited for a good oral examination. The rostral position of the lip commissures and limited opening of the mouth means a direct view generally will tell us very little about any developing pathology. A thorough routine examination will require sedation, a headstand, good dental speculum, mouthwash with large dental syringe, bright head light and dental mirror or even better an oral endoscope.

The routine oral and dental examination should be considered a clinical examination and every surface of every tooth, the interproximal spaces, gingival margins and all the soft tissues of the mouth should be systematically examined - as routine. Once small lesions are identified, then clients can be given an informed choice about whether they would like to pursue preventative treatment.

Consideration should be given to the mastication and the possibility that there are altered eating patterns to cope with dental pain – this may be obvious in cases such as shear mouth, but another clue are individual focal overgrowths that develop from horses skilfully avoiding using specific areas of the mouth.

This focal overgrowth has developed due to altered mastication to avoiding the painful area.

Equine Dental Key Pathology

Research has shown us that the gross and ultrastructural anatomy has several important differences from other species but essentially the basic dental tissues (cementum, dentine, pulp) are virtually identical. The response of these tissues to disease is also very similar, and applying basic dental pathological principles to the equine anatomy gives us the understanding of progression of dental disease in the horse.

Long section of a maxillary cheek tooth showing the pulp horns descending to the occlusal surface. This tooth actually has an apical abscess, with these pulps unaffected. (Image courtesy P.Dixon)

Normal occlusal anatomy

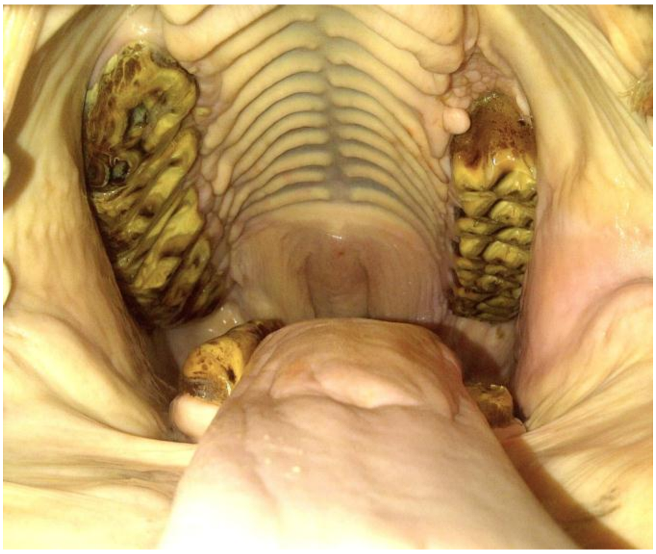
The constant eruption of a finite crown and attrition on the occlusal surface means we are always looking at a cross section of the tooth when viewing the occlusal surface. The pulp recedes slowly to prevent vital occlusal exposure, being replaced by secondary dentine which is present as glassy smooth brown staining regions. Maxillary cheek teeth also have two cement filled infundubula (the equivalent of incisor 'cups'). These will be seen as roughly crescent shaped enamel bordered structures, filled with off-white coloured cementum. Each maxillary tooth has two, a rostral and a caudal infundibulum, and each one will have a small central defect, which is the remnant of the occlusal vascular supply. This should not be confused with a dentinal / pulp defect. Mandibular teeth do not have infundibula, but have deeply in-folded enamel to increase the abrasive surface area instead.

Pulps are numbered according to the system initiated by Dacre (2004) and adapted by DuToit (2009) giving us a common standard system of pulp numbering.

Occlusal images of a maxillary (left)) and a mandibular tooth (right). Note presence of 2 crescent-shaped enamel bordered infundibula of the maxillary tooth, absent in mandibular teeth.

Dental pathology

Some dental disease will result in outward clinical signs such as facial swelling, dysphagia, nasal discharge, salivation or even poor performance. However, many dental diseases especially those in the early stages will show no clinical signs at all. For example, in cases of pathological dental fracture, the client often describes the problem as sudden onset, due to the displaced fracture fragments traumatising soft tissue resulting in dysphagia. The pulp disease preceding the fracture, which may have taken many years to develop, has gone un-noticed. In some cases a variety of dental conditions may be present at any one time in a horses' mouth with no apparent outward signs. If a horse has pain on one side of the mouth, he will simply eat on the other side, often for many years. Close inspection however, will reveal the subtle changes that indicate the developing problems.



This horse has been chewing on the left side (2,3 arcade) for many years, resulting in a shear mouth on the right side (1,4).

This severely decayed tooth (410) was removed from the above case. Now 16 years old, the dead necrotic apex shows no sign of root formation – likely from around 4 years of age. A probe is inserted in the open necrotic apex (left) through to the occlusal opening (right). The occlusal surface is near vertical.

Problems with the pulp – pulpitis
Pulp tissue may become infected or severely inflamed through fracture, infundibular disease or most commonly through *anachoresis* – the establishment of blood-borne bacteria within the inflamed pulp after which a number of scenarios may arise:

1. As often seen in young patients, the pulp may become severely inflamed and an apical granuloma may develop – often referred to as an apical abscess, the inflamed apical pulp may or may not survive this acute insult.

2. If the pulp survives the initial insult, some pulp 'horns' within the teeth may become isolated by reactionary reparative dentine, sealing off the apical regions from the insult. These pulp horns will be effectively dead, and will no longer lay down secondary dentine. The result is eventual fissure formation occlusally, influx of food material and progression of caries.

3. The pulp may slowly die, failing to 'seal off' the insult. Apical disease develops slowly, often in combination with occlusal defects (as above). Eventually infection may burst into the sinus, or the teeth may become mechanically unstable due to deep caries and fracture. Thus most fractures are actually pathological rather than 'idiopathic' as they are often described.

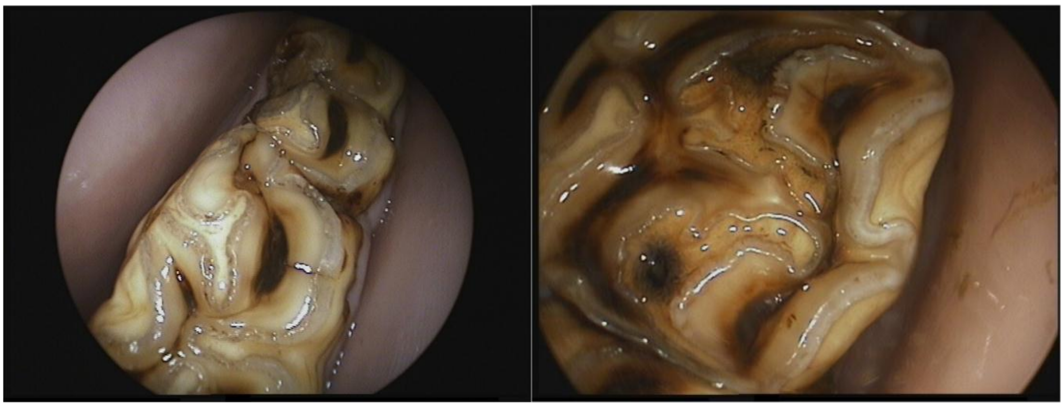
The author uses these three broad categories to describe the vitality of teeth in cases of cheek tooth pulpar pathology and fracture, and subsequently to decide upon a treatment strategy:

Category of cheek tooth pathology / endodontic status	**Description**	**Action**
Category 1	The pulp has survived the insult, tertiary dentine may be present, no apical infection is evident, no occlusal dentine defects visible oroscopically (some fractures may be within this category)	No action required; monitor closely (up to 3 years)
Category 2	No evidence apical disease, tertiary dentine bridges have formed within the pulp, but occlusal pulp is exposed and caries is present (or Grade 3+ infundibular caries)	Treatment using endodontic / restorative techniques is appropriate
Category 3	The apex and some or all of the pulp system is septic / compromised (includes some fractures including *all* maxillary saggital fractures)	Extraction of tooth required

Identification of occlusal defects of secondary dentine is clear evidence of a disturbance of the normal pulpar secondary dentine production and represents evidence of pulpitis. If there is corresponding apical change then it is highly likely that the tooth will require extraction; without apical change, and preferably after a computed tomography can, endodontic therapy may be useful.

Dentinal fissures – 'cracks'

Small lesions such as fissures, cracks or infractions of equine teeth are commonly identified oroscopically (see images below). Complete fractures follow the same planes as many of these lesions however very little clinical research has been performed to link these conditions. It seems likely that these 'cracks' may be precursors to 'idiopathic' fractures, suggesting that dental fractures are most likely to be pathological, not idiopathic. Some lesions with food impaction and secondary caries may be candidates for restorative therapy, but currently most of these lesions are untreatable and regular examination is recommended. Fissure lines, or cracks may also be seen between carious infundibula and are an indication for infundibular restoration.



Dentinal fissures appear to occur in the same positions and planes as fractures. Further research is required to link the two conditions.

This tooth has occlusal secondary dentine defects identifiable in the pulp horns 1 and 3, two years after an aggressive 'bit seat' was performed – the endodontic system is compromised and there is septic pulpitis with pulpar and dentinal caries. There may or may not be an apical abscess present.

Infundibular caries (IHC)

Some cheek teeth, notably the (maxillary) 09, 06 and 11 have been well documented to have areas, usually apically, that are devoid of the normal cement 'filling' that should be present throughout their whole length right up to the apical enamel reflection. In teeth that have apical infundibular cemental defects (hypoplasia), these areas will eventually appear as cavities, due to attrition at the occlusal surface. At this point, and the age at which they appear depends on the size of the defect within the infundibulum, food material packs into the cavity and the process of caries and tooth destruction starts.

After years of ingress of food material (substrate for fermenting bacteria) acid destruction of the inside of the tooth may result in lateral spread to dentine, pulp and the apex, or pathological fracture from a saggital midline plane of weakness. Such fractures are not idiopathic, but pathological following years of dental decay - and again are not the result of a horse chewing on a stone.

The rostral infundibulum of this 209 tooth is lacking cementum (hypocementosis) and has food impacted into the cavity with secondary caries (left); both infundibula are undergoing cleaning and debridement in preparation for infundibular restoration (some food material is still present in the distal aspect of the rostral infundibulum, right). When fully cleaned, the depth of the cavity is clear. In this case the enamel border of the infundibulum is still complete.

Abnormalities affecting the infundibula of the maxillary cheek teeth (CT) have been described previously as infundibular cemental hypoplasia (IH) and infundibular caries (IC) (Baker 1979; Wafa 1988; Kilic *et al* 1997). IH most commonly affects the apical aspect of the infundibulum although rarely there may be more complete or even total absence of cementum (Dacre 2004). Dental caries has been defined as a progressive acidic demineralisation of the inorganic matrix of dental tissues secondary to bacterial fermentation of impacted carbohydrate substrate and subsequent organic matrix loss (Blood and Studdert 1999; Lundstrom 2010). In Sweden infundibular caries of the 106/206 was found to be specifically related to presence of a novel bacteria (*Streptococcus devreisei*) (Lundstrom 2010). Clinically, once ICH lesions are large enough to be identified occlusally, dental caries through either or both of the above mechanisms is invariably present and thus in this study the term infundibular hypoplasia/caries (IHC) has been used.

IHC provides a central plane of structural weakness in the tooth predisposing it to pathological fracture when constantly exposed to the normal forces of mastication and attrition (Dacre *et al* 2007). Advanced lesions of both rostral and caudal infundibulae, especially those that coalesce, are likely to result in significant structural weakness of the CT (Johnson and Porter 2004). A recent study showed caries affecting the full length of the infundibulum in 8.2% of infundibula studied, most commonly in the 12-20 year age group, and concluded that this would be likely to predispose the tooth to pathologic fracture (Fitzgibbon, DuToit and Dixon 2010). Also, extension of caries from the infundibulum has been shown to cause apical sepsis in 16% of maxillary CT apical infections (Dacre *et al* 2008).

IHC of the rostral infundibulum (RI) or caudal infundibulum (CI) and has been classified and graded as follows (Dacre 2005) :

Grade 1 – Caries of infundibular cementum only
Grade 2 – Caries of infundibular cementum and enamel
Grade 3 – Caries of infundibular cementum, enamel and dentine

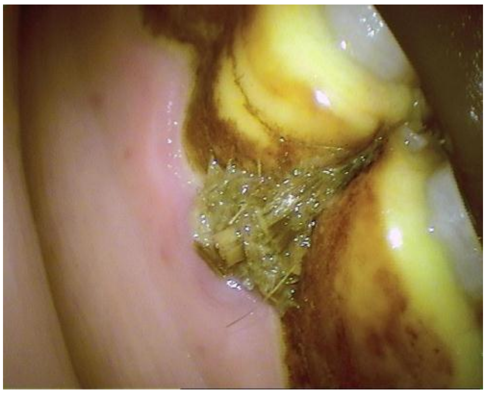
The author uses a slight modification of the described classification subsequently:

Grade 4 – Grade 3 rostral and caudal infundibulum, coalescing lesion
Grade 5 – Advanced caries resulting in apical abscessation, fracture or tooth loss

Images showing Grade 1-5 caries

Periodontal disease

Periodontal disease may have a number of causes and progress in variable ways depending on the anatomical arrangement of the teeth with each other. Displaced teeth, abnormal spacing between teeth, uneven interproximal anatomical are all causes of diastema formation resulting in periodontal disease. Even small amounts of food trapped sub-gingivally in periodontal pockets is very painful for horses, and will cause them to adapt their eating patterns to compensate. Focal overgrowths will develop with the altered mastication and this sets up a vicious cycle of pain, inflammation, overgrowth formation, further food stasis, then more pain, inflammation and so on. Trapped food causes gingival recession, peripheral cement caries and formation of a 'valve' diastema. Other cases with less perfect interproximal junctions may progress more quickly developing deep, severe periodontal pockets. Once again, horses will adapt their eating patterns to cope with the pain and disguise the problem, so it is up to us to find the developing disease before the overt clinical signs appear – often when things are really severe.



Food impaction, interproximal cemental caries and gingival recession – an early 'valve' diastema - treatment at this stage will prevent problems later.

Most periodontal disease occurs secondary to other developmental or pathological conditions: diastema, dental displacements and rotations, fractures or functional abnormalities. Primary periodontal disease is rare. Horses have a pellicle layer which in areas of stasis may develop to a thick plaque like substance which in turn appeaers to occasionally cause marked peripheral caries with destructive lytic lesions however these have yet to be linked definitely with periodontal disease (Fig 1). Despite the current lack of evidence, it seems logical that loss of interproximal cementum and dentine through such caries would result in the stasis of food in the resultant space.

Severe peripheral caries with dental plaque formation on lingual aspect of Triadan 310

Feed types play an important role. The softer the feed, the larger the range of motion and the less crushing motion used. With soft feedstuffs, such as green grass pasture, a wider range of mandibular motion is used. Feed material is ground in a circular pattern, rather than crushed. This wide range of motion creates a large amount of soft tissue contact, gingival crevicular fluid (GCF), and saliva flow. The soft tissue contact together with saliva mechanically cleanses the teeth, thus preventing feed stasis. Horses secrete 50 ml/min of saliva from the parotid salivary gland. Salivary flow is stimulated by mastication.

Without mastication, salivary flow is limited to that amount needed to maintain a moist intraoral environment. Horses in free-range situations feed for approximately 14 hours per day. By calculation only, not by direct measurement, that would mean horses create over 40 litres of saliva per day when feeding on grass from one gland alone. The previously mentioned benefits of saliva, mechanical cleansing, acid buffering, and antibody production are very important in prevention of gingivitis and periodontal disease when its flow is both voluminous and continuous. GCF fluid flow and its advantageous components, leukocytes, and antibodies are important also. Together, these two host defense mechanisms provide a substantial barrier to infection.

When horses consume harder feeds such as hay and grain, all the above parameters change in favor of the development of periodontal disease. Range of motion is reduced; teeth and parts thereof become protuberant; feed stasis occurs; and decay and the cascade is set in motion. The saliva that is produced is absorbed by the dry feed to some degree, thus reducing its effectiveness. Because the time of feeding is reduced, the total daily saliva and GCF production is dramatically reduced. The net result is a much greater time for static feed material to decay. Reduced soft tissue contact and reduced range of motion leads to decay of feed material, thus creating the environment for periodontal disease to flourish.

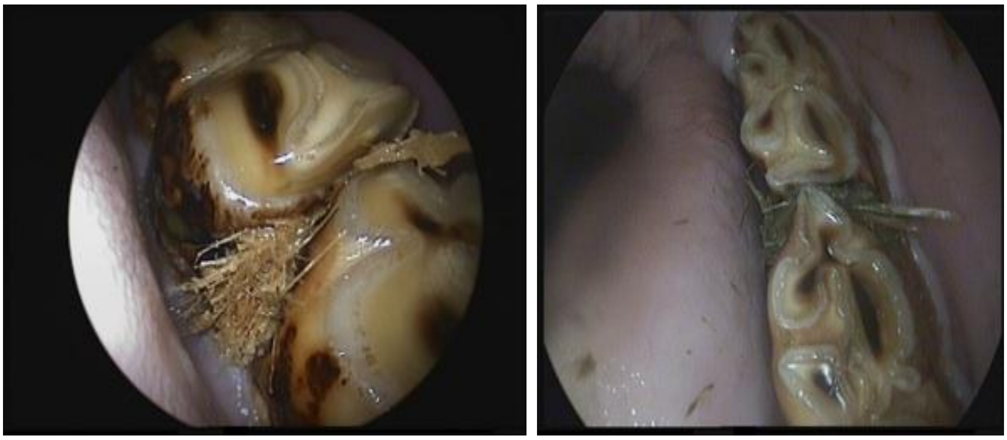
Examination and Assessment

Oral examination is carried out as previously described paying particular attention to interproximal spaces, and the buccal and lingual aspects of cheek teeth for gingival recession, impacted food material with or without occlusal diastemas (Fig 2).

Early periodontal disease; food impaction with no occlusal diastema

Following this, meticulous cleaning of diastemas is required using picks, crocodile forceps, flushing units and scalers. Peripheral caries lesions should be debrided. This process can be painstakingly slow, and may require significant levels of sedation and analgesia including regional nerve blocks on occasion.

The condition of the tooth and periodontium is examined for gingival inflammation and erosion, condition of sulcular epithelium, pocket depth and mesial/distal length, condition of the supragingival and subgingival cementum, attachment loss, and tooth mobility. The interproximal spaces should be examined particularly carefully to assess the type of junctional contact between the teeth i.e. parallel or otherwise (see Fig 3), and for displacements, rotations and fractures.



Variations of the anatomy of the interproximal space leading to food impaction

Periodontal disease assessment should be performed using a combination of examination using a mirror, oroscopy and radiography to give a tooth mobility / periodontal disease index (Wiggs & Lobprise) as follows:

Grade 0 no PDL loss
Grade 1 Gingivitis, no attachment loss
Grade 2 <25% attachment loss
Grade 3 <50% attachment loss
Grade 4 >50% attachment loss

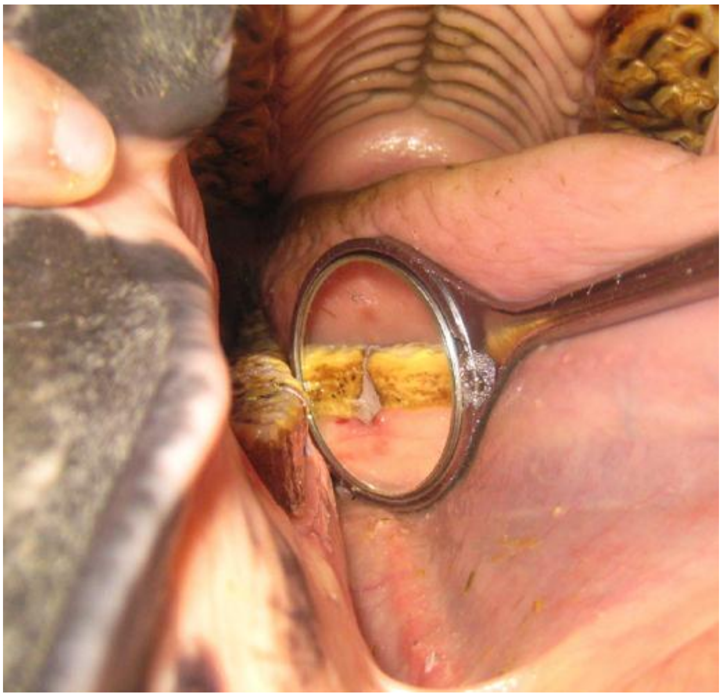
Treatment and Prevention
In recent years there have been a number of treatments advocated for the management and treatment of equine periodontal disease. These include corrective dental floating, removal of necrotic food material impacted in interproximal spaces, use of abrasive prophy powders mixed with water and propelled by pressurised gas, widening of interproximal spaces using motorised burrs, application of temporary ‘patches’ of dental impression material, application of semi-permanent interproximal ‘bridges’, the use of perioceutic agents and exodontia.

The treatment may be broken down into simple steps which will cover all types of periodontal disease:

1. Meticulous cleaning of interproximal spaces and periodontal pockets

2. Short term measured to improve periodontal health
    a. Corrective floating, equilibration
    b. Perioceutic agents e.g. doxycycline gel
    c. Temporary ‘patches’ to prevent immediate influx of food material

3. Long term measures to prevent further periodontal disease
    a. Diastema widening
    b. Bonded hard ‘bridges’ to occlude diastema more permanently



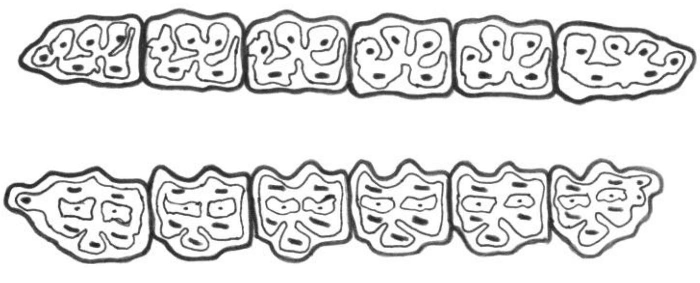
Cleaned diastema and periodontal pocket with temporary vinyl polysiloxane 'patch'

Interproximal 'bridges' using bonded resin polymer to occlude diastema

Further research and long-term studies are required in this area to ascertain the effectiveness and safety of these treatments. Personal experience has shown that after careful examination and assessment of cases a combination of the above techniques, initially utilising minimally invasive procedures can produce excellent results. For more severe and chronic cases, the use of interproximal 'bridging' or widening of diastema can also be very effective.

Dental charting

Recording of findings from the oral examination is important for good clinical practice and for owners to keep a record, and to help owners understand the pathology present. For this reason the author prefers dental charts with the outline of a head and teeth that are easily recognisable as such (see below). Whatever style of chart is chosen, it is imperative that there are anatomically accurate and detailed occlusal surface images for recording occlusal pathology (see below).



Cheek tooth occlusal surface images used in the authour's dental charts.

Many practitioners use abbreviations for equine dentistry however many abbreviations 'borrowed' from human or small animal dentistry are innapropriate for equine dentistry. Some more commonly used appropriate abbreviations are listed below:

- O - Missing / absent tooth/teeth
- 106 506 – Permanent tooth / Deciduous tooth
- SN 111 – Supernumerary distomolar *(not 112)*
- DGL/4 – Diagonal bite (400 incisor teeth longest)
- VC – Ventral curvature, DC – dorsal curvature (relating to incisors)
- MAL2 / MAL3 – Overbite (Parrot) / Underbite (Sow)
- FX – Fracture (can add Triadan, aspect etc)
- CAL – Calculus / tartar
- SEP – Sharp enamel points
- HK, RMP, ATR, = FO – Focal overgrowths
- Inf/Ca 1-4 or Inf.Ca or IC or IHC – Infundibular Caries Grade 1-4
- D or DI or DIA – Diastema
- PD1-4 – Periodontal Disease Index 1-4
- M1-4 – Mobility Index 1-4 (movement 1-4mm in any direction)
- X – Extracted
- BSF – Buccal slab fracture (pulps 1-2)
- SAG – Saggital fracture – i.e. InfCa

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Radiography of the equine head and teeth
Diagnostic imaging of the head and dental tissues may be performed using the imaging modalities of radiography, ultrasonongraphy, scintigraphy and computed tomography (CT). Each technique has its own merits and disadvantages and they each offer additional information to the findings from the oral examination to enable the clinician to obtain a clinical diagnosis.

Many practitioners will have access to radiography and ultrasonography, and many head and dental disorders may be diagnosed with high degrees of confidence using modern digital radiographic equipment.

Radiography
Prior to the advent of digital radiography the diagnostic efficiency of radiography for apical infection of cheek teeth was approximately 50%. However, with the advent of modern digital systems and attention to good technique this is dramatically increased (70% sensitivity, 90% specificity). Image quality is of utmost importance and the practitioner should pay careful attention to the basics of good radiography including exposure, positioning, restraint of the patient and collimation of the beam. Exposure factors are no longer as much of a concern as with older film based systems; digital systems have wide latitude and the exposure and contrast can be altered to adjust for small errors in exposure. However care should be taken to ensure higher exposures do not ‘burn out’ the finer anatomical detail of e.g. paranasal sinuses. Stabilisation of the patient is of paramount importance and good sedation and stable positioning of the head is essential. Reducing exposure factors to the shortest possible will also help maximize image quality and reduce ‘movement blur’.

Indications for radiography of the equine skull are numerous but most commonly include clinical signs associated with periapical dental disease, disorders of the paranasal sinuses or nasal cavities (unilateral nasal discharge, facial swelling, quidding and discharging sinus tracts). Occasionally, it may be useful to radiographically examine horses with suspected abnormalities of the guttural pouches, pharynx/larynx and traumatic injuries of the skull.

A prerequisite of good radiographic interpretation is a thorough knowledge of dental and sinus anatomy and the normal radiographic anatomical appearance.

Standard views should include:

- Latero30°dorsal–lateroventral oblique
- Latero35-45°ventral–laterodorsal oblique
- Dorso-ventral

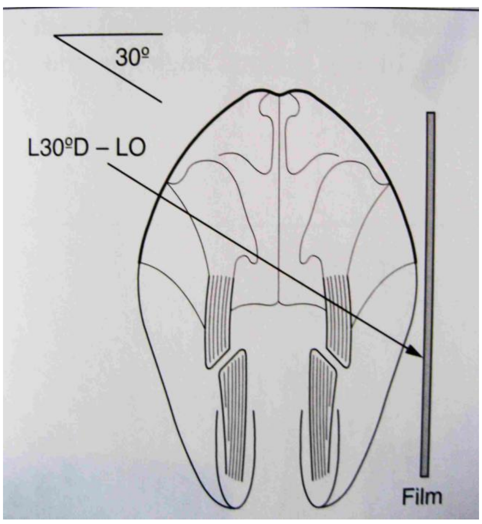

Fig 1. Latero30°dorsal–lateroventral oblique

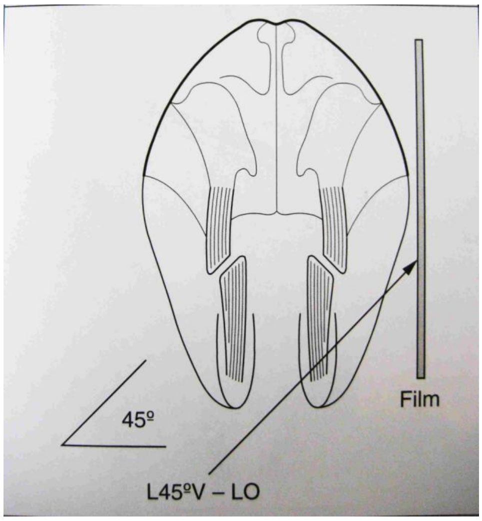

Fig 2. Latero35-45°ventral–laterodorsal oblique

These views usually will provide the clinician with all the radiographic information that is required. The minimum possible dorsal or ventral angulation should be used when taking oblique radiographs to reduce the separation of structures of the left and right sides of the head, but also to decrease distortion of the structures the clinician is trying to assess. Additional views are occasionally necessary to clearly visualise the clinical crown of the cheek teeth, the wolf teeth, canines and incisors, and some skull fractures.

Whichever view is being taken the angle must be observed carefully to avoid inadvertent rostro-caudal angulation, i.e. to ensure the oblique angle is made only from the lateral plane. This is easiest in practice if the head is positioned vertically or horizontally, especially with smaller mobile type systems on mobile stands. The rostral aspect of the facial crest gives an approximate marker for the centre of the cheek teeth rows and serves as a good centering point for radiography of the cheek teeth.

An alternative approach to finding /ensuring the correct angles are used is by following the 'hemisphere model' for radiographic.

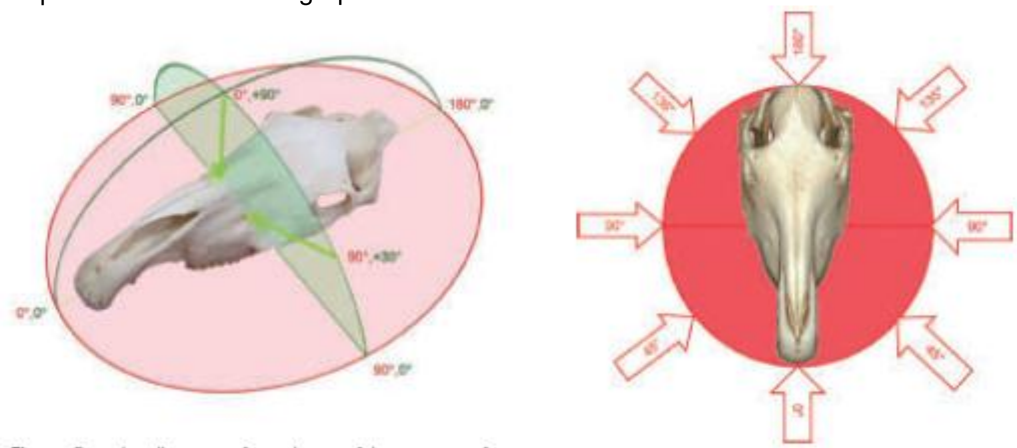

Fig. 3. Representations of the Hemisphere Model for radiographic positioning (Stoll et al 2011)

Other views that are sometimes indicated include:

- Open mouthed obliques - to view the occlusal aspect of the cheek teeth
- Intra-oral views - usually of the incisors and canines or to evaluate traumatic damage to the rostral skull (use bisecting angle technique as below).
- Oblique dorso-ventral views or dorso-ventral views with offset mandible - to image one maxillary arcade in DV plane or nasal cavity in particular
- Lateral views of the guttural pouches or laryngeal/pharyngeal area
- Tangential oblique views to image the temporo-mandibular joints (Townsend et al 2009).

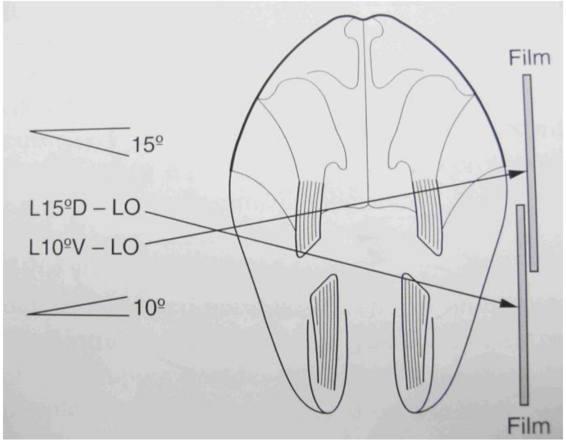

Fig. 4. Open-mouthed oblique views for obtaining images of clinical crown, interproximal spaces and periodontal tissues.

Tips for good equine skull radiographs:

- Restrain the horse under sedation and avoid the use of a halter if possible (even rope halters will cast a radiographic shadow).
- Use a large cassette and collimate the primary beam to include a large area, e.g. the entire maxillary dental arcade and sinuses if a maxillary dental disorder is suspected, can make interpretation of skull radiographs easier as abnormalities can be related to easily identified anatomical structures. This also allows all 6 teeth of one arcade to be imaged avoiding misinterpretation of findings.
- Rest the nose of a sedated horse on a stool to reduce swaying movements of the head.
- Keep the plate aligned vertically for latero-lateral projections – fluid lines will appear horizontal to the ventral border of the plate, which makes interpretation easier.
- Attach the cassette directly to the head using bungee type cords as an alternative way to prevent movement blur and means a second person is not required to hold the cassette holder.
- Remember to angle the beam slightly rostro-caudally if imaging the caudal CT, and caudo-rostrally if imaging the rostral CT.
- Consider 10° caudo-rostral angle of beam for standard oblique views especially mandibular CT.
- Use a lower exposure to view the paranasal sinus contents, incisors or guttural pouch/laryngeal areas as compared to the relatively radio-opaque cheek teeth.
- Place a small radio-opaque marker (e.g. nail, drawing pin) on the area of maximal swelling and take an additional lateral or oblique radiograph to help when deciding if radiographic changes are likely to be clinically significant.
- Guide a blunt, malleable, metallic probe into any draining tracts and hold in place with tape.
- Always remember to radiograph the contralateral side for comparison.
- Know your skull anatomy and what the radiographic view you are taking should look like!

Common faults that occur during skull radiography include:

- Using too small a cassette (and missing the area of interest) or being unable to identify which teeth are present
- Allowing rostro-caudal obliquity to compound the angles and create overlapping of structures
- Inadvertent rostro-caudal angulation of the x-ray beam, particularly when taking lateral oblique views
- Axial rotation when taking dorso-ventral views
- Inadequate exposures - although exposures vary depending on patient size and the x-ray machine and cassette systems used

Images obtained should then be assessed for:

- Anatomical abnormalities e.g. oligodontia, dysplasia
- Pathological findings
    - Bony structures of head
    - Soft tissue swellings
    - Sinus compartments
    - Dental tissues
        - Lamina dura denta surrounding reserve crowns and apices of teeth
        - Periodontal ligament space
        - Dental structures e.g. pulp, infundibula

Intraoral radiography
More recently intra-oral radiography has been described and may be useful in certain instances, however long reserve crowns in young horses can result in difficulty obtaining images of apices without excessive angulation of the beam. Small custom-shaped plates are held in the mouth using a bespoke holder and images are obtained using the bisecting angle technique (Fig 5,6). Interpretation of images should always be performed alongside standard oblique views.

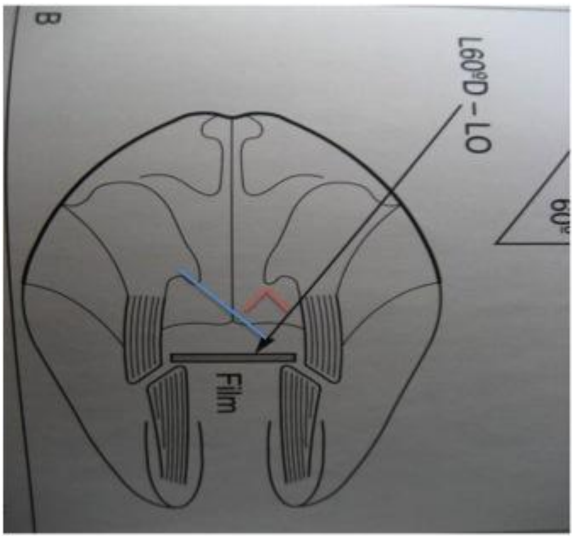

Fig 5. Bisecting angle technique for obtaining intra-oral radiograph

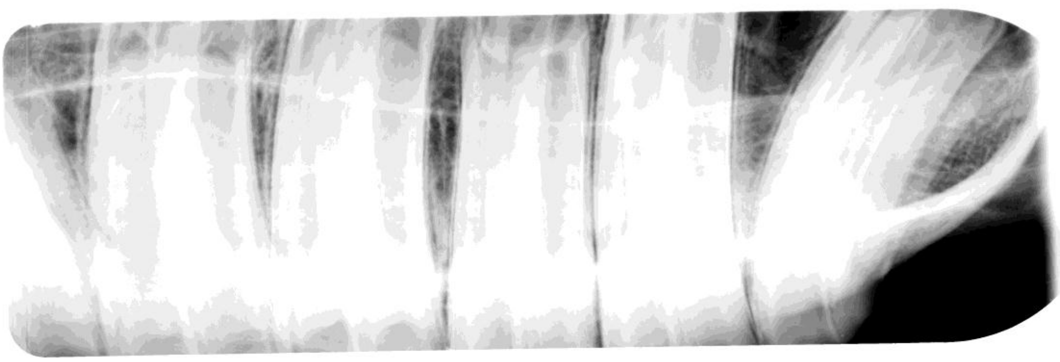

Fig 6. Intra-oral radiograph of caudal maxillary arcade.

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