Bit-Mouth Interaction in the Horse: A Multifactorial Analysis of Material, Geometry, Anatomy and Rider Influence

A Triangulated Study Combining Literature Review, Expert Interviews and Mechanical Analysis

Master's thesis in Materials Chemistry

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MASTER'S THESIS 2026

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Master's Thesis 2026
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Cover: An assortment of equestrian bits displayed on a dark background, representing the diversity of mechanical designs used to mediate communication between horse and rider. The collection includes snaffle, gag and leverage bits in various materials and configurations.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2026

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Abstract

Understanding bit-mouth interaction in horses requires an integrated evaluation of material properties, bit geometry, equine oral anatomy and rider-related factors. This study employed a triangulated qualitative design combining a structured literature review, mechanical material analysis and expert interviews to investigate how these factors influence pressure distribution and the risk of bit-related injuries. Mechanical data demonstrated substantial differences between commonly used bit materials, where metals provided greater structural stability but increased the risk of tooth-related injuries, while softer materials such as TPU and leather reduced stress concentrations on the teeth yet were associated with a higher prevalence of lesions induced from friction. Bit geometry and fitting emerged as equally critical determinants, with thin, correctly sized mouthpieces offering superior stability and reduced tissue compression. Expert interviews highlighted underdocumented clinical findings, including low grade mobility and excessive wear of the P2 teeth, as well as the central role of rider balance, rein tension and technique in modulating mechanical load. Variation in equipment use was identified as an important, but under-recognized strategy for reducing cumulative stress on the tissue. Overall, the findings demonstrate that bit–mouth interaction is multifactorial and cannot be understood through material or design parameters alone. An integrated approach that considers mechanical behavior, anatomical prerequisites and rider influence is essential for improving bit selection, fitting practices and equine welfare.

Keywords: bit-related injuries, equine oral cavity, bit wear, biomechanics horse bits, horse bits, equine oral injuries.

Acknowledgements

I would like to express my sincere gratitude to my supervisor and examiner Magnus Karlsteen for valuable guidance, feedback and support throughout the project. I am also grateful to the clinical experts, Ylva Rubin and Torbjörn Lundström, who contributed with their professional insights and generously shared their experience. This significantly strengthened the analysis of bit-related injuries and anatomical considerations. Finally, I would like to acknowledge the support from friends and family who provided helpful discussions and encouragement during the development of this work.

Vendela Eriksdotter Rubin, Gothenburg, June 2026

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

A	Area
DB	Double Bridle
DDS	Doctor of Dental Surgery
DVM	Doctor of Veterinary Medicine
F	Force
FEI	Fédération Èquestre Internationale
NCED	Nordic College of Equine Dentistry
p	Pressure
P1	First Premolar (maxillary) tooth, also known as wolftooth
P2	Second Premolar tooth
SB	Snaffle Bridle
SLU	Swedish University of Agricultural Sciences
TL	Torbjörn Lundström
TPU	Thermoplastic Polyurethane
YR	Ylva Rubin

Nomenclature

Below is the nomenclature that has been used throughout this thesis.

Anatomy

posterior	toward the rear or toward the deeper, back-facing part
anterior	toward the front of the body
lateral	away from the midline of the body, toward the sides (opposite of medial)
medial	toward the midline of the body (opposite of lateral)
caudal	toward the rear end of the body or toward the back of the skull
rostral	toward the front end of the body or toward the incisors (opposite of caudal)
ventral	toward the underside of the animal
dorsal	toward the upper side of the animal
rami	branches or arms of a structure
extrinsic	structures originating outside the region they act upon
intrinsic	structures originating within the region they act upon
occlusal	relating to the chewing surfaces of the teeth
occlusal surface	the surfaces of the teeth that meet during biting
ipsilateral	located on or affecting the same side of the body
contralateral	located on or affecting the opposite side of the body
palatine	relating to the palate
commissures	corners of the mouth where the lips meet
buccal	relating to the cheek or cheek-side of the teeth
gingiva / gingivae	gums; mucosal tissue surrounding the teeth
alveolar	relating to the tooth sockets (alveoli)
epiglottic	relating to the epiglottis

lingual	relating to the tongue
glossopharyngeal	relating to the glossopharyngeal nerve
hypoglossal	relating to the hypoglossal nerve
maxillary	relating to the upper jaw
mandibular	relating to the lower jaw
premolar	tooth located between canine and molar
hypsodont	teeth with high crowns and continuous eruption
pulp	soft tissue inside the tooth containing nerves and vessels
cementum	calcified tissue covering the tooth root
enamel	hard mineralized outer layer of the tooth
dentine	hard tissue beneath enamel and cementum

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1

Introduction

In the equestrian sport the bit is a key tool in the communication between the horse and the rider. It enables the regulation of tempo, direction, frame and movement of the horse. However, the prevalence of bit-related injuries exceeds levels considered acceptable from a welfare perspective [1]. Such injuries can impair the horse's comfort and performance, and they may also cause uncertainty for riders, who often lack clear guidance on why these injuries occur and how they can be prevented. Despite extensive discussion of bit design in equestrian practice, few studies have systematically examined how material properties, geometry and oral anatomy interact to influence injury risk. Several studies have documented the presence of bit related lesions, yet the underlying mechanisms remain poorly understood due to the complex and multifactorial nature of the problem [1–6]. Numerous parameters affect the occurrence of a bit related injury, making it challenging to design controlled scientific studies with conclusive results. Existing science is largely based on observations from a veterinary perspective, while engineering based analyses of bit mechanics are scarce [1, 7–9]. The guidance commonly provided to riders is largely rooted in tradition and lacks a foundation in empirical scientific evidence. Consequently, there is a clear need to consolidate current evidence and expert knowledge to develop informed recommendations for preventing bit related injuries. Understanding how material, surface properties, and geometrical design influence bit-mouth interaction is therefore essential for developing safer and more welfare-oriented equipment.

1.1 Aim

The aim of this thesis is to analyze how material properties, surface characteristics and geometrical design influence bit–mouth interaction and the occurrence of bit-related injuries. A further aim is to synthesize these findings into evidence-based recommendations for bit selection, fitting practices and welfare-oriented equipment design. This thesis addresses the following research question:

How do material properties, surface characteristics and bit geometry influence pressure distribution and the risk of bit-related injuries in riding horses?

1.2 Limitations

This thesis is conducted as a time-restricted academic project, which limits the extent and depth of the analyses that can be performed. Controlled experimental studies would have been valuable for validating several of the mechanisms discussed, but such investigations fall outside the methodological and temporal scope of this work. Furthermore, the research area is relatively underexplored, resulting in variability in data availability and consistency across sources.

To maintain methodological coherence, the study focuses exclusively on bit related injuries in riding horses within the disciplines of dressage, showjumping, and eventing. Horses used in driving, racing, or trotting were excluded due to their different biomechanical demands, which would not allow for meaningful comparison within the scope of this thesis.

2

Theory

To understand how the material, surface properties, and geometrical design of a horse bit influence the interaction between horse and rider, a broad theoretical foundation encompassing both biological and technical perspectives is required. Key aspects include the equine oral anatomy, the design and function of the bit, and the biomechanical principles governing bit–mouth interaction. In addition, the horse's natural behaviours and oral reflexes, as well as the mechanical properties of different materials, play crucial roles in determining pressure distribution and the development of bit related injuries. This chapter presents the theoretical background necessary to analyse bit–mouth interaction from both a veterinary and an engineering perspective, thereby forming the foundation for the subsequent analysis in this study.

2.1 Equine Oral Anatomy

Equine anatomy is complex and extensive, making a complete description beyond the scope of this work. However, the anatomical structures necessary for understanding this study are outlined in this section. In the posterior part of the cranium lies the occipital bone, forming the posterior wall. An overview of the skull is displayed in Figure 2.1. The maxilla forms the upper jaw and houses the upper cheek teeth, positioned laterally in the face and articulating with nearly all facial, frontal, and temporal bones. Medially, it presents the concave palatine bones, which constitute the major portion of the hard palate. The nasal bones form most of the nasal cavity, each ossifying from a membrane. The mandible forms the lower jaw and is the largest bone of the face [10].

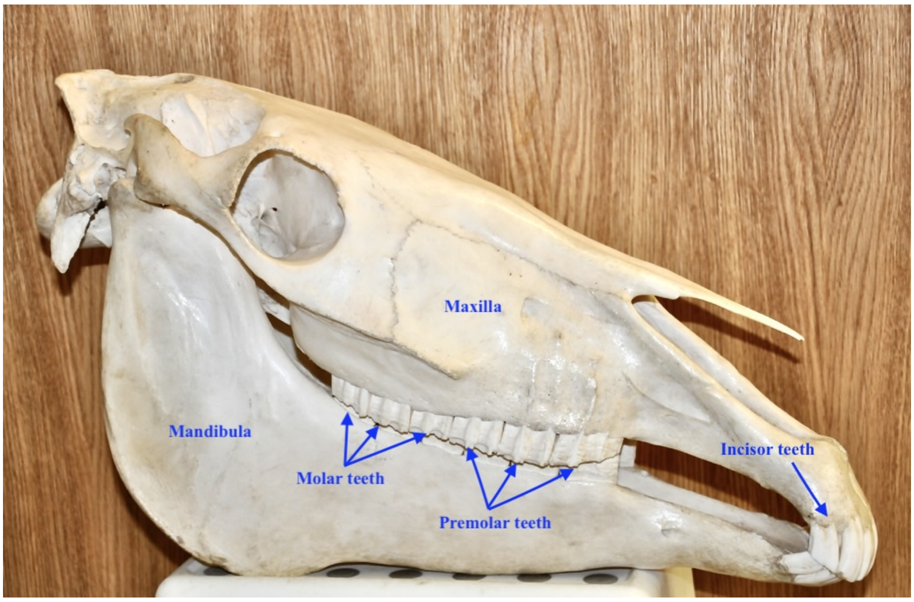


Figure 2.1: Lateral view of an equine skull with anatomical landmarks indicated. The maxilla, mandibula, incisors, premolars and molars are highlighted for orientation. Source: Private communication, DVM Ylva Rubin, (2026).

The oral cavity of the horse is a long oblong space bounded caudally by the soft palate, ventrally by the mandible and tongue, dorsally by the palate, and laterally by the cheeks. When the mouth is closed, the intraoral structures nearly fill the entire cavity, leaving only a small space between the epiglottis and the root of the tongue. The interior is lined by a continuous pink or dark coloured mucous membrane extending from the lips to the pharynx. The lips consist of two musculo-membranous folds enclosing as the oral opening and meeting as the commissures near P2. They are richly vascularized and their sensory innervation derives from the trigeminal nerve, the largest cranial nerve, which connects to the lateral aspect of the pons. Motor innervation arises from the facial nerve, originating just caudal to the pons. The same pattern applies to the cheeks. Intraorally, the gingivae consist of dense fibrous tissue integrated with the alveolar periosteum, anchoring the teeth within their sockets. The hard palate is bordered by the alveolar arches and the soft palate caudally, and its osseous foundation consists of the premaxilla, maxilla and palatine bones. Sensory innervation is provided by branches of the trigeminal nerve, and vascular supply by the palatine arteries and veins [10].

The tongue comprises a mucous membrane, glands, muscles, vessels and nerves. It occupies the ventral part of the mouth between the rami of the mandible and its dorsal surface is free throughout most of the cavity. It maintains full contact with the palate except at its caudal surface within the epiglottic space. The lingual musculature is divided into extrinsic and intrinsic groups, the latter consisting of interwoven fibres running in multiple directions. The extrinsic muscles include the styloglossus, hyoglossus, and genioglossus. The styloglossus retracts the tongue, the hyoglossus retracts and depresses it, and the genioglossus protrudes, depresses, and retracts it. Sensory innervation is provided by the lingual and glossopharyngeal nerves, while the hypoglossal nerve supplies the motor fibres [10].

The teeth morphologically consist of calcified papillae embedded in the alveolar parts of the mandible and maxilla. Horses possess two sets of teeth, a deciduous set used during early life and a permanent set that replaces it during growth. Based on position and morphology, the teeth are classified into incisors, canines, and premolars and molars. Each tooth is numbered from the midline outward, meaning the first cheek tooth in the maxilla is designated P1. However, this vestigial “wolf tooth” is not always present; in horses lacking it, the first cheek tooth is termed P2. Each jaw contains twelve cheek teeth with six premolars and six molars. The occlusal surface of each tooth consists of a complex pattern of enamel, dentine and cementum [10]. In hypsodont equine teeth, the clinical crown continues to erupt throughout much of the horse’s life and root formation is markedly delayed. In fact, the root starts to develop when the occlusal surface of the opposing crowns make contact. At this point, no more crown will be generated [11]. The central region of the tooth contains the pulp, a soft gelatinous tissue richly supplied with blood vessels from the infraorbital and mandibular branches and nerves from branches of the trigeminal nerve. The pulp is surrounded by dentine, enamel and cementum. The enamel layer constitutes the hardest tissue in the body [10].

The tissues within the oral cavity are lubricated by saliva. Equine saliva contains alkaline ions such as sodium, calcium, phosphorus, bicarbonate, urea, and potassium. In an oral cavity with sound teeth, this composition maintains a pH of approximately 8.0. However, if the teeth are carious, the saliva may become acidic and drop to around 4.0 [12].

2.2 Bit Design and Function

The function of the bit is to be an assisting tool in the communication between horse and rider, in addition to helping the rider control the speed, direction of movement and degree of self-carriage of the horse. This functions primarily by applying rein tension to the bit positioned in the horse’s oral cavity. There are several types of bits and they operate in different ways [2].

Figure 2.2: Single-jointed bits. Photograph by the author.

The single-jointed bit, viewed in Figure 2.2, is told to exert a nutcracker-like action on the bars of the mouth, causing the central joint to protrude towards the palate. However, when rein tension is applied, the joint is displaced further from the palate as the mouthpiece compresses the tongue.

Figure 2.3: Double-jointed bits, with the upper bit featuring eggbutt rings and the remaining bits equipped with loose rings. Photograph by the author.

The double jointed bit, seen in Figure 2.3, lies more uniformly across the tongue, as the central link creates a U-shaped profile in contrast to the V-shaped profile produced by a single jointed bit. This decreases the probability of putting pressure on the palate or compressing the mandibular rami. When rein-tension is applied the mouthpiece exerts pressure on the tongue instead [2]. However, studies indicate that the middle link in the double-jointed bit should be short to avoid locating the joints directly over the bars [3]. Bits designed with a port, as viewed in Figure 2.4, tend to be situated nearer the cheek teeth than snaffles [3].

A double bridle is a possible progression in combination with increased training level. It consists of a bridoon and a curb as seen in Figure 2.5. The design of the bridoon is similar to the snaffle having one or two joints and exerting no leverage mechanism. In contrary, the curb has an unjointed mouthpiece, a curb chain and a shank altogether creating a leverage mechanism. The curb bit can differ in length of the shank and may come with or without a port. The tightness of the curb chain affects the rotation of the curb, secondly impacting the magnitude and direction of forces. However, the complexity of the pressure distribution is high as the curb bit is not a fixed lever, but described as holding a floating fulcrum where the lever form and extend as required. It is of utmost importance that the rider and horse have reached a sufficient level of skill and experience before transitioning to the DB as the bridoon and curb should be used independently of each other [13].

Figure 2.4: Ported bits. Photograph by the author.

Figure 2.5: Bridoon and curb of correct proportional length, equipped with a curb chain and curb strap. Source: Private communication, DVM Ylva Rubin, (2026).

When selecting length of the bit, the width of the mouthpiece should equal the width of the interdental space, i.e. the distance between the left and right commissures of the lips. The bit should then be adjusted on the bridle into the corners of the lips without causing wrinkles [4]. Bits with a mouthpiece wider than the interdental space have been shown to shift considerably further posteriorly and laterally when unilateral rein tension is applied than a mouthpiece equally wide as the interdental space. In addition, jointed mouthpieces that are wider than the interdental space also carry an increased risk of making direct contact with the mandibular P2 [5].

2.3 Biomechanics of Bit-Mouth Interaction

The pressure caused by the bit is influenced by the weight of the mouthpiece, cheekpiece tension, rein tension, in addition to the contact area of the bit with the structures in the oral cavity. This follows from the fact that pressure is equal to force divided by area ($p = F/A$) [14]. The head and neck of the horse follow patterns original for each gait during motion and the rider should follow these patterns. Studies have been shown to produce small variations in the distance between the hand of the rider and the bit causing the characteristic pattern of rein tension in each gait respectively. In one study, the change in distance between the wrist of the rider and the bit was shown to be 1.5 cm. These changes in distance generate rein-tension oscillations with measured values of 20-40 N [13].

Unilateral rein tension generates caudal movement of the bit ring on the ipsilateral side while the contralateral ring moves medially. Applying force to the contralateral rein can antagonize the inward movement. Bilateral rein tension causes caudal movement of both bit rings and deep indention of the tongue [4]. An eggbutt single jointed snaffle displaces less laterally than a single jointed ring snaffle. When the snaffle is double jointed the difference in lateral displacement is non-significant. The eggbutt single jointed snaffle and both types of double jointed snaffles have similar lateral displacement. There is also evidence that the posterior displacement is decreased with a double jointed bit compared to a single jointed.

The single jointed ring snaffle and the double jointed eggbutt snaffle possesses a higher risk of touching the gingiva of the P2 compared to a single jointed eggbutt snaffle. This suggests that a the gingival area near the mandibular P2 may be at lower risk of pressure with a correctly fitted single jointed eggbutt snaffle compared to a single jointed ring bit or a double jointed bit [5].

When comparing a snaffle bridle and a double bridle, the DB naturally exhibit higher occipital force due to it being heavier. One study, indicated a mean addition of 0.86 kg for a DB resulting in increased mean occipital forces of 3.6-9.5 N depending on the gait. Nevertheless, this could be mitigated by using a wide, thick, uniformly padded headpiece. The combined rein tension of the DB is significantly lower than for the SB specifically in collected trot. In other gaits, the rein tension is similar for both types of bridles [13]. The curb bit has a more limited possibility of movement within the mouth and do not interfere with the mandibular P2. Studies thus conclude that the curb bit is more likely to cause pressure on the bars and tongue, while snaffles may cause pressure in the area of the gingival tissues near the mandibular P2 [5].

The tongue has contact with the palate when the mouth is closed and studies have shown that inserting a bit in the interdental space cause indentation of the tongue. In the aim of distributing the force from rein-tension over a larger area, a thicker bit has often been used. However, this may result in more discomfort than a thinner bit utilizing less volume [4]. In Figure 2.6 the tongue compression from the bit is illustrated.

Figure 2.6: Radiographic image showing tongue compression induced by bit pressure. Source: Private communication, DDS Torbjörn Lundström (2026).

The skeletal oral dimensions are significantly smaller in mares than in geldings, also in ponies than horses. However, the breed of the horse has a significant impact in the oral dimensions, especially the nasal parts. All oral dimensions but the width of the lower jaw positively correlate with each other, i.e. larger mouth means also larger distance between upper and lower jaw etc. The space in the mouth may slightly increase as the horse becomes adult due to hypsodont teeth and continuous eruption of cheek teeth, while the tongue remain the same thickness. However, horses do have individual differences despite being the same age, breed, sex etc. A bit should be thin enough to fit in the oral cavity while the horse has its mouth closed. Otherwise the tongue may be compressed, impede the blood flow and numb the tongue. A thicker bit has historically been seen as kinder to the horse as it distributes the pressure more due to a larger contact area. However, modern studies have shown thicker bits to cause more discomfort and stress than thinner bits. On average, horses have room for no more than 14 mm thick bits, without encroaching on the space of the tongue [14].

2.4 Equine Habits and Natural Oral Reflexes

The horse has different types of natural oral reflexes, but also learnt behaviours, that may be accustomed or protective. In studies, the bit has been shown to be raised to the cheek teeth by elevation followed by retraction of the dorsum of the tongue. This behaviour was increased with increasing length of the bit and too low a position of the bit [4]. Studies suggest a reduced sensitivity to bit pressure, a behaviour such as leaning on the reins is a solution for the horse to release the discomfort of pressure against the very sensitive palatine tissues rather than loading the pressure onto the tongue [3].

2.5 Materials and Mechanical Properties

From a materials chemistry standpoint, horse bits operate within a chemically aggressive and mechanically dynamic environment where electrochemical reactions, tribological processes and structure-dependent deformation mechanisms occur simultaneously. The equine oral cavity functions as an alkaline, ion-rich electrolyte containing bicarbonate, phosphate, chloride, calcium and organic molecules, creating conditions that promote corrosion, tribocorrosion and surface film breakdown. Metallic materials respond through electrochemical oxidation, passive layer formation and dissolution, galvanic interactions and micro-scale surface roughening, all of which alter frictional behaviour and stress transfer to tissues. Polymers such as TPU exhibit viscoelastic relaxation, time-dependent creep, chain mobility and moisture-induced softening, leading to increased adhesive friction and surface wear under cyclic loading. Natural collagen-based materials such as leather undergo hydration-driven swelling and changes in surface energy that influence friction and compliance.

These behaviours arise directly from fundamental structure–property relationships central to materials chemistry. Metallic bonding and crystalline lattices generate high stiffness, hardness and thermal conductivity, while the polymer chain architecture governs elasticity, damping and abrasion resistance. Oxide-forming metals such as titanium rely on passivating surface chemistry for corrosion resistance and biocompatibility. Understanding the bit–mouth interaction therefore requires integrating chemical composition, microstructure, corrosion kinetics, surface energy and mechanical properties to evaluate how materials degrade, how forces are transmitted and lastly how tissues respond. This materials chemistry framework forms the basis for the comparative material analysis conducted in this thesis.

2.5.1 Materials Used in Horse Bits

The main metals used in horse bits are copper, nickel, iron, chromium, and zinc. However, iron is by far the most common, being present in approximately 97% of metal bits, whereas the other metals occur in less than 1% when present. Bits are typically composed of iron alone or iron combined with a surface coating alloy [7].

Several types of bits are also manufactured from other materials, such as polymers and elastomers. The specific composition of these materials is rarely disclosed, and the only polymer type consistently stated is thermoplastic polyurethane (TPU). Leather is another material used to cover metal bits in order to provide a different surface finish and tactile sensation [15].

Titanium is a more recently adopted metal in bit manufacturing, valued for its biocompatibility, low density, and corrosion resistance. Titanium bits have been associated with lower subcutaneous temperatures in the muzzle and neck after training, which may contribute to increased equine comfort [9].

Bits composed solely of iron undergo corrosion, as seen in Figure 2.7 when placed in the interdental space due to contact with horse saliva [7]. Although excessive iron intake can be harmful, current studies indicate that the degradation of iron bits over time does not release concentrations high enough to pose toxicological concern [7].

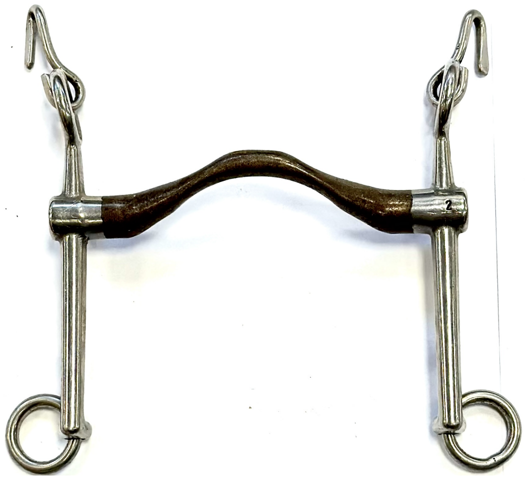


Figure 2.7: Corroded iron bit. Photograph by the author.

2.5.2 Mechanical Properties

The mechanical properties of a material reflect how it responds or deforms to an applied load or force. To assess how different materials affect the tissues within the oral cavity, these properties are important to understand.

Metals and their alloys have atoms arranged in a dense and ordered structure compared to polymers [16]. Generally, this results in a relatively stiff and strong structure that do not fracture easily compared to polymers. Several of the characteristic metal properties are a result of the large amount of non-localized electrons metals possess.

Young's modulus is a measurement of how resilient the material is to elastic deformation and can be thought of in terms of stiffness [16]. A greater value indicates a stiffer material. Elastic deformation signifies a nonpermanent deformation, where the material returns to its original shape after releasing the applied load. The point at which elastic deformation transitions into permanent plastic deformation is defined as the yield strength. If the deformation is further continued the maximum stress that the material can sustain in tension, the tensile strength will be attained. It is almost impossible to manufacture a material without defects and fracture toughness is a way of knowing how resistant the material is to fracturing when a defect is present. In other words, it describes the ability of a material to absorb energy and resist crack propagation in the presence of flaws [16].

Ductility is a measurement of the degree of irreversible deformation when the structure fractures [16]. Materials with low ductility are considered to be brittle. This is quantitatively measured in percent elongation. The hardness of a material is crucial for evaluating its resistance to localized plastic deformation. In this context, how easily the bit acquires scratches, bite marks or dents. Common types of surface changes bits are subjected too are bite marks, burnishing, and saliva staining. Bits produced from metals, especially copper, may be subjected to pitting corrosion, but iron bits may also undergo corrosion forming rust [8]. The oral cavity has a unique corrosion environment due to its alkaline electrolyte mixture with sodium, bicarbonate, potassium, calcium, phosphate and urea. The pH in healthy equine saliva is around 8, but in a carious conditions it can drop to approximately 4-6 [12]. Hence, the bit material must be resistant to corrosion under the specific environmental conditions.

Corrosion fatigue is the result of cyclic stress and a corrosive environment [16]. Chemical reactions from corrosion may result in small pits that can further serve as points of increased stress concentration. The pits themselves can further accelerate the propagation rate of the cracks due to the corrosive surroundings. This is prevented by choosing a corrosive resistant material. Many ferrous alloys, with the exception of stainless steel, are susceptible to corrosion. Titanium is an inert material very resistant to corrosion. Polymers are often highly resistant to corrosion. In regards of design, crevice corrosion is a factor that should be considered as it can enable corrosion in materials that are usually corrosion resistant. This type of corrosion occurs due to concentration differences of ions in an electrolyte as well as in two regions of the same metal piece. If possible shielded or occluded regions and crevices should be avoided to prevent this [16].

2.6 Bit-Related Injuries

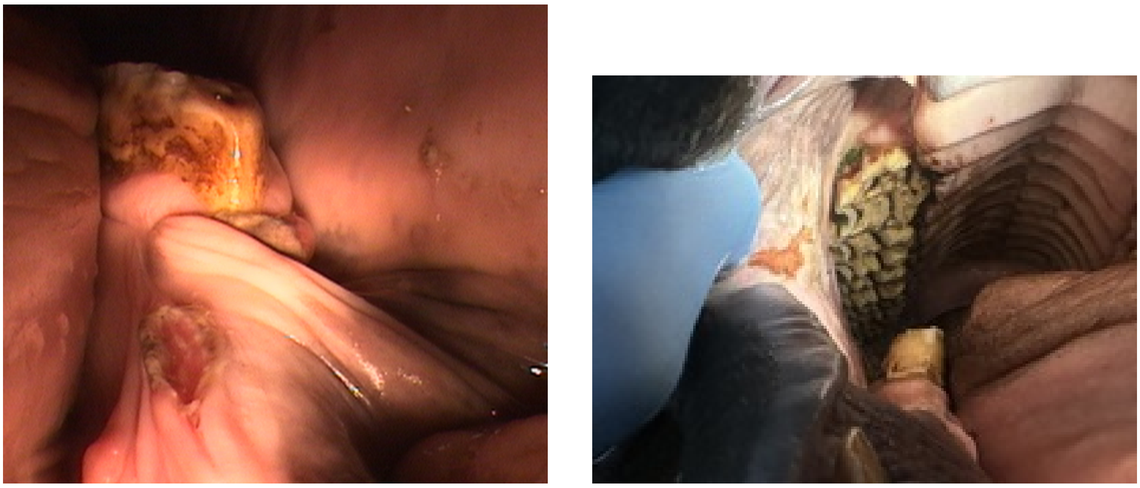
Ulcers in different areas of the mouth, such as lips, buccal, tongue and oral, are considered to be very common world-wide [1]. The significantly most occurring type is the traumatic ones and they stem from pinching the mucosa of the cheeks laterally against the rostral maxillary teeth, poorly fitted bits in addition to poor riding technique. Examples of different types of bit-related injuries are viewed in Figures 2.8 – 2.9.

However, there can be other causes as well. These type of traumatic lesions seen in ridden horses with bit and bridle have not been reported in unridden horses. One study indicate ridden horses with bit and a bridle to have significantly more prevalence of ulcers. Unridden horses also had a prevalence of ulcers in this study despite regular prophylactic floating. The findings in the study suggested a more evidence-based prophylactic dentistry and individually adjusted bits and bridles to manage this. The prevalence of injuries in the hard palate and tongue was low [1].

Different types of bit-related injuries are periosteal bone spur formation of the bars, erosive lesions, fractures of lower P2 or canine teeth, injuries of soft tissues like tongue, commissures, mucosal lining of bars [6].

Horses with a postnormal relation of their cheekteeth has shown to be more prone to get buccal ulcerations opposite to their P2's. This is theorized to happen due to an increased risk of localised pressure on the cheeks caused by the tack as there is rostral overgrowth of the maxillar P2's [1].

Figure 2.8: Acute lesion in the commissures caused by a poorly fitted jointed bit, resulting in pinching of the commissures. Source: Private communication, DVM Ylva Rubin, (2026).



(a) Severe acute lesion on the bar. Source: Private communication, DVM Ylva Rubin, (2026).

(b) Acute buccal lesion. Source: Private communication, DVM Ylva Rubin, (2026).

Figure 2.9: Acute lesions identified during oral examinations of sedated horses using a speculum, attributed to bit-related trauma. Source: Private communication, DVM Ylva Rubin, (2026).

2.7 Risk Factors and External Influences

Studies indicate that decreased rein length is associated with increased rein tension and a higher prevalence of aversive conflict behaviours. The rider typically generates the baseline rein tension and has a substantial influence on the overall tension profile. In studies comparing rein tension in ridden and unridden horses, markedly lower tensions were observed in the latter, where the horses regulated the tension themselves [6].

Noseband tightness has been shown to correlate with the prevalence of bit-related injuries, where a more tightly fitted noseband, regardless of type, increases the risk of oral ulcers. However, complete removal of the noseband increases the risk of commissure lesions by a factor of 2.55 compared to using a loosely fitted noseband. This supports the stabilizing effect of the noseband on the bit and illustrates why it should be used in combination with the bit [17].

To date, there are no sufficiently well-designed studies providing conclusive evidence on how discipline, competition level, temperament, anatomy or noseband type influence the prevalence of bit-related injuries.

2.8 Engineering Framework for Bit-Mouth Interaction

The mechanical relationships between force, contact area and pressure follow the fundamental principles in contact mechanics [18]. An increased applied force or decreased effective contact area adds pressure. The bit-mouth interface represents a non-conforming contact as a stiff body interacts primarily with soft and deformable tissues. There is no predefined contact area within the oral cavity, but develops through tissue deformation under load. To clarify, when pressure is applied, the contact area will increase as the tissue deforms. In mechanical terms, this together with their dissimilar profiles are characteristics of non-conforming elastic contact and the geometry of the contacting bodies governs the stress distribution. The gravitational force will always apply a normal force at the bit, hence the density of the bit will decide how big the force will be. At the point where the horse wears a bridle with a bit without the impact of a rider, and disregarding the forces generated by the horse itself, the external loads acting on the bit consist of the gravitational force associated with its mass and the cheekpiece tension transmitted through the bridle.

Frictional interactions further influence the mechanical loading [18]. Classical tribology describes how the normal load, friction coefficient and relative motion decide the frictional forces generating shear stress on the oral tissues. In addition, the topography of the bit influences the real area of contact which is typically a fraction of the nominal contact area. Increased surface roughness governs high local pressures at asperity peaks, especially for a stiff material interacting with a soft tissue in a non-conforming elastic contact. It further reduces the real contact area and amplifies the frictional shear stresses. Hence, the surface finish of the bit is a critical parameter in the mechanical loading of the oral tissues. The nominal contact area increases with a greater diameter of the bit and therefore also the real contact area between bit and mouth. This parameter influences the stress concentration as it controls the asperity peaks. However, if the bit is too thick for the deformation of tissue to occur freely, this causes a smaller effective contact area, greater relative motion and a higher localized stress. The distribution of pressure will increase when pressure is applied only if the tissue can deform.

The anatomical, biomechanical and mechanical considerations presented earlier in this chapter enables the identification of key parameters in the interaction, force transmission and distribution of the bit-mouth interaction as well as the durability. These parameters include rein tension, cheekpiece tension, bit geometry (shape, joints, curvature, thickness and length), material properties (friction coefficient, elastic modulus, hardness, surface roughness, thermal conductivity, density, corrosion resistance, fatigue resistance and yield strength), relative motion between the oral tissues and the bit and tissue resistance. Together, these parameters have direct influence on the resulting forces exerted on the different oral tissues and are directly linked to fundamental mechanical principles, such as real contact area, shear stress and deformation.

3

Methods

The study employed a triangulated qualitative design, combining a structured literature review with expert interviews and technical data. This approach was chosen to address existing knowledge gaps and to integrate empirical findings with extensive clinical experience. The triangulation strengthened the validity of the conclusions by allowing multiple sources of information to be compared and synthesized.

3.1 Literature Review

To be included in the review, studies examining correlations between different bit designs and the prevalence of bit related injuries were required to have performed a complete oral examination using a speculum and sedation. This is to ensure diagnostic reliability. Furthermore, only studies conducted on riding horses were included; studies on driving, racing, or trotting horses were excluded due to the fundamentally different biomechanical and sport-specific demands in those disciplines. The search strategy is further presented in Appendix A.

The available literature on bit-related injuries is heterogeneous, with substantial variation in study design, diagnostic criteria and sample sizes. This limits the comparability of findings and necessitates a cautious interpretation of reported injury prevalence and mechanisms. Several studies rely on observational data rather than controlled experiments, which restricts causal inference.

Scientific articles were searched in databases such as PubMed, Google Scholar, and ScienceDirect. Titles and abstracts were screened for relevance, after which full texts were assessed according to the inclusion and exclusion criteria. Reference lists of included studies were also reviewed to identify additional relevant publications.

3.2 Material Selection and Property Analysis

Mechanical data for commercially available bits were requested from Fager Equestrian, Sprenger, Beris Gebisse, Trust Equestrian, Globus Sport, Bombers Equestrian, Happy Mouth (Toklat Originals), Neue Schule, and Shires Equestrian. Several manufacturers were unable to provide complete mechanical specifications or detailed material data for their bit designs. As a result, the available information varied substantially between brands.

Due to the lack of standardized or comprehensive technical data from manufacturers, additional mechanical property data were obtained from the Granta EduPack 2024 R1 materials database. This database provides verified material property ranges for metals, polymers, and elastomers commonly used in engineering applications. The Granta data were therefore used to supplement missing manufacturer information and to enable a more consistent comparison of material categories. Supplementary material data is provided in Appendix B.

The material comparison was conducted using a materials chemistry framework to evaluate how intrinsic chemical composition and microstructure influence mechanical and surface behavior in the oral environment. The material comparison was conducted based on properties relevant to both mechanical performance and materials chemistry in the oral cavity. Granta EduPack was used to extract quantitative data for relevant materials, including Young's modulus, yield strength, hardness, fracture toughness, density, thermal conductivity and corrosion resistance. These properties were selected because they reflect the underlying bonding mechanisms and therefore determine how materials deform, transmit force, resist wear and chemically interact with alkaline saliva.

This limitation reduced the possibility of performing a fully standardized comparison across all commercially available bit materials. The reliance on Granta data for certain materials was taken into account when interpreting the results, particularly in relation to variability between specific commercial formulations and the generalized material classes represented in the database.

3.3 Interviews

Semi-structured interviews were conducted with DDS Torbjörn Lundström and DVM Ylva Rubin, both of whom possess extensive expertise in equine dentistry and equine oral health. They were chosen due to their achievements and long-standing experience within the field. DDS Lundström has worked with equine dentistry for more than 40 years, taught at the Swedish University of Agricultural Sciences (SLU) for over 25 years, published multiple scientific articles, served as chairman of NCED, contributed significantly to animal welfare, and in 2025 was appointed honorary doctor in veterinary medicine at SLU. DVM Rubin has worked with equine dentistry for more than 25 years, is an examined equine odontologist, a member of the Animal Welfare, Infection Control and Anti-Doping Committee, a member of NCED, an official FEI veterinarian, and a consultant for the Swedish Equestrian Federation.

The interview questions, presented in Appendix C were developed based on gaps identified during the literature search as well as the experts' clinical experience. The questions were provided in writing, and both experts responded independently before any discussion. Both interviews were conducted as oral interviews in person. All responses were considered equally, regardless of whether the experts agreed or differed in their assessments. In addition to the structured questions, both experts were invited to contribute their own reflections based on their extensive professional experience.

The interview responses were analysed using an inductive thematic approach. After processing the material several times, key statements were identified and grouped into preliminary categories. These categories were then compared across both experts to identify areas of agreement, divergence, and complementary perspectives.

The analysis focused on recurring themes related to bit mechanics, oral pathology, and practical clinical experience. All interpretations were grounded in the experts' written responses, and no weighting was applied based on seniority or background.

3.4 Ethical Aspects

All participants received information about the purpose of the study and the voluntary nature of their involvement. Both experts provided informed consent and approved that their names, professional titles, and statements could be used in the thesis. No personal data beyond professional background and expertise were collected. The interview material was handled confidentially and stored securely, and the participants were informed that they could withdraw their contribution at any time without providing a reason.

3.5 Methodological Limitations

The triangulated design increases the internal validity of the findings by allowing convergence between mechanical data, anatomical theory and clinical experience. The chosen triangulated design provides a broad and integrated understanding of bit–mouth interaction, but it also entails limitations. The mechanical analysis is based on secondary material data rather than controlled laboratory testing, which restricts the precision of quantitative comparisons. The interview material is limited in sample size and reflects the perspectives of two highly experienced clinicians, which strengthens depth but limits generalisability. Alternative methods such as in vivo pressure measurements or finite element modeling were considered but excluded due to time constraints and the lack of validated anatomical models. These methodological choices influence the scope of the conclusions and should be taken into account when interpreting the results.

4

Results

The results of this study integrate mechanical material data, anatomical considerations and expert assessments to clarify how different factors contribute to bit–mouth interaction. The findings are presented in relation to material properties, bit geometry and stability, and clinically observed injury patterns to provide a coherent foundation for the subsequent discussion.

4.1 Mechanical Material Data

Technical material data for commercially available bits were requested from nine major manufacturers. None of the companies were able to provide detailed information regarding the specific materials used or the mechanical properties of their bit designs. Due to this lack of accessible technical specifications, the material property values presented in this study are based on peer-reviewed literature and the Granta EduPack 2024 database. Representative alloys and polymers corresponding to materials commonly used in bit manufacturing were selected from Granta. These values reflect typical engineering properties of the relevant material classes but cannot be directly equated to the proprietary formulations used in specific commercial bits. Table 4.1 summarizes the mechanical property ranges used for comparison.

Table 4.1: Mechanical and physical properties of materials used in horse bits.

Property	**TPU**	**Stainless Steel 316L**	**Titanium Grade 5**	**Bronze**	**Brass**	**Copper**	**Low C Steel**	**Leather**
Density ($\times 10^3$ kg/m^3)	1.12–1.24	7.61–7.87	4.51	8.05–8.70	8.07–8.48	8.94	7.80–8.82	0.81–1.05
Young's modulus (GPa)	1.31–2.07	190–210	100–105	97–130	95–110	120–140	200–220	0.1–0.5
Yield strength (MPa)	36–42	257–1140	276–360	130–509	100–296	50–340	255–355	2–5
Ultimate tensile strength (MPa)	31–62	515–1300	345–490	322–700	280–511	211–380	379–532	20–50
Elongation (%)	60–550	10–49	20–26	5.3–55	15–52	6–50	25–45	18–75
Hardness (HV)	16–23	170–438	155–165	75.6–200	60–150	46.3–115	113–168	2–3
Fatigue strength (MPa)	16–20	256–542	245–296	154–254	140–207	70.6–115	203–278	4.5–9
Fracture toughness (MPa·m$^{0.5}$)	1.8–4.97	57–137	55–60	28.8–67.9	42.6–76	38.8–95	41.6–79	3–5

The table shows clear quantitative differences between the material categories. All metals and metal alloys consistently exhibit the highest values across the mechanical properties presented. This includes yield strength, ultimate tensile strength, Young's modulus, hardness, fatigue strength, and fracture toughness, where the metallic materials form the upper range in every parameter. Their density values are also uniformly higher than those of TPU and leather.

Within the metallic group, there is noticeable variation. Stainless steel and titanium grade 5 display the highest strength and stiffness values, while copper, brass, and bronze occupy intermediate ranges. Low-carbon steel shows comparatively high toughness and fatigue strength, placing it among the stronger materials in several categories. Despite these internal differences, all metals remain clearly separated from TPU and leather in terms of mechanical performance.

TPU and leather form a distinct group with substantially lower values in all mechanical properties. TPU shows very high elongation combined with low hardness and low modulus, indicating a much more compliant and flexible behavior compared to the metals. Leather has the lowest values for both strength and stiffness in the table, and its density is also markedly lower than that of the other materials. Together, TPU and leather represent the least mechanically robust materials in the dataset.

From a materials chemistry perspective, the observed differences between the materials reflect their distinct atomic structures and deformation mechanisms. Ferrous alloys included both low-carbon steel and stainless steel. Low-carbon steel, with its active surface, is more prone to electrochemical oxidation in alkaline saliva, leading to corrosion and surface roughening. In contrast, stainless steel forms a stable chromium-rich passive film that strongly reduces uniform corrosion, although local depassivation can still modify surface topography and frictional behavior over time. Both classes share high stiffness and hardness due to their crystalline metallic bonding, resulting in limited elastic deformation and high stress transfer to teeth and soft tissues.

Titanium has lower density and a highly stable passivation layer, which provides excellent corrosion resistance and biocompatibility. Its lower thermal conductivity may reduce temperature-related discomfort. TPU display markedly lower stiffness and hardness due to its viscoelastic polymer chains, allowing greater deformation under load and reducing peak pressure. However, viscoelastic relaxation increase adhesive friction and surface wear, consistent with clinical reports of superficial mucosal lesions. These results demonstrate that bonding, microstructure, passivation behavior and viscoelasticity directly governs how bit materials interact with oral tissues.

4.2 Interviews

The interviews with experts in the field, DDS Torbjörn Lundström (TL) and DVM Ylva Rubin (YR), resulted in key findings from their experience, presented in the following sections.

4.2.1 Pressure and Injury Mechanisms

The experts agreed that variation in multiple aspects is an important factor in preventing injuries, as it diversifies the pressure the equipment will exert. Both the bridle and the bit should be varied over the week, and the same equipment should not be used for more than two consecutive days.

Figure 4.1: Correctly fitted bit in a passive state. Source: Private communication, DVM Ylva Rubin, (2026).

Both experts emphasized that a key element appears to be stability of the bit. Hence, the fitting of both bit and bridle is crucial. The mouthpiece of the bit should be completely within the mouth so that the bit rings lie just outside the commissures as demonstrated in Figure 4.1. When applying one-sided rein tension, the bit should not have any room to slide through the mouth. Adjusting the bridle so that the bit is in a passive state before applying rein tension is important to ensure that no extra pressure is exerted on the oral tissues.

According to both YR and TL, the greater the amount of pressure applied over longer periods and with higher frequency, and the lower the tissue resistance, the greater the risk of injured tissue. If pressure is excessive over a prolonged period and applied with too high an intensity, this may result in a chronic ulcer, as shown in Figure 4.2.

Figure 4.2: Chronic ulcer in the commissures with typical surrounding depigmentation. Source: Private communication, DVM Ylva Rubin, (2026).

Excessive pressure also increases the risk of developing defensive behaviors, such as lifting the bit between the cheek teeth, tensing the commissures, or pushing on the bit with the tongue, which sometimes results in the tongue slipping over the bit. This poses a high risk of injury, as the bit then lies directly on the bars. All defensive behaviors represent the horse's attempts to achieve greater stability of the bit, and both YR and TL frequently see the consequences of these behaviors in their practices. Injuries resulting from aversive behaviour toward the bit are demonstrated in Figures 4.3 – 4.5.

Figure 4.3: Lesions in the tongue and buccal mucosa resulting from aversive behaviour in attempts to stabilise the bit. Source: Private communication, DVM Ylva Rubin, (2026).

4.2.2 Bit Geometry and Injuries Related to Different Designs

According to both experts, it is crucial to use an actively tightened chain that creates a leverage point when rein tension is applied if a bit with a leverage mechanism is used. This is demonstrated in Figure 4.4, both with and without rein-tension.

(a) Without applied rein-tension. **(b)** With applied rein-tension.

Figure 4.4: Images showing a correctly fitted double bridle with an actively tightened curb chain. Source: Private communication, DDS Torbjörn Lundström (2026).

A leverage bit with an improperly fitted chain will act caudally instead of rostrally as intended. To prevent the curb from oscillating when releasing rein tension, a curb strap should also be used. Another crucial factor when choosing the length of the bit is ensuring that the upper shank does not exert pressure on the buccal mucosa. When fitting a DB, the mouthpiece of the curb must be wider than the bridoon to prevent the two bits from interfering with each other.

The experts shared the view that when using jointed bits, one should be extra careful to ensure that the length is correct. If the bit is too long, it will be at much higher risk of crushing the buccal mucosa against the cheek teeth. It is also impossible to fit a bit that is too long properly. Either the bit is in a passive state before rein tension, but then the middle link or joint will touch the hard palate behind the incisors, where horses are very sensitive to pressure, and their instinct will tell them to transport the mass caudally, as it is usually food they would process by chewing. The other way a too-long bit can be fitted is by tightening the cheekpieces, resulting in the bit not being in a passive state regardless of rein tension. For the same reason, bent outer links or outer metal plates should not be used, as these also increase the risk of buccal ulcers by pressing the buccal mucosa between the P2s and the bit.

The experts presented a unified view that the general geometry of the bit should be as smooth as possible to avoid unnecessarily high pressure points. Eggbutt rings can provide extra stability for horses with an unquiet mouth. The bit rings should not be too large in diameter due to the increased risk of ulcers in the buccal mucosa from being compressed between the bit and the P2's. Optimally, they agreed that the bit should be 8-12 mm in diameter.

Bits designed with a port aim to relieve pressure from the tongue, but this design increases the pressure on the bars and hence the risk of severe lacerations at the bars. Therefore, a design aimed at placing the majority of its pressure on the tongue is preferable. The tongue is highly keratinized and constructed for higher tissue tolerance, as it transports food further into the mouth, which can sometimes be rough or thistly. Both experts noted that injuries caused by friction are more correlated with the use of synthetic or leather bits compared to bits made of metal. However, metal causes more damage to the teeth, either if the bit exerts pressure against the P2's or if the horse lifts the bit between the cheek teeth. The diameter of the bit should not be too wide, as there is no remaining space for a bit in the oral cavity, and the horse must make space by compressing the tongue to keep its mouth closed.

A type of bit-related injury barely mentioned in the literature, which both experts stated they observe fairly often, is low grade mobility or excessively worn P2's. This appears to be caused either by the horse lifting the bit and holding it between the cheek teeth or by excessive pressure from the bit in a caudal direction. The risk seems to increase with the use of gag bits and improperly fitted jointed or leverage bits. Excessively worn P2's can be seen in Figure 4.5.

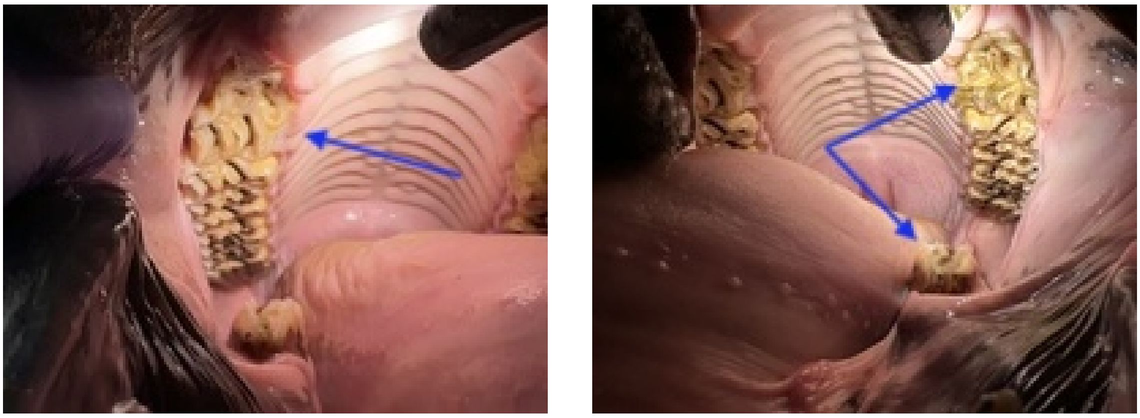


Figure 4.5: Excessively worn P2's. Source: Private communication, DVM Ylva Rubin, (2026).

4.2.3 Anatomical and External Factors

The experts presented a unified view that removal of the P1's should be done before placing a bit in the oral cavity. These pristine remnants are more sensitive to pressure than the other premolar teeth due to their regressed anatomy. In the majority of cases, they cause problems, and by removing them the horse has a much greater chance of being comfortable with the bit. They no longer have any practical function, and hence the horse will not live a longer or better life with remaining P1's. The surgical procedure is not too invasive and is performed with sedation, local anesthetics, and a speculum during regular dentistry visits, with a short recovery time. The P1 can be viewed below in Figure 4.6.

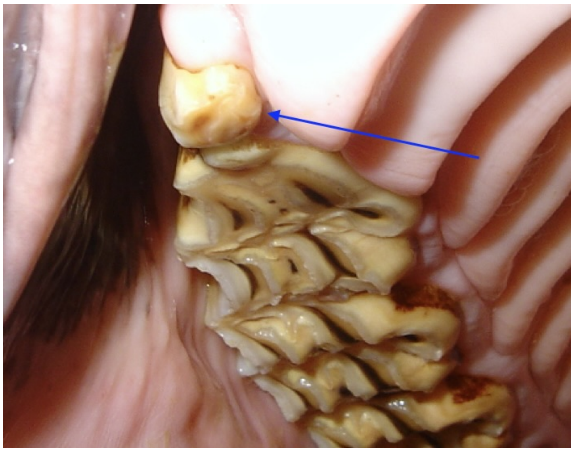


Figure 4.6: Oral cavity with non-extracted and excessively worn P1, or "wolf teeth". Source: Private communication, DVM Ylva Rubin, (2026).

YR added that there are oral anatomical parameters that can further complicate the horse's ability to hold the bit comfortably in the oral cavity. Approximately 20% of all horses have a post-normal relation of the cheek teeth and require regular treatment to ensure that the hooks that can form on the maxillary P2's do not injure the opposing mandibular mucosa. However, with sufficient treatment, most horses can still manage to carry the bit comfortably despite this anatomical deviation.

The experts were aligned in their view regarding nosebands. These also need to be properly and not to tightly fitted to decrease the risk of injuries. During the years when the horse is still developing its skull and changing its teeth, the noseband should not cross regions with erupting teeth, as this may cause discomfort and lesions as seen in Figure 4.7. Changing teeth can cause pain and inflamed tissue, making these areas extra sensitive during that time. When the skull is fully developed, at 7–8 years of biological age, the noseband can cross the regions with cheek teeth without causing discomfort in horses with a normal oral status.

Figure 4.7: Lesion caused by a flash noseband. Source: Private communication, DVM Ylva Rubin, (2026).

Both interviews indicated that the experts considered the prevention of bit-related injuries to depend on achieving high stability and low pressure. Hence, the rider's ability to communicate with the horse in a clear yet discreet manner is crucial. The optimal choice of bit and bride can therefore vary over time and between individual horse–rider combinations.

Expert YR emphasized that it is the rider's task to teach the horse how to make space for the bit and hold it correctly. This can be a time-consuming process and requires a lot of patience, but when carried out correctly, the horse can thereafter often manage many types of bits and carry them comfortably with a quiet mouth. YR advocated the use of a correctly fitted, relatively thin unjointed bit for this process, as it is the most uncomplicated bit and prevents the horse from lifting it, thereby teaching the horse to carry the bit in the correct position. Unjointed bits in different designs and materials are displayed in Figure 4.8.

Figure 4.8: Different types of unjointed bits. Source: Private communication, DVM Ylva Rubin, (2026).

5

Discussion

The findings of this study highlight several interacting mechanisms that influence bit-related pressures and injury risk. These mechanisms are interpreted in relation to established mechanical principles, anatomical prerequisites and expert clinical experience. In the following discussion, the results are examined in relation to material behavior, geometric design, equine oral anatomy and rider-related factors to provide an integrated understanding of the multifactorial nature of bit–mouth interaction.

5.1 Material Properties and Their Clinical Implications

This section analyses how key material properties influence the clinical performance of bit materials, with a focus on stiffness, hardness, friction, corrosion behavior and their combined effects on oral tissues.

5.1.1 Stiffness and Deformation

The stiffness of a bit material fundamentally determines how mechanical loads are transmitted to the oral tissues. Metals such as stainless steel, bronze, brass, copper and low-carbon steel exhibit Young's modulus values between approximately 95 and 220 GPa, meaning that they undergo minimal elastic deformation during rein tension. This mechanical rigidity preserves bit geometry but also concentrates force at the point of contact, particularly when the bit approaches the mandibular P2 region or compresses the tongue. When the bit contacts the mandibular P2 region or compresses the tongue, the limited deformation of the metal concentrates stress in a small area, increasing the likelihood of pressure-related injuries.

In contrast, TPU and leather possess Young's modulus values several orders of magnitude lower, typically between 0.1 and 2 GPa. Their capacity for elastic deformation allows them to absorb part of the applied load, reducing peak stress on teeth and bony structures. This compliance makes softer materials more forgiving in situations where accidental tooth contact may occur. However, the increased deformation also enlarges the effective contact area with soft tissues, which can influence frictional behavior and the development of shear forces during bit movement. The balance between reduced stress concentration and increased surface interaction is therefore central to understanding the clinical implications of materials with low stiffness.

5.1.2 Hardness, Wear and Surface Damage

Hardness governs a material's resistance to indentation, scratching and surface wear, and thus plays a critical role in how the bit surface evolves during use. The metals analysed in this study display hardness values ranging from approximately 60 to over 400 HV, which limits the formation of bite marks and surface defects. A harder surface generally remains smoother over time, reducing the potential for abrasive interactions with the mucosa. However, the high hardness of metals relative to enamel and dentin increases the risk of dental trauma if direct contact occurs. Even brief or accidental impacts may result in accelerated wear of the tooth surface.

TPU and leather, with hardness values between 2 and 23 HV, are considerably softer and therefore unlikely to damage teeth. Their low hardness, however, makes them more susceptible to surface deformation, abrasion and indentation. Resulting surface roughness increases friction and may contribute to mucosal irritation, particularly during lateral bit movement or when the horse manipulates the bit with its tongue. The clinical implications of hardness are therefore bidirectional. Harder materials protect soft tissues but may endanger teeth, whereas softer materials protect teeth but may compromise the mucosa.

5.1.3 Friction and Soft Tissue Lesions

Frictional behaviour is a central determinant of soft-tissue injury. TPU and leather generally exhibit higher friction coefficients than metals. Their viscoelastic nature increases adhesive interactions with the mucosa, which can lead to superficial abrasions, commissure lesions and irritation along the bars of the mouth. These tendencies are consistent with the expert interviews, where both experts reported that synthetic and leather-covered bits are more frequently associated with friction-related injuries.

Metals typically provide lower friction due to their smooth, hard surfaces and reduced adhesive interactions with soft tissues. However, friction can increase significantly if a metal surface becomes scratched, pitted or corroded. Even minor surface irregularities may alter the tribological behavior of the bit, demonstrating that friction is not solely a material property but also a function of surface condition. The interplay between friction, surface wear and tissue sensitivity therefore plays a decisive role in determining the clinical outcome of different bit materials.

5.1.4 Corrosion in the Oral Environment

The equine oral cavity constitutes a chemically active environment characterised by alkaline pH, high ionic strength and continuous mechanical agitation. These conditions promote electrochemical reactions that affect metallic materials to varying degrees. Low-carbon steel readily oxidizes, forming rust layers that increase surface roughness and hence elevate frictional forces against the mucosa. Copper-based alloys may undergo galvanic interactions and ion release, influencing salivation, taste and corrosion kinetics. Although such processes do not necessarily compromise structural integrity, they can significantly alter surface topography and thus affect tissue interaction.

Stainless steel forms a stable chromium-rich passive film that provides excellent resistance to uniform corrosion, allowing the surface to remain smooth under most conditions. Titanium exhibits the most stable passivation behavior due to its oxide surface layer, resulting in exceptional corrosion resistance, biocompatibility and long-term surface stability. These materials therefore maintain low friction and predictable mechanical behavior over time.

Polymers do not corrode in the electrochemical sense, but they undergo mechanical and chemical degradation through hydrolysis, abrasion and viscoelastic fatigue. Such degradation can create surface defects that increase friction and contribute to soft-tissue irritation. The oral environment thus affects all materials, but through different mechanisms that ultimately influence clinical outcomes.

5.1.5 Material Choice Cannot Be Isolated

Material selection cannot be made independently of the horse's oral anatomy, the bit's geometry, its fit or the rider's technique. Metals offer stability, low friction and long-term surface integrity, but their high stiffness and hardness increase the risk of tooth-related injuries and concentrated pressure on the bars and tongue. TPU and leather reduce the risk of dental trauma due to their compliance, yet their higher friction and susceptibility to surface wear make them more likely to cause soft-tissue lesions. Titanium combines low density, excellent corrosion resistance and favorable biocompatibility, but even its advantages depend on correct fit and appropriate use.

Hence, there is no universally optimal material. Instead, the choice must be tailored to the individual's oral conformation, tissue sensitivity, training level and behavioral responses. Horses prone to frictional injuries may benefit from a low-friction metal bit, whereas horses with dental vulnerabilities may require a softer material. When softer materials are used, friction-related injuries may potentially be mitigated through biocompatible lubricants or surface treatments. Ultimately, the interaction between material chemistry, mechanical behavior and anatomical context determines the clinical performance of any bit material.

5.2 Bit Geometry, Anatomical Constraints and Pressure Distribution

Stability of the bit and reduction of pressure are key factors in the prevention of bit-related injuries, which is confirmed by established mechanical relations. However, a crucial factor is to regard the anatomy of the horse as a primary precondition. This fundamental starting point is only vaguely highlighted in the literature, and the mechanical relations presented in some articles are taken out of context. The use of thick bits follows the well-known mechanical relation that resulting pressure depends on the area, but this disregards the requirement that the tissue must be able to deform freely in order to absorb pressure, as well as the condition of stability, which is impossible if the horse cannot comfortably place the bit in a closed mouth. A thin bit, in this context approximately 8–12 mm, is therefore preferable. To further achieve stability, the bit must be of proper length. Studies have indicated, and the experts confirmed, that the bit is most stable when the bit rings lie just outside the commissures and no additional length of the mouthpiece extends beyond the interdental space. The bit must be properly fitted, with no additional pressure exerted beyond that generated by gravitational force before rein tension is applied.

5.3 Injury Patterns and Under-Documented Clinical Findings

Certain types of bits were observed to cause injuries more frequently, such as gag bits and ported bits, but choosing the incorrect size or fitting any bit improperly can further increase the risk of injury. Ported bits have previously been reported to increase the risk of injuries to the bars. This study highlights two injury mechanisms that appear underdocumented in the literature; low-grade mobility and excessive wear of the P2s. This may be due to the difficulty of diagnosing such conditions and the requirement of actively searching for them. Excessive wear of the P2s is very difficult to diagnose unless one has been taught how to identify it. This also helps explain why it is still commonly perceived as positive when the horse chews on the bit.

5.4 The Multifactorial Nature of Bit-Related Injuries

The subject of interest is a multifactorial issue that requires substantial additional research to be fully understood. Material and geometry cannot be assessed in isolation but only provide a fundamental understanding of their contributions to the problem. Additionally, gaining clarity regarding anatomical prerequisites and how abnormalities may be treated can significantly decrease the risk of injuries, improve the choice of equipment and the education of the horse, and thereby enhance welfare. Horses with sensitive or already injured P2s may become more comfortable with a bit made of a softer material such as TPU, whereas horses with sensitive mucosa may be more comfortable with a metal bit. Overall, this may be a matter of individual preference.

5.5 Rider Influence and Communication Dynamics

Prevention of bit-related injuries would become easier with increased knowledge among practicing riders and trainers. Both experts agreed that if trainers and riders understood fundamental anatomical prerequisites and how these affect the choice and fitting of bit and bridle, fewer bit-related injuries would likely occur. The way in which horse and rider are educated naturally affects the total amount of pressure exerted on average during work. Hence, applying the lowest possible rein tension may not always be the optimal solution; it may be better to apply slightly higher pressure at a single moment than to accept a higher static rein tension at all times. However, the goal must be to aim for the lowest possible rein tension on average, without losing clarity in communication between horse and rider. The horse should balance itself and not rely on the bit for balance. Thus, the rider's balance will influence the horse's ability to do so. Understanding why balance and effective communication are not achieved, and how to adjust these factors, may be the most difficult and underestimated proficiency in equestrian sports.

Variation in equipment and pressure points, strongly supported by both mechanical principles and expert opinion, reduces cumulative loading and thereby lowers injury risk. When pressure points are varied, the repeated load on average will decrease. This naturally lowers the risk of tissue tearing.

5.6 Methodological Considerations

A methodological limitation of this study is the incomplete and inconsistent technical information provided by manufacturers, which required the use of generalized material property ranges from the Granta database rather than exact specifications for each commercial bit. This reduces the precision of the material comparisons and may obscure differences between specific formulations. The findings based on expert interviews should also be interpreted with caution, as they reflect the clinical experience of two highly qualified practitioners but may not capture the full variation in professional perspectives. Additionally, the limited number of eligible studies in the literature review means that some relevant research may have been excluded, which affects the width of the evidence base. Together, these factors introduce uncertainty that should be considered when interpreting the conclusions. The triangulated design, however, strengthens internal validity by enabling convergence between mechanical data, anatomical theory and clinical experience.

5.7 Synthesis in Relation to the Research Question

The integrated analysis demonstrates that material properties, surface behavior and bit geometry jointly determine how forces are transmitted within the oral cavity. The findings show that no single parameter can explain injury risk. Instead, injuries arise from the interaction between mechanical behavior, anatomical constraints and rein tension. This synthesis clarifies how each factor contributes to pressure distribution and tissue vulnerability by clarifying how each factor contributes to pressure distribution and tissue vulnerability, and by identifying the conditions under which specific materials or designs may increase or reduce risk. Collectively, these findings fulfil the aim of the thesis by demonstrating how material properties, surface behaviour and bit geometry jointly influence pressure distribution and injury risk.

5.8 Sustainability Considerations

From a sustainability perspective, bit materials differ markedly in environmental impact and resource efficiency. Stainless steel and titanium exhibit long service life and high corrosion resistance, reducing material turnover and waste generation. Polymers and leather require more frequent replacement due to wear and moisture-induced degradation, increasing resource consumption. Improved bit fitting and reduced injury prevalence contribute to social sustainability by promoting equine welfare and ethical training practices. Although the environmental footprint of individual bits is small, equipment choices and maintenance practices collectively influence the long-term sustainability of equestrian disciplines.

5.9 Concluding Remarks

Taken together, the findings of this study demonstrate that bit–mouth interaction is governed by a complex interplay primarily between material properties, bit geometry, anatomical prerequisites and rider-related factors. While the mechanical principles underlying pressure distribution and stability are well established, their practical implications are often oversimplified in the existing literature. The present results highlight the importance of individualized equipment selection, correct fitting and informed rider education, as well as the need to recognize under documented injury mechanisms such as low grade P2 mobility and excessive wear. Although methodological limitations introduce some uncertainty, the study contributes to a more integrated understanding of how mechanical, anatomical and behavioral factors collectively influence the risk of bit-related injuries. Continued research is therefore essential to refine evidence-based guidelines and further improve equine welfare.

6

Conclusion

This thesis demonstrates that bit–mouth interaction is governed by a multifactorial interplay between material properties, geometric design, anatomical prerequisites and rider-related dynamics. No single parameter can explain injury risk; instead, injuries arise from the combined effects of mechanical behaviour, oral conformation and rein tension patterns. The study therefore provides an integrated framework for understanding how bit-related pressures develop and how they may be mitigated.

The results clarify how stiffness, hardness, friction and corrosion resistance influence both soft-tissue and dental injury mechanisms, and show that material suitability depends on the individual horse's oral anatomy and tissue sensitivity. Geometric considerations further highlight that bit thickness and length must be evaluated in relation to intraoral volume and the position of the mandibular P2s.

A key contribution of this work is the identification of underdocumented injury mechanisms, specifically low-grade mobility and excessive wear of the P2s, which appear clinically relevant yet are rarely described in existing research. Their presence underscores the need for improved diagnostic awareness and more systematic documentation of subtle dental changes.

The findings also emphasise the substantial influence of rider-related factors. Balance, technique and rein tension modulate the magnitude and distribution of forces to a greater extent than material or geometry alone, reinforcing the importance of rider education and evidence-based fitting practices.

Future research should include controlled, well-designed studies that systematically evaluate how different bit and bridle designs influence the prevalence, type and severity of bit-related injuries. Such work is essential for refining evidence-based guidelines and improving equine welfare across equestrian disciplines.

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A

Appendix A: Literature Search Strategy

Table A.1: Literature search strategy

Database	Search terms	Inclusion criteria	Exclusion criteria
Web of Science	"horse bit" OR "equine oral cavity" OR "bit-related injuries" OR "bit mechanics"	Peer-reviewed articles; studies on horses; focus on bit mechanics, oral anatomy, or bit-related lesions; English language; publication year 1960–2025	Non-equine species; non-peer-reviewed sources; studies not addressing bit use, oral tissues, or biomechanics
PubMed	"equine oral lesions" OR "bit pressure" OR "bridle biomechanics" OR "equine dentistry"	Veterinary medicine focus; clinical or cadaveric studies; imaging studies (fluoroscopy, radiography); material-related studies	Human dentistry; unrelated veterinary species; studies on training methods without bit involvement
Google Scholar	"horse bit material" OR "bit wear" OR "equine saliva biomechanics" OR "noseband pressure"	Literature relevant to biomechanics; theses; broad screening for missing sources	Non-scientific blogs; opinion pieces; sources lacking methodological transparency
Manufacturer sources	"bit material" OR "metal horse bits"	Technical material data sheets; chemical composition; mechanical properties relevant to bit design	Marketing-only pages without any technical data

B

Appendix B: Supplementary Material Data

Table B.1: Material classes and database entries used from Granta EduPack

Material class	EduPack entry used	Relevance to bit analysis
Ferrous alloys	Low-carbon steel, Stainless steel (AISI 316)	Represents the dominant class of metal bits; provides data on stiffness, hardness, corrosion behaviour and density relevant to mechanical load transfer and surface wear.
Copper alloys	Cu–Zn brass, Cu–Sn bronze, Pure copper	Included due to their presence in multi-metal bits and their influence on taste, salivation, galvanic behaviour and corrosion susceptibility in alkaline saliva.
Titanium	Ti–6Al–4V (Grade 5)	Represents modern titanium bits; used for evaluating biocompatibility, oxide passivation, low density and reduced thermal conductivity.
Polymers	Thermoplastic polyurethane (TPU)	Used to model soft mouthpieces; provides information on viscoelastic deformation, hardness, friction behaviour and susceptibility to surface wear.
Leather (natural materials)	Collagen-based natural materials (proxy class)	Used as an analogue for leather-covered bits; relevant for friction, moisture absorption and surface softening under cyclic loading.

C

Appendix C: Interview Questions

The semi-structured interview questions used for the expert interviews are presented below. The questions were developed based on gaps identified during the literature review and were intended to guide, rather than restrict, the interviews. The experts were encouraged to further elaborate as much as they desired.

C.1 Geometric Design of the Bit

A1. Can you describe how different aspects of the bit's geometric design and material selection, based on your experience, influence the risk of bit-related injuries?

A2. Which specific design parameters do you find most important, and why?

A3. Are there materials that are repeatedly associated with certain types of injuries?

C.2 Injury Types Associated with Bit Design

A4. What types of injuries (location, tissue type, lesion characteristics) do you most commonly observe in connection with different bit designs and materials?

A5. Can you give examples of recurring patterns or associations you have noticed?

C.3 Risk Factors for Bit-Related Injuries

A6. Which factors do you consider most significant for the development of bit-related injuries, based on your clinical experience?

A7. How do these factors interact in your assessment?

A8. Are there factors that are often underestimated in discussions about bit-related injuries?

C.4 Anatomical Variations in the Equine Oral Cavity

A9. How do individual anatomical variations in the horse's mouth (e.g., dental irregularities, tooth condition, soft-tissue variations) influence the risk of bit-related injuries in your experience?

A10. Which anatomical variations do you find particularly important?

A11. How should these variations be considered when selecting bits and bridles?

A12. Do you observe differences related to the horse's age?

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