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EVIDENCE REVIEW

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Equine temporomandibular joint diseases: A systematic review

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Abstract

Background: The temporomandibular joint (TMJ) is a unique joint that enables mandibular movement. Temporomandibular diseases (TMDs) impair joint function, leading to more or less specific clinical signs.

Objectives: To compile and disseminate clinical data and research findings from existing publications on equine TMD.

Study design: Systematic review.

Methods: Following PRISMA 2020 guidelines, literature searches were conducted in PUBMED, Scopus, and Web of Knowledge. The inclusion criteria covered case reports and research articles on equine TMDs. The selected records were grouped considering septic TMJ arthritis, primary TMJ osteoarthritis (OA), and non-arthritic TMDs. A risk of bias assessment was performed for the research articles.

Results: Equine TMD has been described in 51 publications to date, with septic TMJ arthritis accounting for 41.2% of TMD cases, fractures/luxations for 29.4%, and primary TMJ OA for 21.6%. Trauma was confirmed or suspected in 54.9% of TMD cases. The severity of clinical signs was mild to moderate in primary TMJ OA and mild to severe in septic TMJ arthritis and non-arthritic TMDs. Clinical signs were related to the underlying cause, particularly in terms of TMJ swelling, pain, and masticatory problems. Among diagnostic imaging modalities, CT was utilised in 92.2% of horses, radiography in 84.4%, and ultrasonography in 21.6%.

Main limitations: The lack of clinical data in some reports. A risk of bias due to missing data.

Conclusions: TMDs are infrequently described, with trauma being the most common TMD cause. TMDs are associated with TMJ dysfunction; however, the diagnostic protocol is varied. Regardless of the TMD type, a detailed diagnostic protocol should include a thorough history, detailed TMJ examination, and radiography as the first imaging choice in field practice, with CT as the 'gold standard' in clinical settings. For septic TMJ arthritis, a bacterial culture is recommended, while for primary TMJ OA, functional tests and local analgesia.

KEYWORDS
cause, clinical signs, diagnosis, horse, TMD, TMJ

1 | INTRODUCTION

The temporomandibular joint (TMJ) is a unique synovial joint formed by the condylar process of the mandible and the zygomatic process of the temporal bone.[1,2] It comprises two joint compartments of different sizes,[3,4] separated by a biconcave fibrocartilaginous intra-articular disc,[2] also known as the meniscus.[5,6] This diarthrodial joint is divided into a larger dorsal compartment (discotemporal joint [DTJ]) and a smaller ventral compartment (discomandibular joint [DMJ]).[2–4] Physiologically, these compartments do not communicate,[7] although they were previously thought to be connected.[8] However, communication between the compartments may occur if the intra-articular disc becomes permeable or perforated,[7] which can happen in certain diseases.[9,10] This potential communication is of particular interest to practitioners and researchers who administer intra-articular contrast agents during diagnostic imaging[7,8,11,12] and medications during local treatment.[13–18]

The TMJ possesses unique anatomical and phenotypic characteristics, with its articular surface covered by fibrocartilage,[19] rather than hyaline cartilage found in peripheral joints.[20] Fibrocartilage is primarily composed of type I and type II collagen and glycosaminoglycans, making it highly resistant to shear force and compressive load.[19] The collagen fibres within the articular cartilage are differentially oriented,[21] and glycosaminoglycans are unevenly distributed, indicating that while compressive loads are dispersed throughout the entire TMJ, they are not uniformly distributed.[19] This structural arrangement supports the complex movements of the TMJ, which include both rotational and translation movements during mastication,[22] particularly mediolateral excursions associated with cheek teeth occlusion during forage grinding.[22,23]

The normal mastication cycle, which involves the phases of opening, closing, and power strokes,[24,25] is facilitated by the contractile activity of muscles (the temporal, masseter, medial pterygoid, and lateral pterygoid) innervated by the mandibular branch of the trigeminal nerve and supported by ligaments (the lateral and the caudal ligaments).[2,26] Thus, the TMJ enables mandibular movement relative to the skull,[22] aided by these four muscles and two ligaments[2,26] during activities like mastication[24,25] and working on-bit.[27]

TMJ dysfunctions in horses manifest with varying degrees of severity and are associated with temporomandibular disease (TMD), which presents a range of reasons for veterinary consultation. These can include signs of TMJ dysfunction such as aversive behaviours,[16,17] decreased performance,[15,17] masticatory problems,[10,14] and inability to open[28,29] or close[30,31] the mouth. The presence and specificity of clinical signs appear to be related to the underlying cause of specific TMD including septic arthritis,[5,6,9,10,13,14,28,32–36] osteoarthritis (OA),[6,15–17,29,37,38] fractures,[30,34,39–41] and joint luxation.[30,31,34] However, in cases of less frequently reported conditions such as neoplasia (like melanoma[36] and squamous cell carcinoma[42]) and dentigerous cyst near the TMJ,[43,44] the connection between clinical signs and the underlying cause is less clear.

Given recent clinical cases sparking discussions on TMD's role in equine sports medicine,[18,45,46] particularly regarding poor performance,[15,17] a systematic review of co-occurrence of specific clinical signs and diagnostic features in relation to the cause and history of TMD would greatly benefit both equine practitioners and researchers. The aim of this systematic review is to compile and disseminate clinical data and research findings from existing publications on equine TMD. Following the PICOT (Population, Intervention, Comparison, Outcome, Time) format, the research question is formulated as: 'In horses with TMDs (P), what clinical signs and diagnostic findings and methods (I), compared with negative results (C), have been reported in relation to the cause and history (O) in existing publications (T)?'

2 | MATERIALS AND METHODS

2.1 | Eligibility criteria

The inclusion criterion for this systematic review encompassed case reports and research articles on equine TMD publication from 1950 onwards.

2.2 | Exclusion criteria

Articles without full-text availability in English or lacking an available abstract were excluded. Book chapters were excluded.

2.3 | Search strategies

Literature searches were conducted in July 2024 using the following electronic search databases; PUBMED (search date: 18.07.2024; search strategy: no. 1: horse*[tw] OR equine*[tw], no. 2: temporomandibular joint*[tw] OR temporomandibular[tw] OR TMJ[tw] OR mandibular condyle*[tw], no. 3: no. 1 AND no. 2; retrieved records: 86), Scopus (search date: 18.07.2024; search strategy: TITLE-ABS-KEY (horse OR equine) AND ('temporomandibular joint' OR temporomandibular OR TMJ OR 'mandibular condyle'); retrieved records: 117), Web of Knowledge (search date: 18.07.2024; search strategy: no. 1: TS = (horse* OR equine*), no. 2: TS = ('temporomandibular joint*' OR temporomandibular OR TMJ OR 'mandibular condyle*'), no. 3: no. 1 AND no. 2; retrieved records: 151). No additional filters and limits were used. Detailed search strategies and search strings are available in Methods S1.

2.4 | Selection process

The selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines.[47] All retrieved records were compiled into an Excel file. Duplicates were manually removed. Subsequently, an unblinded screening was conducted, initially based on the title and then on the abstract. In the first

step of selection, titles pertaining to species other than horses were excluded. If the species could not be determined from the title, the records proceeded to the second step of selection. In the second step of selection, abstracts unrelated to horses or not relevant to TMJ were excluded. Records meeting the inclusion criterion and surviving the selection process underwent full-text retrieval. Two independent reviewers (the first and last authors) evaluated the full content of each publication for inclusion in the analysis. Details of the search records are available in Table S1. No automation tools were used in the process.

2.5 | Data collection process

A data extraction sheet was developed based on the template provided by the Cochrane Consumers and Communication Review Group.[48] The first author manually extracted data from each record, which was then reviewed by the last author. Any disagreements were resolved by a third party (the second author). An example of the data extraction sheet is available in Methods S2. The extracted information included: the year of publication, the aim of the study, the TMJ status, the study type, the scope of the Primary Research Question (PRQ),[49] the level of Evidence-Based Medicine Rating (EBMR) in the hierarchy of evidence (if applicable),[49,50] demographic data of horses, information on the studied groups, the main diagnostic and/or therapeutic methods used, therapeutic outcome, funding source, and ethical approval. For clinical cases, descriptive outcomes were recorded. No automation tools were used in the process.

2.5.1 | Record grouping process

The records were manually grouped by the first author and then reviewed by the last author. Any disagreement was resolved by a third party (the second author). The records were grouped based on TMJ status and study type. For TMJ status, records were categorised as concerning naturally occurring TMD, induced TMD, or normal TMJ. For study type, records were classified as case reports, research articles, or reviews and commentaries. Detailed information on the record grouping is provided in Tables S2–S6. All case reports concerning naturally occurring TMD (Table S2) were included in the final analysis. Research articles were grouped into studies on naturally occurring TMD (Table S3), induced TMD (Table S4), and normal TMJ (Table S5), with only those on naturally occurring TMD being included. Regardless of TMJ status, all reviews and commentaries (Table S6) were excluded. Finally, records were grouped by TMD type into septic TMJ arthritis, primary TMJ OA, and non-arthritic TMDs. Each case report was assigned to a single group, while research articles could be assigned to multiple groups; such articles were marked with an asterisk (*) in the relevant tables. Data were summarised as the number and percentage of horses within each group (intra-group) and across all analysed horses with TMD (inter-group). No automation tools were used in this process, and no additional methods were employed to prepare the data for presentation.

2.5.2 | Risk of bias assessment

The risk of bias in research studies was assessed using the Cochrane group's 'Risk Of Bias In Non-randomised Studies of Interventions (ROBINS-I)' tool[51] by two independent reviewers (the first and last authors). Any disagreements were resolved by a third party (the second author). No automation tools were used in this process. The Robvis visualisation tool was used to create a traffic-light plot to illustrate the risk of bias assessment.

2.5.3 | Data synthesis

The risk of bias level was used as a source of heterogeneity. However, due to significant heterogeneity, conducting a meta-analysis was not feasible. Therefore, data analysis was descriptive, and the results were summarised in tables.

3 | RESULTS

3.1 | Study selection

A total of 354 records were retrieved. The search and selection process is depicted in Figure 1. The primary reasons for study exclusion were discrepancies with the search parameters, such as content unrelated to horses or the TMJ. Of the 86 publications concerning equine TMJ, the most common reason for excluding, which applied to 8 publications, was the unavailability of the full text in English. Of these excluded records, five were in German, two in Portuguese, and one full text was unavailable. Consequently, 77 publications met the inclusion criteria for equine TMJ and were considered for equine TMD record selection. These 77 publications included 20 case reports, 42 research articles, and 15 reviews and commentaries, which are summarised in Tables S2–S6. Among the equine TMJ case reports, all addressed naturally occurring TMD. Of the equine TMJ research articles, 8 publications focused on naturally occurring TMD, 5 on induced TMD, and 48 on normal TMJ. Ultimately, 28 publications (20 case reports and 8 research articles) met the equine TMD inclusion criteria and successfully passed the exclusion and grouping processes.

Regarding TMD type, 9 case reports and 3 research articles were assigned to the septic TMJ arthritis group. Five case reports and 4 research articles were assigned to the primary TMJ OA group, while 6 case reports and 3 research articles were categorised under non-arthritic TMDs. Notable, two research articles involved multiple TMD types and were therefore assigned to more than one group. Each case report described TMD in a single horse. The research articles, however, reported on TMD in 11 out of 11 horses,[6] 4 out of 59 horses,[36] 2 out of 2 horses,[32] 3 out of 103 horses,[37] 3 out of 3 horses,[41] and 8

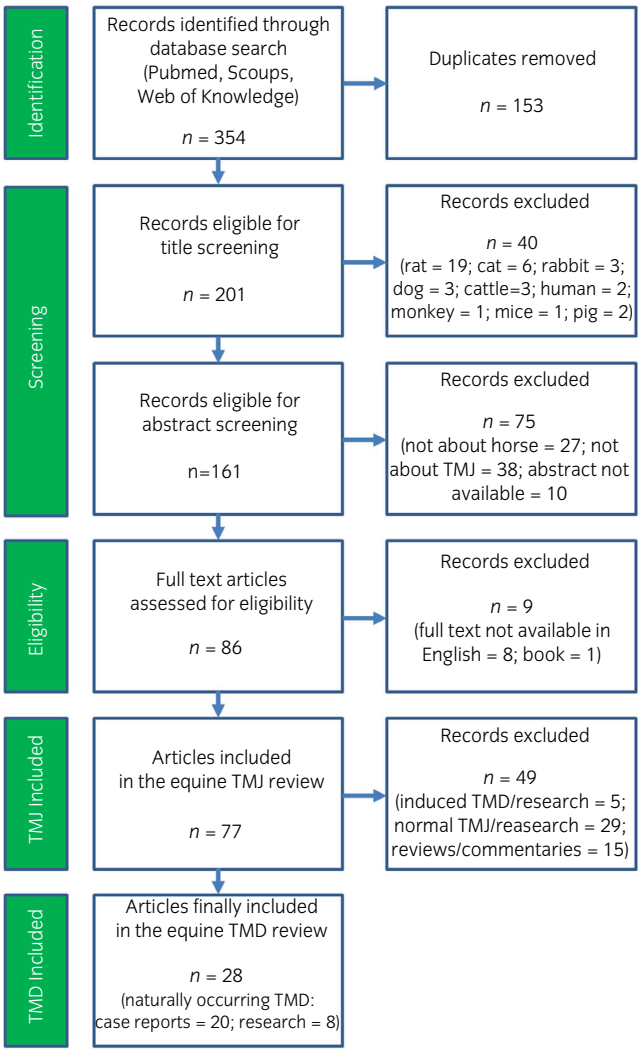

FIGURE 1 PRISMA flow diagram depicting studies included and excluded from the review.

out of 18 horses[40]; resulting in detailed discussion of TMD in a total of 51 horses. Additionally, 2 research articles focused on the intra-articular disc features[52] and radiological signs[53] of TMJ OA, but these were analysed at the individual TMJ level rather than the horse level. Therefore, their sample sizes were not included in further estimations.

3.2 | Causes, history, clinical signs, and diagnostic findings of septic TMJ arthritis

Septic TMJ arthritis was discussed in 21 horses (41.2% inter-group), including 9 clinical cases (Table 1) and 12 horses involved in research studies (Table 2). In 5 horses, septic arthritis co-occurred with osteomyelitis,[5,14,33,36] and in 3 horses, secondary TMJ OA was noted.[5,28,35] One case involved septic arthritis co-occurred with fracture and luxation.[34] Among the horses with septic TMJ arthritis, 8 horses (38.1% intra-group; 15.7% inter-group) had a history of trauma.[5,6,10,32] In 5 horses within this group (23.8% intra-group; 9.8% inter-group),[9,14,35,36] trauma was not observed but it was considered the most likely reason for infection due to the presence of a wound in the orbit area. The remaining 8 horses (38.1% intra-group; 15.7% inter-group) had no reported history of trauma.[6,13,28,33]

Horses with septic TMJ arthritis were presented to the veterinarian due to a wound on the head (13 horses; 61.9% intra-group; 25.5% inter-group) and/or moderate to severe TMJ dysfunctions. Moderate TMJ dysfunctions included masticatory problems in 13 horses (61.9% intra-group; 25.5% inter-group),[6,9,10,13,14,33] which were related to difficulty eating (9 horse),[6,33] inappetence (2 horses),[9,13] reduced appetite (1 horse),[10] or quidding (1 horse).[14] Severe TMJ dysfunctions were noted in 3 horses (14.3% intra-group; 5.9% inter-group),[28,32] with signs including an inability to masticate (2 horses)[32] and inability to open the mouth (1 horse).[28] Additionally, 3 horses were presented due to pain or restriction in the movement of the mandible or head,[28,33,34] and 2 horses had less specific signs such as pyrexia,[28,35] which was either associated[35] with ataxia and weakness or not.[28]

In all horses with septic TMJ arthritis, clinical signs such as TMJ[5,10,13,28,33,35] or periorbital[9,14] swelling were reported (16 horses; 76.2% intra-group; 31.4% inter-group). Among these, 14 horses (66.7% intra-group; 27.5% inter-group) exhibited pain during palpation,[5,6,9,10,13,14,28] while 2 horses (9.5% intra-group; 3.9% inter-group) did not.[33,35] Additionally, masseter muscle atrophy was observed in 2 horses (9.5% intra-group; 3.9% inter-group).[9,35] Moderate to severe TMJ dysfunctions were noted in 13 horses (61.9% intra-group; 25.5% inter-group), including discomfort[10] or inability to open the mouth,[28] impaired range of mandible movement,[35] and difficult[6] or unable[10] mastication.

In this TMD group, the results of oral examination were reported for 5 horses (23.8% intra-group; 9.8% inter-group),[9,10,13,34,35] while dental data were missing for 16 horses (76.2% intra-group; 31.4% inter-group).[5,6,14,28,32,33,36] Among the examined horses, 2 horses (9.5% intra-group; 3.9% inter-group) had no oral or dental abnormalities,[10,35] while 3 horses (14.3% intra-group; 5.9% inter-group) exhibited primarily incisor malocclusion.[9,13,34]

In 15 horses (71.4% intra-group; 29.4% inter-group), septic TMJ arthritis was confirmed by bacterial culture. Synovial fluid analysis, including biochemical and cytological evaluations, was completed for only 3 horses (14.3% intra-group; 5.9% inter-group).[10,13,28] Bacterial culture samples were primarily collected intraoperatively from 10 horses (47.6% intra-group; 19.6% inter-group),[5,6,10,14,35] while 2 horses (9.5% intra-group; 3.9% inter-group) had synovial fluid collected by arthrocentesis,[13,28] and 3 horses (14.3% intra-group; 5.9% inter-group) had fistula discharge cultured.[9,32] Among the bacteriologically examined horses, 2 horses (9.5% intra-group; 3.9% inter-group) had a polymicrobial bacterial infection.[6,32] Single bacterial isolates included *Streptococcus equi ssp zooepidemicus* (5 horses; 23.8% intra-group; 9.8% inter-group),[6,9,13,32,35] *Staphylococcus aureus* (2 horses; 9.5% intra-group; 3.9% inter-group),[5,6] and in one horse each (4.8% intra-group; 2.0% inter-group) *Fusobacterium necrophorum*,[14] *Rhodococcus equi*,[6] *Actinobacillus* sp.,[6] or *Escherichia coli*.[6] No bacterial growth was noted in 2 horses (9.5% intra-group; 3.9% inter-

TABLE 1 Case reports on temporomandibular joint diseases (TMD) focused on septic temporomandibular joint (TMJ) arthritis.

Paper	Demographic data	Diagnosis	History	Clinical signs	Oral examination	Arthrocentesis (SFC/LA)	Diagnostic imaging/ laboratory tests	Outcome/treatment
Balducci et al.[5]	1-year-old gelding; Quarter Horse	Septic TMJ arthritis; secondary TMJ OA; osteomyelitis	Trauma; wound in the orbit area	TMJ swelling; pain during TMJ palpation	No data	No (No/No)	Radiography; CT (bacterial culture from IA samples (bone): *S. aureus*)	Arthrotomy and curettage under GA
Elzer et al.[28]	15-year-old gelding; Thoroughbred	Septic TMJ arthritis; secondary TMJ OA	No trauma in history; pain in movement of the mandible; inability to open the mouth; pyrexia	TMJ swelling; pain during TMJ palpation; inability to open the mouth	No data	Yes (Yes/No)	Radiography; guttural pouch endoscopy; ultrasonography; SF analysis, bacterial culture: no bacterial growth; CT	Arthroscopic debridement under SS
Lean et al.[14]	11-year-old mare; Australian Stockhorse	Septic TMJ arthritis; osteomyelitis	Trauma; wound in the orbit area; masticatory problems: quidding	Periorbital swelling; pain during palpation	No data	No (No/No)	Radiography; CT; (bacterial culture from IA samples [bone]: *F. necrophorum*)	Arthrotomy and curettage under GA
Frietman et al.[10]	3.5-year-old gelding; Paint Horse	Septic TMJ arthritis	Trauma; wound in the orbit area; masticatory problems: reduced appetite	TMJ swelling; pain during TMJ palpation; discomfort while opening the mouth	No oral or dental abnormalities	No (No/No)	Radiography; ultrasonography; (bacterial culture from IA samples [SF]: no bacterial growth, SF analysis); CT	Arthroscopic partial mandibular condylectomy and temporal bone resection under GA
Barnett et al.[35]	2-year-old mare; Thoroughbred	Septic TMJ arthritis; secondary TMJ OA	Trauma; wound in the orbit area; ataxia; weakness; pyrexia	TMJ swelling; no pain during TMJ palpation; masseter muscle atrophy	No oral or dental abnormalities	No (No/No)	Radiography; ultrasonography; CT (bacterial culture from IA samples [SF]: *Str. zooepidemicus*)	Partial mandibular condylectomy and temporal bone resection under GA
Nagy and Simhofer[9]	2-year-old mare; Noriker	Septic TMJ arthritis	Trauma; wound in the orbit area; masticatory problems: inappetence	Periorbital swelling; pain during palpation; masseter muscle atrophy	Incisor malocclusion	No (No/No)	Radiography; CT (bacterial culture from fistula discharge: *Str. zooepidemicus*)	Mandibular condylectomy, meniscectomy under GA
Carmalt and Wilson[13]	12-year-old mare; Thoroughbred	Septic TMJ arthritis	No trauma in history; masticatory problems: inappetence	TMJ swelling; pain during TMJ palpation	Incisor malocclusion; excessive incisor; feed accumulation	Yes (Yes/No)	Radiography; SF analysis; bacterial culture: *Str. zooepidemicus*	Arthroscopic debridement and lavage under GA
Devine et al.[34]	9-month-old mare; American Paint Horse	Septic TMJ arthritis; temporal bone fracture; luxation of TMJ	Trauma; wound in the orbit area; restriction in movement of the mandible	No data	Incisor malocclusion	No (No/No)	Radiography; CT	Euthanasia

(Continues)

TABLE 1 (Continued)

Paper	Demographic data	Diagnosis	History	Clinical signs	Oral examination	Arthrocentesis (SFC/LA)	Diagnostic imaging/ laboratory tests	Outcome/treatment
Weller et al.[33]	12-year-old mare; Thoroughbred	Septic TMJ arthritis; osteomyelitis	No trauma in history; pain in movement of the head; masticatory problems: difficulty eating	TMJ swelling; no pain during TMJ palpation; impaired range of mandible movement	No data	No (No/No)	Radiography; scintigraphy; ultrasonography; (post-mortem: histopathology)	Euthanasia

Abbreviations: CT, computed tomography; GA, general anaesthesia; IA samples, samples collected intraoperatively; LA, local analgesia; OA, osteoarthritis; SF, synovial fluid; SFC, synovial fluid collection; SS, standing sedation; TMJ, temporomandibular joint.

group).[10,28] No horse suspected of septic TMJ arthritis underwent TMJ local analgesia.

In all horses, septic TMJ arthritis was confirmed radiologically. Radiography was used for 21 horses (100% intra-group; 41.2% inter-group)[5,6,9,10,13,14,28,32–36] and computed tomography (CT)[5,6,9,10,14,28,32,34–36] was used for 19 horses (90.5% intra-group; 37.3% inter-group). Additionally, 4 horses (19.1% intra-group; 7.8% inter-group) were examined ultrasonographically,[10,28,33,36] and 1 horse each (4.8% intra-group; 2.0% inter-group) was examined using endoscopy[28] and scintigraphy with histopathology.[33] Findings from diagnostic imaging, as well as the outcome and treatment of horses with septic TMJ arthritis, are listed in Tables 1 and 2, and described in detail in the referred publications.

3.3 | Causes, history, clinical signs, and diagnostic findings of primary TMJ OA

Primary TMJ OA was discussed in 11 horses (21.6% inter-group), including 5 clinical cases (Table 3) and 6 horses participating in research studies (Table 4). None of the horses with primary TMJ OA had a history of trauma.

Horses with primary TMJ OA were presented to the veterinarian due to TMJ swelling (5 horses; 45.5% intra-group; 9.8% inter-group)[6,29,38] and/or predominately mild to moderate TMJ dysfunctions. Mild TMJ dysfunctions included aversive behaviours (2 horses),[16,17] clunking/clicking during mastication (2 horses),[16,17] and problems with working on-bit (2 horses) reported as decreased performance[15] and difficulties in ride.[17] Moderate TMJ dysfunctions included masticatory problems[6,16,29,37] related to difficulty eating (3 horse)[6] and quidding (2 horse),[16,29] as well as problems with working on-bit reported as a head-shaking (4 horses).[16,37] Mild TMJ dysfunction was noted in 3 horses (27.3% intra-group; 5.9% inter-group), while moderate TMJ dysfunction was observed in 7 horses (63.6% intra-group; 13.7% inter-group). One horse (9.1% intra-group; 2.0% inter-group) was referred for examination due to severe TMJ dysfunction accompanied by severe weight loss and hard TMJ swelling.[29]

In horses with primary TMJ OA, clinical signs including TMJ swelling and/or joint effusion, were present in 5 horses (45.5% intra-group; 9.8% inter-group)[6,29,38] and absent in 3 horses (27.3% intra-group; 5.9% inter-group).[15–17] Pain during TMJ palpation was noted in 5 horses (45.5% intra-group; 9.8% inter-group),[6,15,38] while 2 horses (18.2% intra-group; 3.9% inter-group) did not exhibit pain.[17,29] Normal mastication was reported in 2 horses (18.2% intra-group; 3.9% inter-group),[17,38] masticatory data were missing for 5 horses (45.5% intra-group; 9.8% inter-group),[15,16,37] and moderate to severe TMJ dysfunction was noted in 4 horses (36.4% intra-group; 7.8% inter-group).[6,29] Reported masticatory problems ranged from difficulty eating[6] to inability to open the mouth and masseter muscle atrophy.[29]

In this TMD group, the results of oral examination were reported for 3 horses (37.3% intra-group; 5.9% inter-group).[15–17] Dentistry data were missing for 8 horses (72.7% intra-group; 15.7% inter-group),[6,29,37,38] and in one horse, an oral examination was not

TABLE 2 Research articles on temporomandibular joint diseases (TMD) considering septic temporomandibular joint (TMJ) arthritis.

Paper	Demographic data	Study type EBMR/PRQ	Studied issue	Diagnosis	History/clinical signs	Oral exam/ arthrocentesis (SFC/LA)	Diagnostic imaging/ laboratory tests	Outcome/ treatment
White et al.[6]	11 horses (4 M, 4 G, 3 S); 3 months to 30 years; different breeds	Level 4 (Case series)/ therapeutic PRQ	Long-term outcome of surgicall treatment of horses with TMD	Septic TMJ arthritis (8 horses); primary TMJ OA (3 horses)	Trauma (3 horses), no trauma (8 horses)/TMJ swelling; pain; masticatory problems: difficulty eating	No data/No data	Radiography; CT; bacterial culture from IA samples (SF or bone) 6/8 horses: *S. aureus*, *Str. zooepidemicus*, *R. equi*, *E. coli*, *Actinobacillus* sp., polimicrobal	Mandibular condylectomy; meniscectomy under GA
Manso-Díaz et al.[36a]	59 horses (26 M, 31 G, 2 S); 22 days to 25 years; different breeds	Level 4 (Case series)/diagnostic PRQ	Compare radiographic signs between horses with head diseases	Septic TMJ arthritis and osteomyelitis (2 horses/1/2 cases by botryomycosis); temporal bone fracture (1 horse); melanoma (1 horse)	No history/a final diagnosis of head disease	No data/No data	Radiography; CT	No data
Warmerdam et al.[32]	2 horses (1 G, 1 S); 7 months to 7 years; German and Dutch warmbloods	Level 4 (Case series)/ therapeutic PRQ	Outcome of treatment of septic TMJ arthritis	Septic TMJ arthritis	Trauma; wound in the orbit area/ TMJ swelling; inability to masticate	No data/No (No/No)	Radiography; CT; (bacterial culture from fistula discharge: 1/2 horse: *Streptococcus* sp., *Clostridium* sp.; 2/2 horse: *Str. zooepidemicus*)	General medication; fistulous tract removement under GA

Abbreviations: CT, computed tomography; EBMR, Evidence-Based Medicine Ratings; GA, general anaesthesia; G, gelding; IA samples, samples collected intraoperatively; LA, local analgesia; M, mare; OA, osteoarthritis; PRQ, Primary Research Question; S, stallion; SF, synovial fluid; SFC, synovial fluid collection; TMD, temporomandibular joint diseases; TMJ, temporomandibular joint.

[a]Research articles that are assigned to more than one TMD group.

performed due to the inability to open the mouth.[29] All examined horses showed various degrees of cheek teeth overgrowth.

No horse suspected of primary TMJ OA underwent bacterial culturing. However, synovial fluid analysis was performed in one horse (9.1% intra-group; 2.0% inter-group).[16] This synovial fluid was collected by arthrocentesis. Additionally, arthrocentesis was performed in 2 more horses (18.2% intra-group; 3.9% inter-group) for TMJ local analgesia.[15,17] In both cases, a positive response was evidenced by improvements in the results of the functional test. In both cases, the functional test included working on-bit. In one case it was assessed subjectively by an experienced test rider,[15] while in the other case, the result was quantified using inertial measurement units (IMUs; Lameness Locator®).[17]

In all horses, primary TMJ OA was confirmed radiologically. Radiography was used for 6 horses (54.6% intra-group; 11.8% inter-group)[6,16,29,38] and CT was used for 10 horses (90.9% intra-group; 19.6% inter-group).[6,15–17,37,38] Additionally, 2 horses (18.2% intra-group; 3.9% inter-group) were examined ultrasonographically,[6,16] and 2 horses (18.2% intra-group; 3.9% inter-group) underwent dissection and histopathological examination post-mortem.[16,38] Interestingly, only one horse (9.1% intra-group; 2.0% inter-group) underwent magnetic resonance imaging (MRI) of TMJ, which was also performed post-mortem.[16] Findings from diagnostic imaging, as well as the outcome and treatment of horses with primary TMJ OA, are listed in Tables 3 and 4, and described in detail in the referred publications.

3.4 | Causes, history, clinical signs, and diagnostic findings of non-arthritic TMDs

Non-arthritic TMDs were discussed in 19 horses (37.2% inter-group), including 6 clinical cases (Table 5) and 13 horses participating in research studies (Table 6). Within this group, fractures were described in 13 horses (68.2% intra-group; 25.5% inter-group),[36,40,41] fracture with luxation in 1 horse (5.3% intra-group; 2.0% inter-group),[30] and luxation alone in 1 horse (5.3% intra-group; 2.0% inter-group),[31] totalling 15 horses (79.0% intra-group; 29.4% inter-group) in the traumatic non-arthritic subgroup. Additionally, dentigerous cysts[43,44] and neoplasia[36,42] were each reported in 2 horses (per 10.5% intra-group; per 3.9% inter-group), resulting in a total of 4 horses (21.0% intra-group; 7.8% inter-group) in the non-traumatic non-arthritic subgroup. One case of TMJ neoplasia involved squamous cell carcinoma,[42] and the other involved melanoma.[36]

Horses with traumatic non-arthritic TMDs were presented to the veterinarian due to lateral displacement of the mandible (5 horses; 26.3% intra-group; 9.8% inter-group)[30,31,41] and severe TMJ dysfunctions such as inability/difficulty to open/close the mouth (5 horses; 26.3% intra-group; 9.8% inter-group).[30,31,41] In 9 horses with fractures (47.4% intra-group; 17.6% inter-group), the history and clinical data were limited.[36,40] Additionally, 1 horse with a fracture (5.3% intra-group; 2.0% inter-group) was presented with inappetence and less specific clinical signs such as pyrexia and lethargy, which were associated with meningitis.[39] Horses with non-traumatic non-arthritic TMDs were presented to the veterinarian due to fistula or swelling in the ear area (3 horses; 15.8% intra-group; 5.9% inter-group),[42–44] with or without moderate masticatory problems (difficulty eating; 1 horse; 5.3% intra-group; 2.0% inter-group).[42]

In all horses with non-arthritic TMDs, clinical signs included swelling of TMJ or swelling of fistula in 5 horses (26.3% intra-group; 9.8% inter-group)[30,31,42–44] and absence of swelling in 1 horse (5.3% intra-group; 2.0% inter-group).[39] Pain during TMJ palpation was noted in 2 horses (10.5% intra-group; 3.9% inter-group),[31,44] while no pain was detected in another 2 horses (10.5% intra-group; 3.9% inter-group).[30,43] However, for two case reports and all research articles, many clinical data were missing.[36,39–42] Moderate TMJ dysfunction, characterised by difficulty eating, was observed in 2 horses (10.5% intra-group; 3.9% inter-group).[39,42] Severe TMJ dysfunction, including inability or difficulty to open the mouth[41] or move the mandible in any direction,[30] was observed in 5 horses (26.3% intra-group; 9.8% inter-group).

In this TMD group, the results of oral examination were reported for 4 horses (21.1% intra-group; 7.8% inter-group),[31,41] while 15 horses (78.9% intra-group; 29.4% inter-group) had missing dentistry data.[30,36,39–41,43,44] All examined horses showed no dental occlusion resulting from lateral deviation of the mandible.

Only one horse with non-arthritic TMDs (5.3% intra-group; 2.0% inter-group) underwent bacterial culture of the fistula discharge.[43] This horse had a polymicrobial bacterial infection, including *Streptococcus equi ssp zooepidemicus*, *Enterococcus faecalis*, and *Proteus mirabilis*. Additionally, another horse in this group (5.3% intra-group; 2.0% inter-group) underwent arthrocentesis for local analgesia, with a positive response observed.[31]

In all horses, the non-arthritic TMDs were confirmed radiologically. This included 16 horses using radiography (84.2% intra-group; 31.4% inter-group)[30,31,36,40–42] and 18 horses using CT (94.7% intra-group; 35.3% inter-group).[30,31,36,40–44] Additionally, 5 horses (26.3% intra-group; 9.8% inter-group) were examined ultrasonographically,[31,39,41] and one horse underwent endoscopy (5.3% intra-group; 2.0% inter-group).[39] Furthermore, 2 horses (10.5% intra-group; 3.9% inter-group) had histopathological confirmation of TMD,[42,44] with one sample taken intraoperatively[44] and the other one post-mortem.[42] Findings from diagnostic imaging, as well as the outcome and treatment of horses with non-arthritic TMDs, are listed in Tables 5 and 6, and described in the referred publications.

3.5 | The risks of bias in research studies

The risks of bias in individual studies on naturally occurring TMD are depicted in the traffic-light plot presented in Figure 2. The studies show a low risk of bias due to confounding; however, the risk of bias due to the selection of participants cannot be considered comparable to that of a well-performed randomised trial because most studies are case series, and participant selection is influenced by the availability of cases. Only Carmalt et al.[53] represent a very good selection of participants with a low risk of bias, while Guerrero Cota et al.[52] does not

TABLE 3 Case reports on temporomandibular joint diseases (TMD) focused on primary temporomandibular joint (TMJ) osteoarthritis (OA).

Paper	Demographic data	Diagnosis	History	Clinical signs	Oral examination	Arthrocentesis (SFC/LA)	Diagnostic imaging/ laboratory tests	Outcome/ treatment
Carmalt and Reisbig[17]	6-year-old gelding; Trakehner/ Thoroughbred horse	Primary TMJ OA	No trauma in history; clunking during mastication; tongue protruded; angry behaviour; difficulties in ride	No TMJ swelling; no joint effusion; no pain during TMJ palpation; normal mastication	Minor type-I malocclusions (cheek teeth overgrowth)	Yes (No/Yes) positive response	Functional test; CT	Arthroscopic cyst debridement under GA; euthanasia
Pimentel et al.[38]	15-month-old mare; Quarter Horse	Primary TMJ OA; osteochondrosis-like lesions	No trauma in history; hard TMJ swelling	TMJ swelling; pain during TMJ palpation; normal mastication	No data	No (No/No)	Radiography; CT; (post-mortem: dissections; histopathology)	Euthanasia
Smyth et al.[16]	18-year-old mare; Tennessee Walking Horse	Primary TMJ OA	No trauma in history; episodes of colic; quidding; clicking during mastication; agitated behaviour; difficulties in ride; a head-shaking	No joint effusion	Cheek teeth overgrowth	Yes (Yes/No)	Radiography; ultrasonography; CT; SF analysis; (post-mortem: MRI; dissections; histopathology)	Intra-articular medication; euthanasia
Jorgensen et al.[15]	11-year-old gelding; Danish Warmblood	Primary TMJ OA	No trauma in history; decreased performance; yawned when seeing bridle	Head symmetry (no TMJ swelling; no joint effusion); pain during TMJ palpation	Small enamel points; cheek teeth overgrowth	Yes (No/Yes) positive response	Functional test; CT	Intra-articular medication
Sanders et al.[29]	24-year-old mare; Irish Sport Horse	Primary TMJ OA	No trauma in history; severe weight loss; quidding; inability or reluctance to open mouth; hard TMJ swelling	TMJ swelling; no pain during TMJ palpation; masseter muscle atrophy; inability to open the mouth	Not performed due to inability to open mouth	No (No/No)	Radiography; ultrasonography	Mandibular condylectomy under SS

Abbreviations: CT, computed tomography; GA, general anaesthesia; LA, local analgesia; MRI, magnetic resonance imaging; OA, osteoarthritis; SF, synovial fluid; SFC, synovial fluid collection; SS, standing sedation; TMJ, temporomandibular joint.

TABLE 4 Research articles on temporomandibular joint diseases (TMD) considering primary temporomandibular joint (TMJ) osteoarthritis (OA).

Paper	Demographic data	Study type EBMR/PRQ	Studied issue	Diagnosis	History/clinical signs	Oral exam/ arthrocentesis (SFC/LA)	Diagnostic imaging/ laboratory tests	Outcome/ treatment
Perrier et al.[37]	103 horses (44 M, 59 G); 4 to 26 years; different breeds	Level 4 (Case series)/diagnostic PRQ	Compare radiographic signs between horses with a head-shaking	Primary TMJ OA (3 of 22 cases with treatable primary disease)	No history/a head-shaking	No data/No data	CT	No data
White et al.[6a]	11 horses (4 M, 4 G, 3 S); 3 months to 30 years; different breeds	Level 4 (Case series)/ therapeutic PRQ	Long-term outcome of surgicall treatment of horses with TMD	Septic TMJ arthritis (8 horses); primary TMJ OA (3 horses)	Trauma (3 horses), no trauma (8 horses)/TMJ swelling; pain; masticatory problems: difficulty eating	No data/No data	Radiography; CT; bacterial culture: only in 6/8 horses with septic TMJ arthritis	Mandibular condylectomy; meniscectomy under GA
Guerrero Cota et al.[52]	16 cadaver heads (32 TMJ) (sex not rep.); age not rep.; breeds not rep.	Level n/a (Analytical cross-sectional study)/ basic study	Biochemical and mechanical properties of TMJ intra-articular disc	Normal intra-articular disc (11 TMJ); OA intra-articular disc (21 TMJ)	No data	No data/No data	Biochemical analysis; mechanical test; histology	n/a
Carmalt et al.[53]	1018 horses (2162 TMJ) (sex not rep.); <1 to 20+ years or unknown; different breeds	Level 3 (Retrospective cross-sectional study)/diagnostic PRQ	Compare radiographic signs of TMJ	Anatomical variations of normal TMJ (1442 TMJ); TMJ OA (594 TMJ)	No history/ excluded horses when TMD was a primary reason for CT	No data/No data	CT	No data

Abbreviations: CT, computed tomography; EBMR, Evidence-Based Medicine Ratings; GA, general anaesthesia; G, gelding; LA, local analgesia; M, mare; n/a, not applicable; not rep, not reported; OA, osteoarthritis; PRQ, Primary Research Question; S, stallion; SFC, synovial fluid collection; TMD, temporomandibular joint diseases; TMJ, temporomandibular joint.

[a]Research articles that are assigned to more than one TMD group.

TABLE 5 Case reports focused on non-arthritic temporomandibular joint diseases (TMD).

Paper	Demographic data	Diagnosis	History	Clinical signs	Oral examination	Arthrocentesis (SFC/LA)	Diagnostic imaging/laboratory tests	Outcome/ treatment
Greim et al.[43]	3-year-old gelding; Comptois horse	Dentigerous cysts	No trauma in history; fistula in the ear area	Swelling in fistula area; no pain during palpation	No data	No (No/No)	CT (bacterial culture from fistula discharge: *Str. zooepidemicus*, *E. faecalis*, *P. mirabilis*)	Mandibular condylectomy under GA
Howell et al.[44]	3-year-old mare; Warmblood horse	Dentigerous cysts	No trauma in history; swelling in the ear area	Swelling in TMJ area; pain during TMJ palpation	No data	No (No/No)	CT; histopathology	Surgical removal under GA
Souza et al.[31]	6-year-old stallion; Mangalarga Marchador horse	Luxation of TMJ	Trauma; lateral displacement of the mandible; inability to close the mouth	Swelling in TMJ area; pain during TMJ palpation	No dental occlusion; lateral deviation of mandible	Yes (No/Yes) positive response	Radiography; ultrasonography	Manual reduction under GA
Luedke et al.[30]	6-year-old gelding; Welsh pony	Coronoid process fracture; luxation of TMJ	Trauma; lateral displacement of the mandible; inability to close the mouth	Swelling in TMJ area; no pain during palpation; inability to move mandible in any direction	No data	No (No/No)	Radiography; CT	Closed reduction under GA
Stefanetti et al.[39]	3-month-old stallion; Hanoverian	Mandibular condyle fracture; meningitis	Trauma; pyrexia; lethargy; drooping ear; inappetence	No swelling in TMJ area; difficulty eating	No data	No (No/No)	Ultrasonography; endoscopy; CT	Meningitis treatment
Perrier et al.[42]	12-year-old mare; Belgian	Squamous cell carcinoma of TMJ	No trauma in history; fistula in the ear area; difficulty eating	Swelling in fistula area; difficulty eating	No data	No (No/No)	Radiography (post-mortem: CT; dissections; histopathology)	Euthanasia

Abbreviations: CT, computed tomography; GA, general anaesthesia; LA, local analgesia; OA, osteoarthritis; SFC, synovial fluid collection; TMJ, temporomandibular joint.

TABLE 6 Research articles considering non-arthritic temporomandibular joint diseases (TMD).

Paper	Demographic data	Study type EBMR/PRQ	Studied issue	Diagnosis	History/clinical signs	Oral exam/ arthrocentesis (SFC/LA)	Diagnostic imaging/ laboratory tests	Outcome/treatment
Magri et al.[41]	3 horses (2 M; 1 S); 1 to 2 years; Thoroughbred, Warmblood	Level 4 (Case series)/ therapeutic PRQ	Outcome of surgicall treatment of coronoid process fracture	Coronoid process fracture; secondary TMJ OA	Trauma /inability or difficulty to open the mouth	No dental occlusion; lateral deviation of mandible/No data	Radiography; ultrasonography; CT	Coronoidectomy under GA
Crijns et al.[40]	18 horses (5 M, 3 G, 10 S); 2 months to 16 years; different breeds	Level 4 (Case series)/diagnostic PRQ	Compare radiographic signs of skull fractures	Mandibular condyle fracture (4 horses); temporal bone fracture (4 horses)	Trauma/visible injury, soft tissue involvement	No data/No data	Radiography; CT	No data
Manso-Díaz et al.[36a]	59 horses (26 M, 31 G, 2 S); 22 days to 25 years; different breeds	Level 4 (Case series)/diagnostic PRQ	Compare radiographic signs between horses with a head disease	Septic TMJ arthritis and osteomyelitis (2 horses/1/2 cases by botryomycosis); temporal bone fracture (1 horse); melanoma (1 horse)	No history/a final diagnosis of head disease	No data/No data	Radiography; CT	No data

Abbreviations: CT, computed tomography; EBMR, Evidence-Based Medicine Ratings; G, gelding; GA, general anaesthesia; LA, local analgesia; M, mare; OA, osteoarthritis; PRQ, Primary Research Question; S, stallion; SFC, synovial fluid collection; TMD, temporomandibular joint diseases; TMJ, temporomandibular joint.

[a]Research articles that are assigned to more than one TMD group.

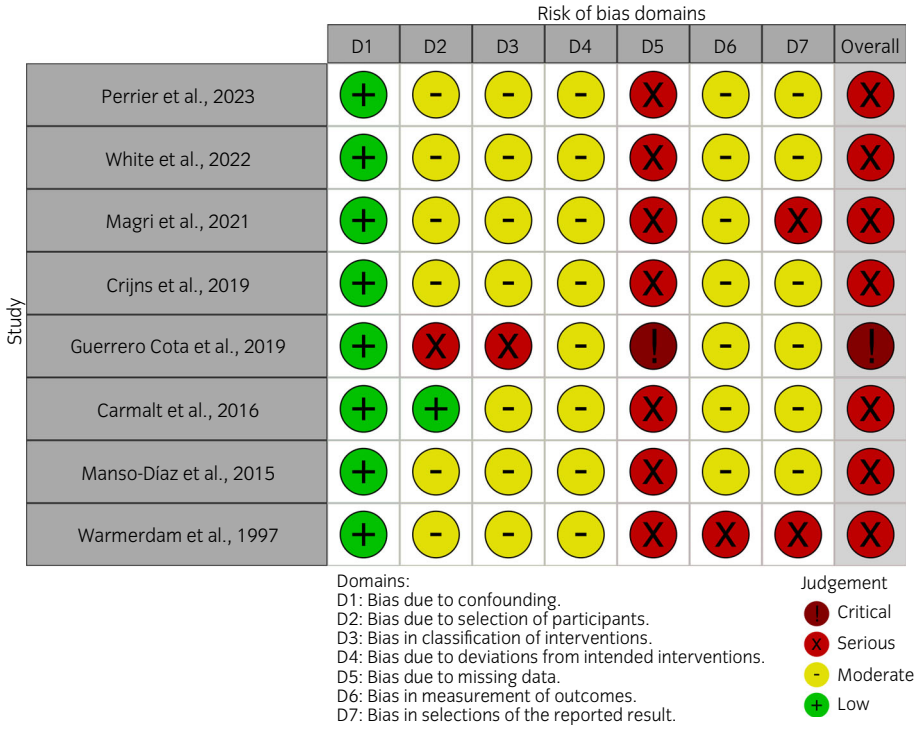

FIGURE 2 Traffic-light plot of the risk of bias in research studies on naturally occurring equine temporomandibular joint diseases (TMD).

present convincing criteria for selecting normal and OA intra-articular disks, leading to serious risks in both participant selection and intervention classification. For all the studies assessed, the risk of bias due to missing data is serious, as most studies are missing parts of the clinical data summarised in Tables 2, 4, and 6, which do not provide a complete picture of the TMD. Therefore, the overall risk of bias for these studies ranged from 'serious' to 'critical'.

4 | DISCUSSION

4.1 | Reported causes of TMDs

TMDs are considered to be rare in horses.[5,18,27] Septic TMJ arthritis was declared to be uncommon in horses,[9,13,14,28,35] while primary TMJ OA was declared to be rarely reported.[16,17] Our review confirms this belief, identifying only 51 horses with TMD in the available literature.

As early as 1999, Weller et al.[33] noted that few cases of TMDs had been reported in horses, and since this time only 20 case reports have been published. At that time, most of the reports involved trauma resulting in TMJ luxation or subluxation, with or without a mandibular fracture.[33] Later, Balducci et al.[5] suggested that septic TMJ arthritis and luxation or subluxation are the most commonly reported TMDs. More recently, White et al.[6] indicated that the most commonly reported TMDs in horses include septic TMJ arthritis, primary TMJ OA, fracture of the mandibular condyle, and luxation or subluxation. Following these changes in reported cases over the years, our review supports the earlier observations by Balducci et al.[5] and White et al.[6] Specifically, we found that septic TMJ arthritis accounts for 41.2% of TMD cases, making it the most frequently reported equine TMD. However, our review also shows that primary TMJ OA (21.6% of TMD cases) is reported slightly less frequently than fractures and/or luxations (29.4% of TMD cases). Within this traumatic non-arthritic subgroup, fractures significantly outnumber luxations. Notably, the reported fractures involved not only the mandibular condyle[39,40] but also the coronoid process,[30,41] zygomatic process of the temporal bone.[34,36,40] Additionally, non-traumatic, non-arthritic cases, such as neoplasia and dentigerous cysts in proximity to the TMJ, are reported incidentally, each accounting for 7.8% of TMD cases.

Smyth et al.[16] stated that trauma is the most common cause of equine TMD, which our estimation supports, showing confirmed or suspected trauma in 54.9% of TMD cases, while 45.1% had no trauma in history. However, this estimation should be considered as an overview, as it is based on a history of existing TMD publications, which may be biased due to missing data and will likely change with future publications on TMDs. Additionally, determining the cause of TMD can sometimes be challenging and should be considered separately for each type of TMD.[9,13,14,28] Our estimation shows that in the majority of septic TMJ arthritis cases (61.9%), there was a history of trauma or trauma was not observed but considered the most likely cause of a wound. In contrast, trauma was not mentioned in the history of 38.1% of septic TMJ arthritis cases. These findings quantitatively support previous descriptive suggestions that trauma is the most commonly reported cause of sepsis TMJ arthritis in horses.[14,28,34,35] These injuries often occur in combination with wounds, fractures, luxations, or both, where bacteria are introduced into the TMJ or surrounding tissue, leading to sepsis.[16] Moreover, in the long term, fracture of the coronoid process can lead to ankylosis,[41] while septic TMJ arthritis can result in osteomyelitis.[5,14,33,36] Both

diseases may also lead to TMJ OA, developing secondary to a traumatic event such as fracture[41] or septic arthritis,[5,28,35] which supports the assertion that trauma is a common cause of TMJ OA.[16] However, based on our estimation, it is notable that in all cases of primary TMJ OA, there was no trauma in history.

TMJ OA may be a primary disease process,[6,15–17,29,38] attributed to wear-and-tear of the articular cartilage over time.[16,17,32] This aetiology is supported by the age-related remodelling of the TMJ, including changes in bone shape,[53] bone density,[53] and articular cartilage structure[54]; as well as dental pathologies[55] that affect the high forces of mastication.[20] These factors suggested that occlusion-related overload on the TMJ could potentially lead to OA. However, the direct link with clinical significance requires further research.[53,55] Case reports describing clinically significant TMJ OA raise suspicions of a primary aetiology when there is no history of trauma or sepsis,[16,17] or when the owner cannot recall any incident of trauma.[29] Therefore, Smyth et al.[16] postulated that primary TMJ OA may be either missed or incorrectly diagnosed due to its nondescript signs, suggesting that the incidence of TMJ OA may be higher than reported. On the other hand, Carmalt[18] cautions against overinterpreting diagnostic results, particularly when linking TMD with poor performance.

4.2 | Reported reasons for presenting a horse to a veterinarian and clinical signs of TMDs

The three TMD groups considered differ not only in their cause but also in their clinical characteristics. Horses with septic TMJ arthritis were typically presented to the veterinarian mainly due to a head wound and/or moderate to severe TMJ dysfunctions, particularly masticatory problems such as difficulty eating,[6,33] reduced appetite,[10] inappetence,[9,13] or quidding.[14] Inability to open the mouth[28] and inability to masticate[32] were less commonly observed in septic TMJ arthritis, but when present, along with lateral displacement of the mandible,[30,31,41] they were the primary reason for intervention in non-arthritic TMDs. On the other hand, horses with primary TMJ OA were usually presented to the veterinarian due to mild to moderate TMJ dysfunctions and, less often, TMJ swelling. It can be observed that TMJ dysfunctions in these cases were more focused on working-related aversive behaviours,[16,17] problems with working on-bit,[15,17] and head-shaking,[16,37] rather than on masticatory problems like difficulty eating,[6] clunking/clicking during mastication,[16,17] or quidding.[16,29]

Detailed clinical examination in most cases of septic TMJ arthritis revealed TMJ[5,10,13,28,33,35] or periorbital[9,14] swelling, often accompanied by pain during palpation.[5,6,9,10,13,14,28] In contrast, joint swelling and/or effusion in primary TMJ OA occurred less frequently, and in some cases, it was painless.[17,29] Although TMJ dysfunction and masseter muscle atrophy were sometimes observed in both TMDs,[9,29,35] the clinical signs of septic TMJ arthritis were generally more severe. Some horses with primary TMJ OA even show normal mastication.[26,27] Experimental studies have demonstrated that after the induction of acute TMJ inflammation, horses did not exhibit pain during TMJ palpation, and none were hesitant to eat.[25,27,56] This suggests that horses with spontaneous TMJ OA may also eat normally and show less specific clinical signs of TMD.

Gradations of inflammation, where clinical signs emerge once the pain from TMD reaches a certain threshold, have recently been suggested[5,6] and supported by clinical reports.[15–17] Mild pain may be accompanied by behavioural signs such as yawning when seeing the bridle[15] or standing at rest with the tongue protruded,[17] as well as during various exercises under saddle due to discomfort while riding.[15–17] Moderate pain may be indirectly recognised through signs like quidding,[14,16,29] clunking/clicking during mastication,[16,17] or head-shaking.[16,34,37] Notably, in 12.6% of horses with head-shaking complaints, CT scans revealed radiological signs of TMJ OA, including disc mineralisation, and in 10.7% of the examined horses, cysts in the mandibular condyle were found.[37] However, head-shaking was not observed in horses with septic TMJ arthritis or non-arthritic TMDs. Severe pain may result in significant TMJ dysfunction, evidenced by the inability to open the mouth,[28,29,41] impaired range of mandible movement,[33] and difficulty[6] or inability[32] to masticate, and a masseter muscle atrophy as a long-term consequence.[9,29,35]

Experimental studies have shown that horses with inflammation-induced TMJ pain may adjust their eating habits, allowing them to maintain weight and body condition.[25] Moderate pain from TMJ inflammation causes enough discomfort to alter the horse's masticatory behaviour, prompting them to perform the power stoke of their masticatory cycle on the contralateral side, reduce the vertical motion of the mandible in favour of rostrolateral motion, and close their mouths slightly faster.[25] These inflammation-induced changes in mastication may become indirectly clinically visible by the production of poorly chewed cylindrical feed boluses, which are ejected as quids.[25] Moreover, acute inflammation responses differ between the TMJ and peripheral joints, with a greater inflammatory response observed in the TMJ, which also appears to dampen the acute immune response more effectively.[56] This suggests that the equine TMJ may be somewhat less susceptible to pain,[23] due to its distinct immune response.[56] Additionally, horses with acute TMJ inflammation tend to avoid pressure on the bit caused by the rein on the affected side. However, TMJ pain may not significantly alter a horse's locomotion, as the handler might counterbalance any instability through increased rein tension on the unaffected side, thereby negating any objective differences.[27] These findings supported clinical reports linking poor performance in sport horses with TMD.[15,17] It is important to note that when wounds, effusion, or swelling of the TMJ, and pain during TMJ palpation are not detectable,[6,29] the disease can progress unnoticed over time until moderate and severe pain leads to more severe TMJ dysfunction and, consequently, more specific clinical signs. Therefore, less obvious clinical signs should also be recommended for the practitioner's attention.

4.3 | Main diagnostic protocols in TMDs assessment

Carmalt[18] postulates that because equine TMDs are uncommon, the diagnostic protocol should focus on eliminating other possible causes rather than confirming TMD directly. The diagnostic process, as

detailed by Carmalt,[18] should begin with a thorough history and then systematically exclude lameness, as well as cardiovascular, respiratory, and dental disease. However, in existing publications, essential data from the history and preliminary examinations, mentioned here, are often missing. Among all the reviewed TMD cases, lameness examination was conducted in only two instances,[15,17] and cardiovascular and respiratory examinations were not described in any case. Surprisingly, dentistry data were absent in 76.5% of TMD cases, despite their importance. The oral examination allows to confirm lateral deviation of the mandible and lack of dental occlusion, which may indicate TMJ fracture[41] and luxation.[31] Dental inspection can detect dental malocclusions, which are potentially linked to equine TMD. Notably, this review highlights a co-occurrence of incisor malocclusion with septic TMJ arthritis[9,13,34] and cheek teeth overgrowth with primary TMJ OA,[15–17] although the causal relationship requires further investigation. The excessive use of full-mouth speculum in routine dental practice has also been speculated to be associated with TMJ OA.[23] However, this hypothesis was rejected in an experimental study, which found no turnover changes in TMJ articular cartilage after 1 h of mechanical overload.[23] The only justification for not performing an oral examination, in some cases, is an inability to open mouth.[29]

Continuing with Carmalt's[18] diagnostic protocol, after completing these preliminary examinations, a detailed visual examination and palpation of both TMJs should be conducted to identify or rule out joint effusion, swelling, and pain during palpation, as well as the presence of wounds or fistulas. However, existing publications often omit essential clinical data. Furthermore, the normal TMJ function and details on the severity of TMJ dysfunction are frequently not reported, even though these should always be documented, particularly in relation to masticatory problems. A detailed assessment of TMJ dysfunction is crucial, as local analgesia may be considered when signs of malfunction are detectable.[15,17,31] However, in cases where mild to moderate dysfunction signs, such as clicking sounds and quidding during mastication, are absent at the time of examination, determining the efficacy of local analgesia can be challenging.[16] In existing publications, local analgesia of the TMJ was performed in only 5.9% of TMD cases, mainly in primary TMJ OA cases assessed functionally[15,17] and TMJ luxation to facilitate further examination.[31] In all instances, a positive response was gauged by the resolution of mild pain signs[15,17] or decreased severity of severe pain signs.[31] However, local analgesia was not performed in any case of septic TMJ arthritis.

A definitive diagnosis of septic synovial infection is based on synovial fluid analysis and bacterial culture, with a positive result considered the 'gold-standard' for confirming septic arthritis.[57] Furthermore, bacterial sensitivity tests guide the selection of antimicrobial medication and affect outcomes.[58] In existing publications, bacteria were cultured in 31.4% of TMD cases, including 71.4% of septic TMJ arthritis cases,[5,6,9,10,13,14,28,32,35] but in no primary TMJ OA cases, and only 5.3% of non-arthritic TMDs.[43] Among these, *Streptococcus equi ssp zooepidemicus* was the most commonly isolated single bacterium,[6,9,13,32,35] though polymicrobial bacterial infection,[6,32,43] *Staphylococcus aureus*,[5,6] and cases with no bacterial growth were also reported.[10,28] The remaining single positive results seem to be less specific.[6,14] This aligns with previous observations that streptococcal bacteria are the most commonly isolated in horses,[5,13,14] in contrary human septic TMJ arthritis, where *Staphylococcus aureus* is the most common microbial agent.[59] In 47.6% of bacterial culture samples, synovial fluid[10,35] or bone fragments[5,14] were collected intraoperatively to avoid additional procedures and reduce the potential risk of iatrogenic infections. However, no complications were reported in any of the arthrocentesis procedures[13,15–17,28,31] performed for local analgesia[15,17,31] or synovial fluid collection.[13,16,28]

In existing publications, synovial fluid analysis was used to support the identification of underlying disease in 7.8% of TMD cases, including both septic TMJ arthritis[10,13,28] and primary OA.[16] Normal TMJ synovial fluid in horses is clear, straw-yellow in colour, and forms filaments of 3.0–5.0 cm in physical evaluation.[23] Its volume is ~0.84 ± 0.3 mL,[23] total protein concentration range from 330 to 700 μg/mL,[56] through 1.26–1.3 mg/μL,[23] to ≤2.6 g/dL,[11] and average neutrophil count of ≤2%[45] or 3.6 ± 2.6 cells/μL,[23] depending on the publication. The concentration of certain biomarkers in synovial fluid, such as total protein, glycosaminoglycans, chondroitin sulphate, hyaluronic acid, and pain-mediating prostaglandin E_2 remains unchanged with the use of a full-mouth speculum in routine dental practice.[23] However, interleukin 8 (IL-8) and transforming growth factor β1 (TGF-β1) concentrations increase with horse's age,[60] while total protein decreases and tumour necrosis factor α (TNF-α) increases with acute TMJ inflammation.[56] The role of synovial fluid biomarkers in equine TMJ OA has been reviewed in light of human research,[61] suggesting a potential future panel for molecular diagnostics and targeted treatment. Considering that synovial fluid can be collected during procedures such as local analgesia,[15,17,31] intra-articular medication,[15,16] and arthroscopy[10,13,17,28] or arthrotomy[5,6,9,14,29,35,43]—as has already been done in the local treatment of primary TMJ OA[16]—the future use of multiplex biomarker assays may hold great potential for targeted regenerative treatment of TMDs,[61] especially considering the difference between fibrocartilage and hyaline cartilage.[62]

Continuing with Carmalt's[18] diagnostic protocol, diagnostic imaging was used to confirm TMDs primarily through conventional radiography and CT in 84.4% and 92.2% of cases, respectively. Additionally, ultrasonography was utilised in 21.6% of TMD cases, and endoscopy in 3.9%. Notably, only one case report in the existing literature mentioned the use of scintigraphy[33] and MRI[16] in the diagnosis of equine TMD, with the MRI being performed post-mortem. Thus, our estimation indicates that CT, radiography, and ultrasonography are the most commonly used diagnostic methods of equine TMD, with CT being the most prevalent. The increasing use of CT in equine imaging has led to a slight decline in the use of radiography. Currently, CT is the most common imaging modality for evaluating TMD, although radiography has traditionally been the most prevalent.[5] Despite this shift, radiography remains the first choice in field practice.

The anatomic complexity of the TMJ region[2,63–65] limits the utility of two-dimensional imaging modalities due to superimposition of the irregular shapes of the condylar process of the mandible and the zygomatic process of the temporal bone. To address this superimposition, the principle of magnification radiography and specific

radiographic projections have been applied.[66–70] Despite these advances many authors highlight the advantages of CT over radiography resulting from the actual reflection of each imaged plane. Furthermore, both x-ray modalities can be enhanced by the intra-articular use of contrast agents, allowing for better delineation of articular cartilage and interpretation of intra-articular soft tissue structures through contrast arthrography[8,12] and contrast-enhanced CT.[7,11]

Jorgensen et al.[15] suggested that MRI and CT are likely the 'gold standard' for TMJ research, but they are not always the first choice in clinical practice. The usefulness of MRI in equine TMJ imaging is limited due to the requirement for a unique and expensive high-field machine and the need for prolonged general anaesthesia,[71] which has so far restricted its clinical use mostly to cadaverous heads.[7,16,65] However, given the number of CTs described in the analysed publications, it is safe to say that CT is also prevalent in clinic practice. Additionally, recent advancements in equipment and room modifications allow for the use of fan beam CT in standing sedated horses.[72,73] High-resolution standing sedated CT of the equine TMJ is becoming increasingly available and can be postulated as the 'gold standard' for TMJ imaging. However, even the evaluation of equine TMJ CT images must be approached with caution, as certain CT finding, termed 'CT anatomical variation', are suspected to be incidental and may not manifest clinically.[53] These CT findings, which deviate from normal CT anatomy,[64] may be observed in some asymptomatic horses.[53] Therefore, in our accompanying publication, every effort is made to discuss the accuracy of CT in diagnosing TMJ OA in relation to histopathological findings.[74]

4.4 | Limitations

The main limitation of this study stems from the limited number of existing publications, particularly research articles on equine TMDs. This estimation supports Witte's[46] assertion that prospective clinical trials, multi-centre reports, and systematic reviews on equine TMDs are lacking due to the rarity of this disease. However, the second Witte's[46] assertion that the lack of research is due to the subtlety or ambiguity of clinical signs of TMD may lose some validity in the future, thanks to the clear summary provided in this review. The limited number of publications is further highlighted by the exclusion of 8 studies lacking full texts in English, which is one of the limitations of this systematic review. Since translations could have contributed valuable cases to the overview of this already rare equine disease, publishing in English or making authorised translations publicly available via a community preprint server would be highly beneficial.

Despite the reason for the small number of publications on this topic, it can be acknowledged, as Jørgensen et al.[15] stated, that little is known about TMD in horses, and it is often very difficult to detect and differentiate TMJ problems from other diseases. Every effort has been made to disseminate the clinical data and research findings arising from existing publications on equine TMD, thereby improving the description of TMD symptomatology in the horse. However, many case reports lack basic data in virtually every assessed category (history, clinical signs, oral examination, arthrocentesis, diagnostic imaging, laboratory tests), which is a significant limitation of this review that affects quantitative estimation. Particularly notable are the limitations in characterising TMJ dysfunction, as it is often unclear how the affected horses eat, with only two cases of primary TMJ OA explicitly stating that the horses demonstrated normal mastication.[17,38] The risk of bias due to missing data was identified as severe in all research articles included; however, in case reports, this could not be assessed using the RoB 2.0[75] or the ROBINS-I[51] tools. It is also evident that there are far more case reports included than research articles, with the latter showing high heterogeneity in the hierarchy of evidence.[49,50] Therefore, data analysis was descriptive, and a meta-analysis was not performed, which is another limitation of this systematic review.

5 | CONCLUSIONS

TMDs are rarely described in equine literature, and trauma is their most common cause. Septic TMJ arthritis is the most frequently reported TMD, followed by fractures/luxations, and then primary TMJ OA. The severity of clinical signs varies among different TMDs, ranging from mild to moderate in primary TMJ OA to moderate to severe in septic TMJ arthritis and non-arthritic TMDs. However, all TMDs are associated with some degree of TMJ dysfunction. Due to differences in causes and clinical signs, the diagnostic protocol is not always uniform. For septic TMJ arthritis, bacterial culture should be included, while for primary TMJ OA, a functional test supported by local analgesia is recommended. If joint intervention, such as arthrocentesis or surgery, occurs during diagnosis or treatment, a synovial fluid sample can be collected for biomarker assays. Regardless of the type of TMD, the diagnostic protocol should involve an exclusion process rather than inclusion, and a thorough clinical examination should always be considered, supported by oral examination and mastication assessment. In TMJ imaging diagnostics, radiography is the first choice in field practice, while CT should be considered the 'gold standard' in clinical practice.

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The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Tomasz Jasiński: Conceptualization; investigation; methodology; writing – review and editing; writing – original draft; data curation; formal analysis. **Bernard Turek:** Conceptualization; investigation; methodology; writing – original draft; writing – review and editing; validation; formal analysis. **Michał Kaczorowski:** Writing – original draft; writing – review and editing; formal analysis. **Walter Brehm:** Formal analysis; writing – original draft; writing – review and editing;

supervision. **Katarzyna Skierbiszewska:** Formal analysis; writing – original draft; writing – review and editing. **Małgorzata Domino:** Formal analysis; writing – original draft; writing – review and editing; conceptualization; methodology; investigation; funding acquisition; project administration; visualization.

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SUPPORTING INFORMATION

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