A descriptive study of feline mandibular fractures presenting to two dental referral practices in South Africa and Canada

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Research Ethics Committee 9 July 2021

LETTER OF APPROVAL

Ethics Reference No	**REC053-21**
Protocol Title	**A comparison of signalment and distribution of mandibular fractures in cats between referral practices in South Africa and Canada**
Principal Investigator	**Dr MDK Conradie**
Supervisors	**Prof G Steenkamp**

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Dedication

This project is dedicated to all the cats included in the study and the veterinarians who were involved in their care and treatment, as well as to future patients who might benefit from this research.

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This project would not have been possible without the support of my supervisors and co-workers.

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Summary

Background: Studies describing feline mandibular fracture aetiology, prevalence, distribution and patient signalment are abundant. In contrast, there is a paucity in the literature describing mandibular fracture conformation and their association with teeth.

Objectives: The aims of this study included: 1) Comparing the aetiology and signalment of feline mandibular fracture cases in two populations of cats, from a referral centre in South Africa (OVAH) and Canada (WCVDS), and 2) Describe mandibular fracture distribution, conformation and association with teeth.

Materials and Methods: The study was conducted as a retrospective descriptive case series evaluating mandibular fractures on preoperative radiographic and/or computed tomographic studies. The mandible was divided into three grouped anatomical sections (symphyseal, mandibular body, caudal mandible) comprising nine individual anatomical regions (symphyseal, parasymphyseal incisor, parasymphyseal canine, canine, premolar, molar, mandibular coronoid process, mandibular condylar process, mandibular angular process). Each region containing a fracture was recorded. In the case of a single fracture involving multiple regions, all regions were recorded as being fractured. Patient demographic data and trauma aetiology were also recorded.

Results: Fifteen patients from the OVAH with 35 fractured regions and 31 patients from the WCVDS with 49 fractured regions were included. Demographic variables were not significantly different between the two groups. The most common aetiology of mandibular fractures was unknown in both groups. The OVAH group had a higher proportion of multiple fracture cases with a significantly higher mean number of fractured regions per cat. The mandibular body was affected in most OVAH cases (60%) and the symphysis least affected in OVAH cases (40%), compared to the symphysis being affected in most WCVDS cases (64.5%) and the caudal mandible least affected in the WCVDS cases (22.6%). There were significantly more parasymphyseal canine and mandibular condylar process fracture cases in the OVAH group. Considering the overall number of fractured regions, the mandibular body represented the most fractured regions in both groups (48.6% OVAH, 42.8% WCVDS). Most of the WCVDS group were single fracture cases with symphyseal separation. All OVAH and 90.9% of the WCVDS mandibular body fractures were displaced irrespective of fracture orientation. Ninety-two percent of OVAH and 100% of WCVDS caudal mandible fractures were displaced irrespective of fracture orientation. Caudo-ventral oblique fractures of the mandibular body were most common in the OVAH group whereas caudo-lingual oblique fractures were predominant in the WCVDS group. Within the mandibular body most fractures were centred around the canine tooth in both groups, with caudo-ventral oblique fractures being most common in the OVAH group. The canine tooth represented 90.9%

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(OVAH) and 56.2% (WCVDS) of all teeth in a fracture line. Of the fractures associated with teeth, type A was most common in both groups (72.7% OVAH, 56.2% WCVDS).

Conclusion: Mandibular fracture distribution and conformation is relatively unpredictable when comparing different populations of cats. A higher proportion of multiple fracture cases with a significantly higher mean number of fractured regions per cat, as well as a significantly higher number of parasymphyseal canine and mandibular condylar process fracture cases were seen in the OVAH group compared to the WCVDS group. Most of the WCVDS group were single fracture cases with symphyseal separation. The canine tooth was predominantly involved in fracture lines in both groups, with type A fractures being most common.

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Table of Contents

Declaration II

Ethics Certificate III

Dedication IV

Acknowledgements V

Summary VI

List of Figures XI

List of Tables XIII

List of Symbols and Abbreviations XV

Chapter 1: Introduction 1

Chapter 2: Literature Review 2

2.1 Anatomy 2

2.1.1 Osteology 2

2.1.2 Feline dentition and periodontium 4

2.1.3 Neurovascular Structures 6

2.1.4 Masticatory muscle myology and mandibular biomechanical forces 7

2.2 Craniomaxillofacial soft tissue and dentoalveolar trauma 10

2.3 Prevalence/incidence and signalment of cats with maxillomandibular fractures 12

2.4 Fracture aetiology 13

2.5 Fracture location, type and number 14

2.6 Classification of mandibular fractures according to involvement of the dental structures 17

2.7 Diagnosis of maxillomandibular trauma 18

2.8 Treatment of maxillomandibular fractures 19

2.9 Conclusion drawn from the literature review 21

Chapter 3: Problem statement 22

3.1 Research questions 22

3.2 Aims and objectives of the study 22

3.3 Hypotheses 22

3.4 Benefits arising from the study 23

Chapter 4: Materials and Methods 25

4.1 Experimental design 25

4.2 Experimental procedure 25

4.2.1 Radiographic and computed tomography procedure 25

4.2.2 Clinical data and image analysis 26

4.3 Statistical analysis 31

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Chapter 5: Results 32
5.1 Study population demographics 32
5.1.1 Study population demographics according to referral centre 32
5.1.2 Study population demographics according to fracture aetiology 34
5.2 Number of fractured regions and distribution 42
5.2.1 Number of fractured regions and anatomical distribution according to referral centre 42
5.2.2 Number of fractured regions and anatomical distribution according to aetiology 46
5.2.3 Fracture laterality according to referral centre 46
5.2.4 Fracture laterality according to aetiology 47
5.3 Fracture conformation 49
5.3.1 Mandibular fracture conformation and regional anatomic distribution according to referral centre 49
5.3.2 Association of masticatory muscle biomechanical forces and relative fracture stability of oblique mandibular body fractures according to referral centre 55
5.3.3 Mandibular fracture conformation and regional anatomic distribution according to aetiology 55
5.3.4 Association of masticatory muscle biomechanical forces and relative fracture stability of oblique mandibular body fractures according to aetiology 56
5.4 Dental structure involvement of mandibular fractures 56
5.4.1 Classification of mandibular fracture involvement of dental structures according to referral centre 56
5.4.2 Classification of mandibular fracture involvement of dental structures according to aetiology 59
Chapter 6: Discussion 60
6.1 Aetiology and demographic variables 60
6.2 Single and multiple fractures 63
6.3 Open and closed fractures 64
6.4 Mandibular fracture distribution with the mandible divided into three grouped anatomical sections 65
6.5 Mandibular fracture distribution with the mandible divided into nine individual anatomical regions 66
6.6 Fracture laterality 69
6.7 Mandibular fracture conformation and regional anatomic distribution 71
6.8 Dental structure involvement of mandibular fractures 75
6.9 Study Limitations 76
Chapter 7: Conclusion 78
References 80
Annexure A 84

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The variation of mandibular fracture distribution in OVAH and WCVDS cats according to aetiology are shown in Tables 1 - 7. 84

The variation of single and multiple fracture cases according to aetiology is shown in Table 8...... 91

Annexure B........ 92

Mandibular fracture conformation and anatomical distribution in OVAH and WCVDS cats according to aetiology are shown in Tables 1 - 14........ 92

Annexure C........ 111

The number of oblique mandibular body fracture conformations and relative fracture stability according to aetiology are shown in Figures 1 - 4. 111

Annexure D 115

The involvement of specific teeth in fracture with associated fractured anatomical region and mandibular fracture conformation in OVAH and WCVDS cats according to aetiology is shown in Table 1. 115

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List of Figures

Figure 2.1: Occlusal view of feline maxillae (A) and mandibles (B) with the teeth numbered according to the modified Triadan system. Page 4

Figure 2.2: Lateral radiographic view of a feline mandible illustrating radiological rostro-caudal fracture orientation and direction of biomechanical forces acting on the mandible. Fracture line orientations are numbered: (1) caudo-dorsal, (2) dorso-ventral transverse, (3) caudo-ventral. Dorsally directed arrow indicates upward directed biomechanical forces when closing the mouth resulting in displacement of caudo-ventral fractures and compression of caudo-dorsal fractures. Caudo-ventrally directed arrow indicates downward directed biomechanical forces when opening the mouth resulting in displacement of caudo-ventral fractures and compression of caudo-dorsal fractures.
Page 9

Figure 2.3: Dorso-ventral radiographic view of a feline mandible illustrating radiological rostro-caudal mandibular fracture orientation and direction of biomechanical forces acting on the mandible. Fracture line orientations are numbered: (1) caudo-buccal, (2) bucco-lingual transverse, (3) caudo-lingual. Arrow indicates mesio-lingual directed biomechanical forces exerted when closing the mouth resulting in displacement of caudo-buccal fractures and compression of caudo-lingual fractures. Note: the mandible is a cadaver mandible used as an illustration of fracture orientation and direction of biomechanical forces only, disregard the abnormal mandibular symphysis (symphyseal separation). Page 10

Figure 2.4: Classification of mandibular fractures type A–F (I–VI) relative to root apex and periodontal ligament involvement[1]. (Figure adapted from Guzu *et al.* Mandibular body fracture repair with wire-reinforced interdental composite splint in small dogs. *Veterinary Surgery*. 2017;46: 1068 – 1077).
Page 17

Figure 4.1 A – B: Anatomical fracture location. A) Laterolateral View, B) Ventrodorsal View. 1 – Symphyseal, 2 – Parasymphyseal Incisor, 3 – Parasymphyseal Canine, 4 – Canine, 5 – Premolar, 6 – Molar, 7 – Mandibular Ramus Coronoid Process, 8 – Mandibular Ramus Condylar Process, 9 – Mandibular Ramus Angular Process. Note: the mandible is a cadaver mandible used as an illustration of anatomical fracture location only, disregard the abnormal mandibular symphysis (symphyseal separation). Page 27

Figure 5.1: Breed distribution and number of cats with mandibular fractures according to referral centre. Abbreviations: DLH, domestic longhair; DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services. Page 32

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Figure 5.2: Age (years) and sex distribution of cats with mandibular fractures according to referral centre. Purple bar indicates male and female cat overlap. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services. Page 33

Figure 5.3: Heat map demonstrating the overall case percentage of OVAH and WCVDS cats (cases) sustaining a fracture in each region. (A) The mandible shown from a lateral perspective with the symphysis purposefully enlarged to be visible on the heat map. (B) The mandible shown from a dorsal perspective with the symphysis purposefully widened in order to clearly show the symphyseal area. The detail of the caudal mandible is not accurate due to overlapping structures. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.
Page 44

Figure 5.4: Heat map demonstrating the percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats. (A) The mandible shown from a lateral perspective with the symphysis purposefully enlarged to be visible on the heat map. (B) The mandible shown from a dorsal perspective with the symphysis purposefully widened in order to clearly show the symphyseal area. The detail of the caudal mandible is not accurate due to overlapping structures. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.
Page 45

Figure 5.5: A stacked bar graph showing the distribution of unilateral, bilateral and symphyseal only mandibular fracture cases (case percentage) according to referral centre. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.
Page 47

Figure 5.6: Bar graph showing the number of oblique mandibular body fracture conformations and relative fracture stability according to referral centre (OVAH: blue; WCVDS: orange) . Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services. Page 55

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List of Tables

Table 2.1: Osteology of the feline skull divided into bones forming the cranium and the maxillofacial region[2]. Page 2

Table 2.2: Normal root number variations of feline permanent dentition[3-5]. Page 4

Table 2.3: Feline masticatory muscles' origin, insertion, and functional biomechanical forces[5-9]. Page 8

Table 2.4: Categories and percentages of feline mandibular fracture aetiology. Page 14

Table 2.5: A summary of mandibular fracture distribution in cats suffering head trauma. Page 15

Table 4.1: Image analysis guide of feline mandibular fracture classification and description. Page 28

Table 5.1: Weight distribution (kg) of cats with mandibular fractures according to referral centre. Page 34

Table 5.2: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the unknown aetiology category. Page 35

Table 5.3: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the motor vehicle accident category. Page 36

Table 5.4: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the falling from a height category. Page 37

Table 5.5: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the animal encounter category. Page 38

Table 5.6: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the human encounter category. Page 39

Table 5.7: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the iatrogenic category. Page 40

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Table 5.8: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the pathological category. Page 41

Table 5.9: Number (percent) of fractured anatomical regions in OVAH and WCVDS cats according to aetiology. Page 46

Table 5.10: Laterality distribution (number, percent of cases) of OVAH and WCVDS unilateral, bilateral and symphyseal only mandibular fracture cases according to aetiology. Page 48

Table 5.11: Mandibular fracture conformation (number, percentage) and anatomical distribution according to referral centre with the mandible divided into three grouped anatomical sections. Page 50

Table 5.12: Mandibular fracture conformation (number, percentage) and anatomical distribution according to referral centre with the mandible divided into nine individual anatomical regions. Page 52

Table 5.13: Dental fracture type (A – F) of the OVAH according to tooth involvement, region affected and fracture conformation. Page 57

Table 5.14: Dental fracture type (A – F) of the WCVDS according to tooth involvement, region affected and fracture conformation. Page 58

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List of Symbols and Abbreviations

CT	-	Computed tomography
HRS	-	High-rise syndrome
kg	-	Kilogram
M1	-	First molar tooth
MVA	-	Motor vehicle accident
Onderstepoort Veterinary Academic Hospital	-	OVAH
PDL	-	Periodontal ligament
Percentage coefficient of variation	-	%CV
PM1	-	First premolar tooth
PM2	-	Second premolar tooth
PM3	-	Third premolar tooth
PM4	-	Fourth premolar tooth
WCVDS	-	West Coast Veterinary Dental Services Ltd
°	-	Degrees

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Chapter 1: Introduction

Previous studies have reported the prevalence of feline mandibular fractures (11.4 – 23.1%[10-12]), patient signalment, aetiology, and distribution of fractures[10,13,14]. Motor vehicle accidents are a major cause of mandibular fractures, whilst falling from a height has been reported with variable predominance and animal altercations reported the least common[10,13-15]. Symphyseal separation has been described as being common, whilst mandibular body and caudal mandible fractures occur with variable prevalence[10,14]. Feline mandibular fracture classification has been broadly reported as single, multiple, unilateral, bilateral, open, closed, single fracture line or comminuted[10,13-15]. Studies in dogs have reported caudo-ventral oblique and caudo-lingual oblique fractures as common mandibular fractures, associated with the mandibular first molar tooth being included in fractures[7,16]. Of the fractures associated with teeth, type A fractures have been most commonly described in humans and dogs, and reported to be specifically associated with the first mandibular molar tooth in dogs[1,7,17-19]. To the best of the author's knowledge there is currently no reference providing detailed descriptions of feline mandibular fracture conformations, or reports of the association of teeth within mandibular fractures, and the conformation of mandibular fractures associated with teeth within fracture lines.

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Chapter 2: Literature Review

2.1 Anatomy

2.1.1 Osteology

The osteology of the skull is divided into bones forming the cranium, which surrounds the brain, and bones forming the maxillofacial region, which encompasses the initial sections of the respiratory and digestive systems (Table 2.1)[2,8].

Table 2.1: Osteology of the feline skull divided into bones forming the cranium and the maxillofacial region[2].

Bones of the Cranium	**Bones of the maxillofacial region**
Paired:	Paired:
1. Exoccipital	1. Incisive
2. Parietal	2. Nasal
3. Frontal	3. Maxilla
4. Temporal	4. Dorsal concha
Unpaired:	5. Ventral concha
1. Supraoccipital	6. Zygomatic
2. Interparietal	7. Palatine
3. Basioccipital	8. Lacrimal
4. Basisphenoid	9. Pterygoid
5. Presphenoid	10. Mandible
6. Ethmoid	Unpaired:
	1. Vomer

The upper jaw consists of the paired maxilla and incisive bones[2,5,8]. The incisive bone is comprised of a body with three processes, one of which is the alveolar process which contains the incisors[2]. The maxillary bone is comprised of a body with four processes, of which the alveolar process bears all the teeth (canines, premolars and molars)[2,3,8]. The space and associated maxillary margin between consecutive teeth is termed the interdental space and interalveolar margin respectively, whilst the bony regions between consecutive teeth and between roots of individual teeth are termed interalveolar and interradicular septa respectively[2,5]. The infraorbital canal, bearing important neurovascular structures, is situated dorsal to the maxillary fourth premolar (PM4) and first molar (M1) teeth[2,3,8]; it extends between the infraorbital foramen rostrally, situated approximately 1 cm dorsal to the maxillary third

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premolar tooth (PM3), and the maxillary foramen caudally, situated immediately medial to the zygomatic arch at the level of the rostral pterygopalatine fossa[2,3,8].

The lower jaw consists of the paired mandibles which are divided into a horizontal body, containing all the mandibular teeth along the alveolar margin, and an edentulous caudal vertical ramus[2,3,5,8]. The body of the mandible is comprised of an incisive part, housing the incisors and canines, and a molar part, housing the premolars and molars[2,3,5,8]. The mandibular occlusal zone is narrower than the maxillary occlusal zone due to the anisognathic design of the feline jaw[5]. Similar to the maxilla, the spaces between teeth are termed interdental spaces with the associated interalveolar margin and intervening interalveolar and interradicular bony septa[2,5]. The incisive parts of the left and right mandibles are united at the symphysis, a fibrocartilaginous joint (*synchondrosis intermandibularis*)[2,3,5,8]. The mandibular body continues caudally as the vertical ramus with three processes, namely the condylar, coronoid and angular processes[2,5,8]. The condylar process is an articular process consisting of two parts, namely the condylar process head and condylar process neck[20]. The head of the condylar process articulates with the mandibular fossa and retroarticular process of the squamous temporal bone forming the temporomandibular joint, whilst the coronoid and angular processes are important masticatory muscle insertions sites[2,3,8]. The mandibular canal, containing important neurovascular structures, is situated ventro-laterally within the mandibular body and extends from the mandibular foramen, located on the caudo-medial aspect of the mandibular ramus between the last molar tooth and the angular process, to the rostral mental foramina, which open on the left and right rostro-lateral aspects of the mandible ventral to the first and second incisor teeth's alveoli[2,5,20,21]. Middle and caudal mental foramina are also present, which open at the level of the third and fourth premolars[2,5,21].

Congenital feline facial asymmetry is rare with most cases of asymmetry ascribed due to trauma with associated maxillofacial fractures[22]. A study of feline mandibular morphology in a population of mesaticephalic domestic shorthair cats revealed a high degree of mandibular morphological symmetry with minimal morphometric variation, as well as a strong positive correlation between mandibular height, length and width[22]. The left and right mandibular body length ratios had the lowest percentage coefficient of variation (%CV) at 1.05%, which represents a 0.5mm difference, whilst the width had the highest %CV at 3.22%, representing a 0.9mm difference[22]. The %CV for the ratios associated with mandibular shape, namely lateral ramus inclination angle ratio and axial ramus inclination angle ratio, illustrated a similarly low level of asymmetry calculated as a difference of 2.5° and 1.8°, respectively[22]. A similar low level of mandibular asymmetry is expected between individuals of other breeds, however, a higher level of asymmetry is most probable between breeds with different skull shapes, such as brachycephalic and dolichocephalic[22].

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2.1.2 Feline dentition and periodontium

Cats have 26 deciduous and 30 permanent teeth which are numbered according to the modified Triadan system (Fig. 2.1)[3,5]. The deciduous and permanent dental formulas are 3/3 i, 1/1 c, 3/2 pm and 3/3 I, 1/1 C, 3/2 PM, 1/1 M respectively[3,5]. The permanent teeth vary in root number due to normal anatomical variations (Table 2.2)[3,4]. The mandibular teeth occupy 45 – 70% of the mandible with variable extension of the roots to the dorsal aspect of the mandibular canal[20,23,24]. The mesial root of mandibular first molar is three times the mesial to distal diameter of the distal root[5].

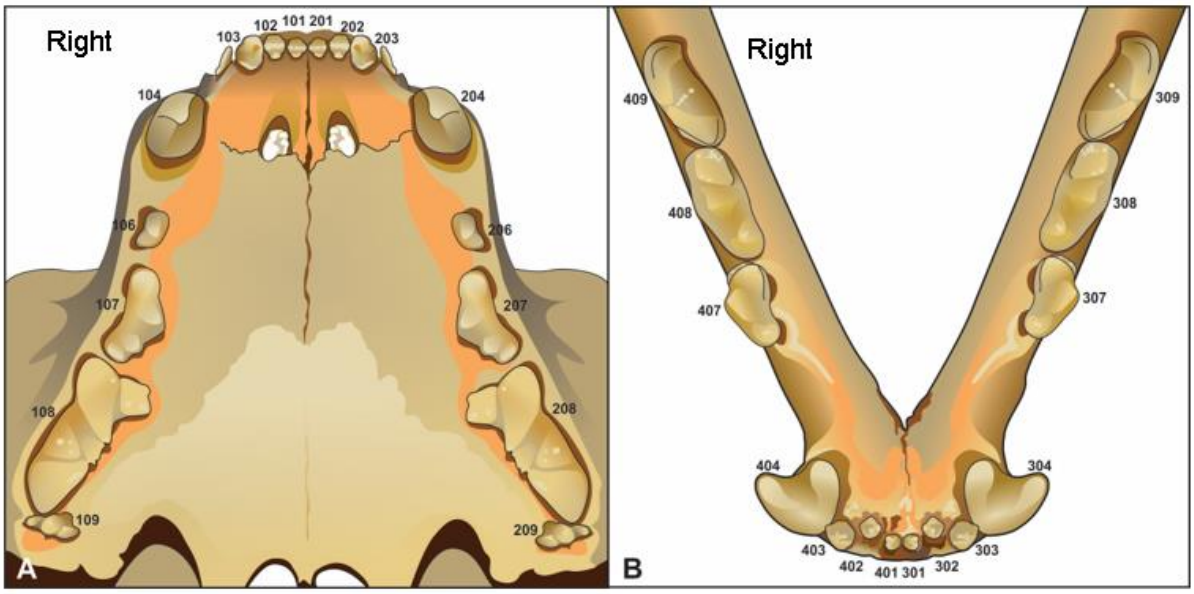

Figure 2.1: Occlusal view of feline maxillae (A) and mandibles (B) with the teeth numbered according to the modified Triadan system.

Table 2.2: Normal root number variations of feline permanent dentition[3-5].

Maxilla	Mandible
Incisors and canines – single roots	Incisors and canines – single roots
PM1 – absent PM2 – single or two roots (separated or fused) PM3 – two or three[4] roots PM4 – three roots	PM1 – absent PM2 – absent PM3 – two roots PM4 – two roots
M1 – single or two roots (separated or fused)	M1 – two roots

Abbreviations: PM1, first premolar tooth; PM2, second premolar tooth; PM3, third premolar tooth; PM4, fourth premolar tooth; M1, first molar tooth.

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The dentition of the feline is classified as heterodont, with secodont and bunodont teeth, as well as brachydont crowns[5]. Tooth development is classified as diphyodont with a set of deciduous teeth replaced by permanent teeth (successional incisor, canine and premolar teeth)[5]. The molar teeth are classified as non-successional permanent teeth with no preceding deciduous counterparts[5].

The tooth is divided into the crown and the root; both the crown and root are mainly composed of dentin (70% organic and 30% inorganic)[5]. The dentin can be classified as primary (dentin present when the tooth erupts), secondary (dentin formed as the tooth matures, making the root canal narrower over time) and tertiary dentin that can be further classified as reparative (produced by reserve mesenchymal cells that differentiate into odontoblasts) and reactionary dentin (produced by already present odontoblasts)[5]. Furthermore, the crown of the tooth is covered by a thin layer of enamel (0.1- 0.3mm thickness), this structure is predominantly formed by inorganic material (96%), mainly hydroxyapatite crystals, and a very small percentage of organic material (4%)[5]; this composition makes enamel the hardest structure in the body[5]. The root of the tooth is covered by cementum and extends to the cementoenamel junction which is located at the neck/cervical region of the tooth[3,5]. The pulp cavity, which contains neurovascular pulp tissue, consists of the pulp chamber and root canals within the crown and roots, respectively[5]. The pulp tissues are connected to peri-apical tissues through foramina at the root apex (apical delta/ramifications), as well as non-apical ramifications at the furcation and other regions of the root which serve as neurovascular channels[3].

The teeth are secured in the alveoli by the periodontal ligament and the gingival attachment[3,5,25]. The periodontal ligament runs from the cementum covering the root to the alveolar bone[3,5,25]. Together, the gingiva, cementum, periodontal ligament and the alveolar bone forms the periodontium[3,5,25]. Alveolodental Sharpey's fibres from the periodontal ligament attaches the root cementum to the cribriform plate (*lamina dura*) of the alveolar bone forming a fibrous joint (*articulatio dentoalveolaris*) also called a gomphosis joint[3,5,25]. In addition to anchoring the tooth to the alveolar bone, the periodontium performs a nervous sensory function, as well as protecting and cleansing the tooth[5]. The alveolar mucosa lines the maxillary and mandibular cortical bone[3,5]. Where it extends into the cheek and lip areas it is known as the labial and buccal mucosae[3,5]. From the mucogingival junction it becomes attached to the underlying bone and is referred to as gingiva[3,5]. Apart from this attached gingiva, there is a small coronal band of gingiva that is unattached and referred to as free gingiva[3,5]. The periodontal ligament provides a supporting tissue framework of circular gingival fibres for the gingiva around the teeth and provides dentogingival fibres which connect the cementum to the free and attached gingiva[3,5]. The free gingiva is present around the teeth, with no attachments to the alveolar bone, and projecting in a coronal direction from the attached gingiva[3,5]. Through the periodontal ligament, the attached gingiva is connected to the coronal periosteum of the alveolar bone via alveologingival fibres and to the cervical region of the teeth[5].

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2.1.3 Neurovascular Structures

The main arterial supply to the head is through the common carotid artery which splits into the external and internal carotid arteries[5,8,26]. The internal carotid arterial blood supply is insignificant in the cat[5,8]. The maxillary artery is the main branch from the external carotid artery, and is divided into 3 parts, the mandibular, pterygoid and pterygopalatine portion[26]. The mandibular portion of the maxillary artery courses along the caudal aspect of the mandibular ramus, following the ventral margin of the retroarticular process, and continues along the caudomedial aspect of the temporomandibular joint between the medial aspect of the angular process and the rostro-lateral aspect of the tympanic bulla[5,26-28]. The alar canal is not present in the feline skull and does not form part of the maxillary artery pathway[8]. Before reaching the wing of the basisphenoid bone, the main artery gives a branch to the temporomandibular joint, as well as branching into the inferior alveolar artery[26]. The inferior alveolar artery enters the mandibular canal, via the mandibular foramen, along with the satellite vein, the inferior alveolar vein[5]. Within the canal it runs along the ventral surface and exits via the rostral, middle and caudal mental foramina[3]. The aforementioned artery supplies tributaries to the mandibular teeth (through apical foramina), the mandible and mandibular soft tissues[26].

The pterygoid and pterygopalatine portions of the maxillary artery extends across the pterygopalatine fossa, coursing lateral to the lateral pterygoid muscle[26]. The infraorbital artery is the rostral continuation of the maxillary artery across the medial pterygoid muscle[26]. It enters the infraorbital canal through the maxillary foramen and exits via the infraorbital foramen[2,3,26]. The satellite infraorbital vein also travels within the infraorbital canal[26]. Caudal, middle and rostral dorsal alveolar branches are given off by the infraorbital artery which supplies the dental structures[26]. Vascular access to the maxillary premolars is achieved through alveolar canals connecting the infraorbital canal to the apical alveolar foramina[2]. Additional vascular supply to the maxillary premolar, as well as the canine and incisor teeth, are achieved through the incisivomaxillary canal[2,26]. The incisivomaxillary canal courses from the medial wall of the infraorbital canal, at the level of the infraorbital foramen, dorsal to the canine alveolus, into the incisive bone[2].

The maxillary nerve, a branch of the trigeminal nerve (cranial nerve V), exits the cranial cavity via the foramen rotundum in the sphenoid bone and courses rostrally over the dorsal surface of the medial pterygoid muscle[8]; within the pterygopalatine fossa, the maxillary nerve continues as the sensory infraorbital nerve coursing through the maxillary foramen into the infraorbital canal and exiting the infraorbital foramen[3,29]. The teeth are innervated through alveolar channels by the caudal, middle and rostral superior alveolar branches, with the latter branches coursing through the incisivomaxillary canal[2,29].

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The mandibular nerve, a branch of the trigeminal nerve (cranial nerve V), leaves the cranium through the oval foramen and branches into motor nerves innervating the muscles of mastication, as well as sensory innervation to the teeth, cheeks and lips of the mandible[29]. The inferior alveolar nerve branches from the mandibular nerve on the lateral aspect of the medial pterygoid muscles, and enters the mandibular canal via the mandibular foramen[26,29]. The inferior alveolar nerve lies dorsolateral in the mandibular canal and supplies caudal, middle and rostral alveolar nerves to the teeth of the mandible[29]. It terminates rostrally as the mental nerves, via the mental foramina, which supply the rostral mandibular soft tissues[26,29].

2.1.4 Masticatory muscle myology and mandibular biomechanical forces

Understanding the biomechanical forces exerted by the muscles of mastication on the mandible are vital to understanding mandibular fracture fragment deviation. The myology of the masticatory muscles is tabled below (Table 2.3). Apart from the caudal belly of the digastric muscle innervated by the facial nerve, all of the masticatory muscles (including the rostral belly of the digastric muscle) are innervated by the mandibular branch of the trigeminal nerve[5,6]. Whilst closing the mouth, the dorsally directed biomechanical forces generated by the masseter, temporal, medial and lateral pterygoid muscles lever the caudal mandible upwards and the forces generated by the digastricus muscle pulls the mandibular body in a mesio-lingual direction[5-7]. The medial pterygoid muscle also generates a dorso-lingual pulling force on the mandible. Whilst closing the mouth, the digastric muscle exerts a downward directed biomechanical force on the mandibular body[5-7]. Intermandibular muscles forming the floor of the oral cavity (genioglossus, geniohyoid, mylohyoid) generate bucco-lingual distractive forces which are directed in any direction[5-7]. Variably directed distractive forces are also generated and exerted on the mandible by movement of the tongue.

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Table 2.3: Feline masticatory muscles' origin, insertion, and functional biomechanical forces[5-9].

Muscle	**Origin, Insertion**	**Functional biomechanical forces**
Masseter	Origin: ventral surface of zygomatic arch Insertion: *Fossa masseterica* and lateral surface of coronoid process	Closing the mouth: upward directed force on caudal mandible
Temporal	Origin: Parietal, frontal and temporal bones in *Fossa temporalis* Insertion: Coronoid process (medial and lateral surfaces)	Closing the mouth: upward directed force on caudal mandible
Medial Pterygoid	Origin: Perpendicular palatine bone, wing of presphenoid and pterygoid bones in *Fossa pterygopalatine* Insertion: Angular process	Closing the mouth: upward directed force on caudal mandible
Lateral Pterygoid	Origin: Perpendicular palatine bone and wing of presphenoid bone Insertion: *Fovea pterygoidea* on medial condylar process	Closing the mouth: upward directed force on caudal mandible
Digastricus	Origin: Paracondylar process Insertion: Caudo-ventral mandible	Opening the mouth: downward directed force on mandibular body Closing the mouth: mesio-lingual directed force on mandible body

Radiological mandibular fracture orientation is described in a rostro-caudal direction (Fig. 2.2 and 2.3)[7]. Accordingly, dorso-ventral fracture orientation as seen on lateral radiographs or sagittal plane computed tomography (CT) includes caudo-ventral, caudo-dorsal and dorsal-ventral transverse fractures (Fig. 2.2)[7]. Given the aforementioned dorsally directed biomechanical force exerted on the caudal mandible whilst closing the mouth as well as the caudo-ventrally directed biomechanical force exerted on the mandibular body whilst opening the mouth, caudo-ventrally orientated fractures of the mandibular body

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are predisposed to significant distraction and displacement of fracture fragments, and therefore, considered relatively unstable (Fig. 2.2)[5,7]. Conversely, caudo-dorsally orientated fractures of the mandibular body are less predisposed to fracture fragment distraction and displacement due to compressive biomechanical forces and are hence considered, relatively stable (Fig. 2.2)[5,7]. Fractures orientated along the long axis of the mandibular body experience variable dorsal distraction[5,7]. Radiological bucco-lingual fracture orientation, as seen on dorso-ventral radiographs or dorsal plane CT includes caudo-lingual, caudo-buccal and bucco-lingual transverse fractures (Fig. 2.3)[5,7]. Caudo-lingual fractures of the mandibular body are not predisposed to significant fracture distraction and displacement given aforementioned compressive mesio-lingual biomechanical forces exerted on the mandibular body when closing the mouth (Fig. 2.3)[5,7]. Conversely, caudo-buccal fractures of the mandibular body are predisposed to distraction and displacement secondary to aforementioned mesio-lingual forces exerted on the mandibular body when closing the mouth (Fig. 2.3)[5,7].

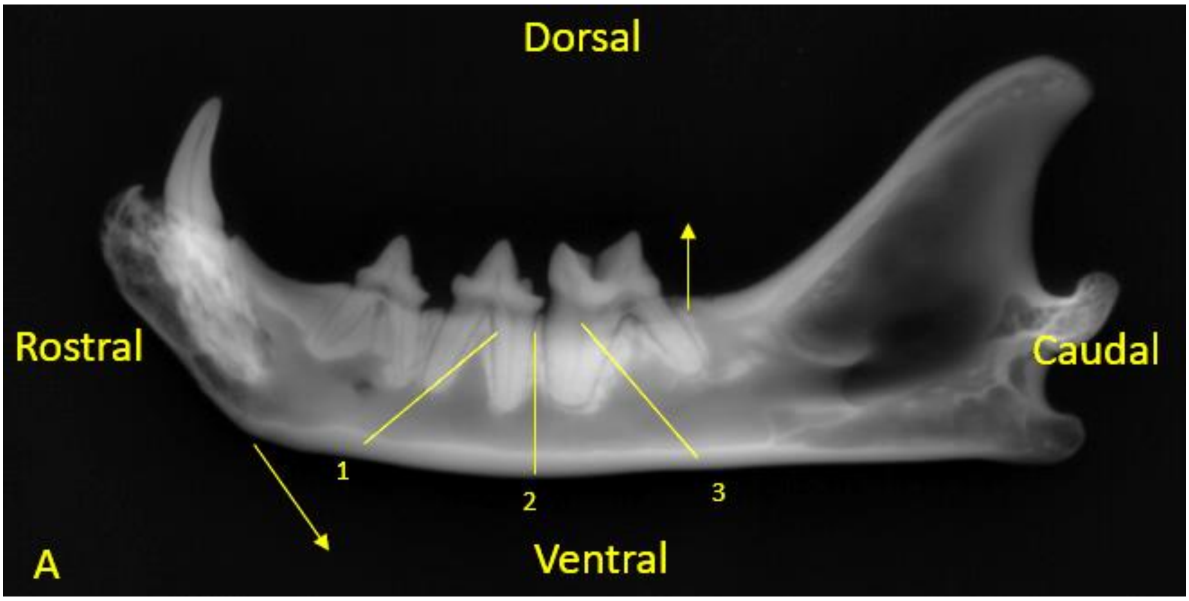

Figure 2.2: Lateral radiographic view of a feline mandible illustrating radiological rostro-caudal fracture orientation and direction of biomechanical forces acting on the mandible. Fracture line orientations are numbered: (1) caudo-dorsal, (2) dorso-ventral transverse, (3) caudo-ventral. Dorsally directed arrow indicates upward directed biomechanical forces when closing the mouth resulting in displacement of caudo-ventral fractures and compression of caudo-dorsal fractures. Caudo-ventrally directed arrow indicates downward directed biomechanical forces when opening the mouth resulting in displacement of caudo-ventral fractures and compression of caudo-dorsal fractures.

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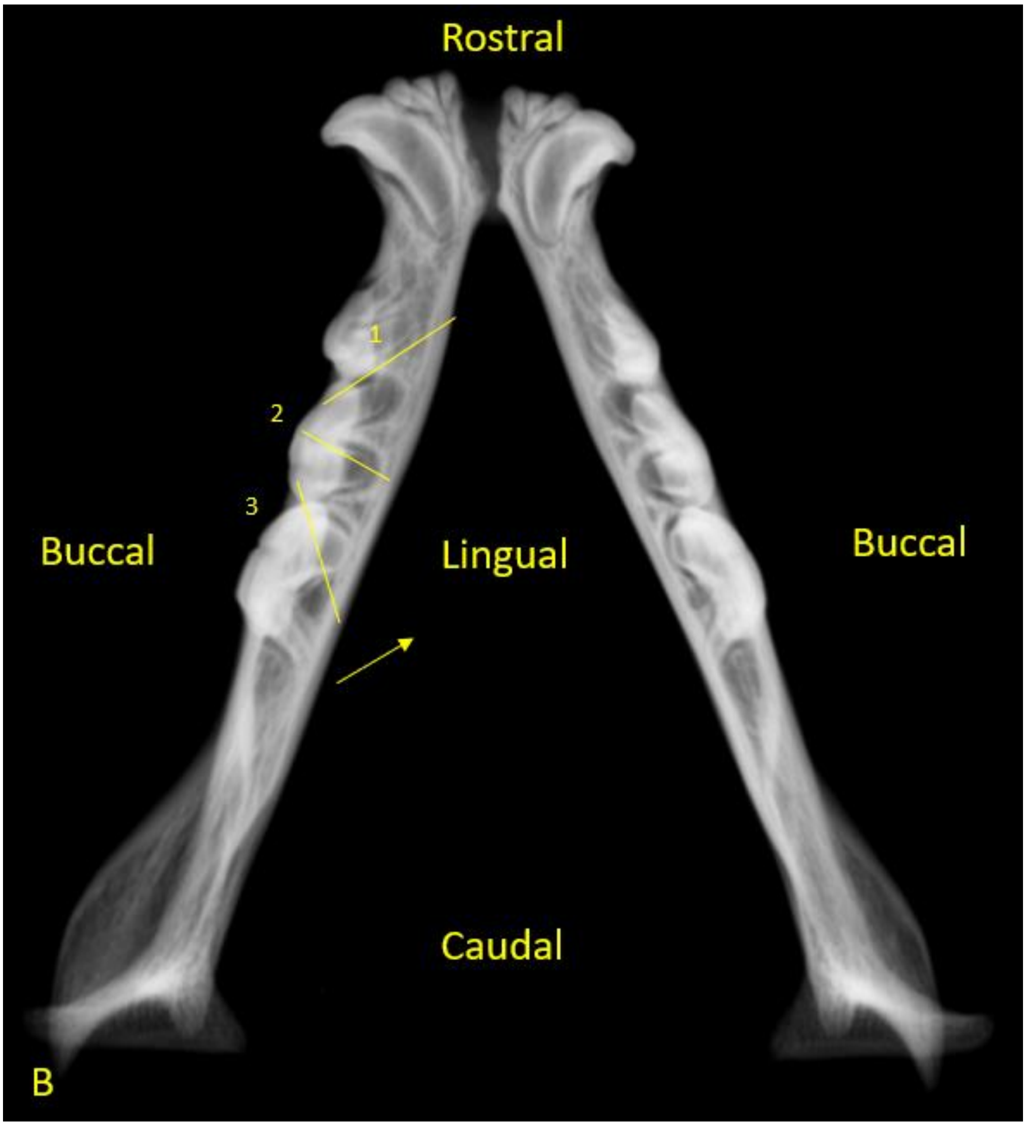

Figure 2.3: Dorso-ventral radiographic view of a feline mandible illustrating radiological rostro-caudal mandibular fracture orientation and direction of biomechanical forces acting on the mandible. Fracture line orientations are numbered: (1) caudo-buccal, (2) bucco-lingual transverse, (3) caudo-lingual. Arrow indicates mesio-lingual directed biomechanical forces exerted when closing the mouth resulting in displacement of caudo-buccal fractures and compression of caudo-lingual fractures. Note: the mandible is a cadaver mandible used as an illustration of fracture orientation and direction of biomechanical forces only, disregard the abnormal mandibular symphysis (symphyseal separation).

2.2 Craniomaxillofacial soft tissue and dentoalveolar trauma

Apart from mandibular fractures, craniomaxillofacial trauma often results in concomitant orofacial injuries including facial soft tissue injuries, oral soft tissue injuries, dental alveolar trauma and ocular injury (possibly manifesting as Horner's Syndrome or ocular muscle trauma)[14,30,31]. The causes of craniomaxillofacial soft tissue and dentoalveolar trauma results from the same causes as those

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associated with mandibular fractures, namely animal encounter (fights or play behaviour), motor vehicle accidents (MVA), falling from heights and malicious human encounter[31]. A statistically significant association between dentoalveolar injuries and trauma aetiology has been shown, specifically in MVA and when being hit by an object[32]. Dental alveolar trauma is described as traumatic injury to the tooth and supporting structures with categorisation according to displacement and mobility of the tooth, involvement of specific regions of the tooth, involvement of surrounding structures and type of pathology[33].

- Tooth displacement out of the alveolus includes[31,33]:

i. Tooth avulsion – tooth completely displaced out of the alveolus

- Tooth displacement within the alveolus with mobility includes[31,33]:

i. Extrusive luxation – tooth partially dislocated out of the alveolus in an axial direction
ii. Root fracture – fracture confined to root of the tooth
iii. Alveolar fracture – fracture involving a portion of the alveolar process typically containing multiple teeth

- Tooth displacement within the alveolus with no mobility includes[31,33]:

i. Intrusive luxation – tooth partially dislocated into the alveolus in an axial direction
ii. Lateral luxation – described as luxation of the tooth within the alveolus in any direction other than axially

- No tooth displacement with loosening includes[31,33]:

i. Subluxation – injury to the dentoalveolar joint and periodontal ligament with tooth remaining in normal position

- No tooth displacement without loosening includes[31,33]:

i. Pulp concussion – traumatic pulp haemorrhage and pulpitis
ii. Uncomplicated crown fracture (enamel-dentin) – fracture line involving the enamel and dentin
iii. Complicated crown fracture (enamel-dentin-pulp) – fracture line extending from the enamel to the pulp, and crown root fracture, described as a fracture line involving the crown and the root

Note – the former two fractures occur commonly due to the very thin enamel layer, measuring only 0.1 mm in certain regions of feline teeth as well as the small distance between the enamel surface and the pulp of feline canine teeth

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The prevalence of dental trauma due to high-rise syndrome (HRS) varies from 1–17%[30,34,35] to 71.4%[30] of cats. Tooth fracture prevalence in HRS studies also varies, however with a lower range, as seen in 0.8%[35], 5.6%[34] and 16.1%[30] of cats with maxillofacial trauma. Of the dental fractures, the mandibular canine teeth are most commonly fractured, the maxillary canine teeth second most common, and maxillary and mandibular fourth premolars the third most common teeth to be fractured[30]. Another study investigating the prevalence of dentoalveolar injuries in cats and dogs with maxillofacial fractures reported 72.1%[32] of patients sustaining traumatic dentoalveolar injuries, with the mandibular teeth being most commonly affected. The maxillary and mandibular canine teeth have also been reported to being most commonly injured[36]. The canine teeth of the cat are predisposed to trauma due to their relatively exposed position while being used in defence and catching of prey[30-32,36]. Trauma may result in periodontal soft tissue inflammation, oedema, vascular stasis and ischaemia with resultant compromise of the pulp and tooth viability[18]. Untreated dentoalveolar trauma might result in apical periodontitis, pulp necrosis and loss of the affected tooth[30,31].

2.3 Prevalence/incidence and signalment of cats with maxillomandibular fractures

Feline mandibular fractures are relatively common representing 11.4–23.1%[10-12] of all feline fractures. Craniomaxillofacial fractures in cats are also common due to head trauma, with one study of 45 cats suffering head trauma reporting 80%[14] cats with craniomaxillofacial fractures (mandibular fractures were present in 86.7%[14] of cats). Reported weight and breed predispositions in cats with mandibular fractures are lacking, with the former most likely due to the relatively similar size of most feline breeds. However, a study by Tundo *et al*. (2019) in 45 cats with maxillofacial fractures included 86.7% domestic shorthair cats.

Even though not statistically significant, males are mildly to moderately over-represented in studies of cats with mandibular and temporomandibular fractures due to all causes (MVA, falling from a height, other trauma)[10,13-15,37]. Interestingly, varying male to female ratios are reported in studies when only mandibular fractures secondary to HRS are included, seen as mild to moderate male over-representation, equal numbers of males and females, as well as mild female over-representation[30,34,35,38,39].

The predominant sterilisation status of cats with mandibular fractures varies greatly between studies, however, the age group is consistently reported as a broad, young to young adult age range[10,13-15,30,34,39]. Cats with mandibular fractures secondary to all aforementioned causes are commonly sterilised males and females less than 5 years of age[14], intact males and females aged 2 years or less[13], as well as intact males and sterilised females aged less than 2.5 years[15]. Similar varying data is reported in studies only

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including cats with mandibular fractures secondary to HRS, seen as either mainly sterilised males and females aged less than 2 years[30], majority intact males and females aged less than 3 years[39], as well as equal numbers of intact and sterilised males and females[34].

It is hypothesised that younger animals are over-represented due to inexperience regarding motor vehicles, heights, dangerous situations, as well as reduced bone density predisposing to fractures[10,11,16]. Some authors hypothesize that male cats with mandibular fractures are over-represented due to roaming, territorial and sexual activity; however, due to the inconsistent presentation of majority intact to neutered/sterilised cats, especially seen in HRS, other authors argue that sexual influence is not a factor influencing gender predisposition[10,11,16,30].

2.4 Fracture aetiology

Motor vehicle accidents have consistently been reported as a major cause of feline mandibular fractures (37.5%[15], 75.5%[14] of cases) and temporomandibular joint injuries (30.5%[13], 32.9%[37] of cases), whilst falling from a height has been reported with variable predominance (2.2%[14], 8.9%[37], 48.8%[13] and 62.5%[15] of cases), and animal fights reported in relatively low percentages of cases (1.2%[13], 4.4%[14] and 16.5%[37]) (Table 2.4). Isolated mandibular fractures such as condylar process fractures are caused most commonly by falling from a height, whilst MVA most commonly result in complex multiple fractures[13]. Feline HRS is defined by some authors as injuries sustained when a cat falls two stories or more, however, other authors include injuries of cats having fallen shorter distances, such as one story or out of a tree, as significant trauma has been noted with shorter distance falls[30,35]. The occurrence of feline HRS is a unique phenomenon due to the ability of cats to orientate the body through gyroscopic turns into a "limbs extended downward" position during a free fall landing[30,34]. The force of impact is first distributed throughout the limbs to the thorax and abdomen, and lastly to the protected head with the chin impacting the ground[30,34,39]. High-rise syndrome has been cited as the most significant traumatic event resulting in symphyseal separation, as well as traumatic temporomandibular joint lesions (condylar process and mandibular fossa fractures, luxations)[10,13]. However, other studies have reported the prevalence of symphyseal separation secondary to HRS being as low as 2.9–10%[30,34,35]. Other maxillomandibular fractures and injuries as a result of HRS are also reported in studies with relatively low prevalence (3–17 %[38,39]), including midline palatine fractures (20.5%[30]), mandibular fractures (9%[39]) and temporomandibular joint subluxations (1%[34]).

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Table 2.4: Categories and percentages of feline mandibular fracture aetiology.

Author	Mandible Fracture Aetiology
Cetinkaya[13]	• Falling – 48% (40/82) • MVA – 30% (25/82) • Kicked – 1/82 (1.2%) • Cat fight – 1/82 (1.2%) • Unknown – 11/82 (13.5%)
Cetinkaya *et al*[15]	• Falling – 62.5% (10/16) • MVA – 37.5% (6/16)
Mestrinho et al[37]	• MVA – 32.9% (26/79) • Unknown – 31.6% (25/79) • Animal interaction – 16.5% (13/79) • External sharp or blunt force – 10.1% (8/79) • Falling – 8.9% (7/79)
Tundo *et al*[14]	• MVA – 75.5% (34/45) • Fights – 4.4% (2/45) • Falling – 2.2% (1/45) • Inanimate object – 2.2% (1/45) • Unknown – 15.5% (7/45)
Umphlet *et al*[10]	• MVA – 53% (33/62) • Fights and Falls – 29% (18/62) • Unknown – 18% (11/62)

Abbreviations: MVA, motor vehicle accident.

2.5 Fracture location, type and number

Symphyseal separation is the most common mandibular trauma in cats hypothesised due to the mandibular symphysis representing a weak point in the mandible, reported as 73%[10] of mandibular fractures, and seen in 64%[14] of cats with craniomaxillofacial injuries (Table 2.5). An association between symphyseal separation and/or parasymphyseal fractures has been reported, with the chance of another fracture in the mandible and skull being 84.6%[14] and 73.1%[14], respectively. The pattern of mandibular fractures has been described as being unpredictable, which is highlighted by studies reporting mandibular body fractures being more common with a low number of caudal mandible fractures, whilst other report caudal mandible fractures being more common than mandibular body fractures[10,14]. A significantly reduced mandibular to first molar height ratio over the distal root of the first molar in small dogs has been described, which has been regarded as a weak point, predisposing

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the molar region to fractures[23]. The "weak point" is hypothesised based on the larger molar tooth being embedded in a comparatively smaller amount of bone with a larger amount of supporting soft tissues (periodontal ligament)[16,23]. To the best of the authors knowledge, a similar association regarding feline mandibular fractures has not been discussed in the literature.

Table 2.5: A summary of mandibular fracture distribution in cats suffering head trauma.

Author	**Fracture Distribution**
Tundo *et al*[14]	• Mandibular Symphysis – 64% (25/39) • Mandibular Body – 38.5% (15/39) • Mandibular Condyle – 56.4% (22/39) • Mandibular Ramus – 43.6% (17/39)
Umphlet *et al*[10]	• Mandibular Symphysis – 73% (55/75) • Mandibular Body – 16% (12/75) • Mandibular Condyle – 6.7% (5/75) • Mandibular Coronoid Process – 4% (3/75)

Feline coronoid process and temporomandibular joint fracture prevalence differ between studies from uncommon to common, with some authors citing the protection afforded by the overlying masseter muscle and the zygomatic arch as an explanation for a lower occurrence[10,13,14,37]. Temporomandibular joint fractures are the most common temporomandibular joint disorder in cats, with fractures of the mandibular head of the condylar process noted most commonly, and mandibular fossa fractures least commonly[13,37,40]. Condylar process fractures have been reported in isolation, however, more commonly occur in association with other fractures such symphyseal separation, mandibular body and ramus fractures, hard palate and zygomatic arch fractures[10,13,41]. Intra-articular temporomandibular joint fractures involving the mandibular fossa occur mostly in conjunction with other intra-articular temporomandibular joint or maxillofacial fractures, and rarely in isolation[13]. Similarly, intra-articular temporomandibular joint fractures are reported as being significantly associated with the presence of temporal bone fractures[37]. Temporomandibular joint ankylosis is a rare to uncommon, unilateral or bilateral short-term complication of temporomandibular joint trauma, occurring within a few weeks post trauma or surgery[13,40,42-45]. Ankylosis is categorised as either affecting the intra-articular structures (true ankylosis), extra-articular structures (false or pseudo-ankylosis) or both[13,40,42-45]. Other less common causes of temporomandibular joint ankylosis in cats include intra-articular haemorrhage with subsequent osteoarthrosis, lesions of adjacent muscles (myositis, fibrosis), infection (osteomyelitis, retrobulbar disease) and neoplasia (especially osteoma in the cats)[5,40,42,43,46,47]. Common traumatic lesions resulting in temporomandibular joint ankylosis include fractures involving the mandibular head

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of the condylar process, coronoid process, retroarticular process, mandibular fossa and zygomatic arch, as well as temporomandibular joint luxation[13,43,47]. Of the aforementioned, fractures of the mandibular head of the condylar process are most commonly associated with temporomandibular joint ankylosis with the majority of these cases also having concomitant mandibular fossa fractures[13]. Even though no statistically significant correlation between age and ankylosis is reported, traumatic ankylosis is mostly noted in young cats whilst temporomandibular joint ankylosis secondary to neoplasia is mostly associated with older age[42]. Temporomandibular joint ankylosis requires surgical intervention as it results in partial to complete inability to open the mouth, facial asymmetry, dental malocclusion and mandibular brachygnathism[13,42,44]. Re-ankylosis of the temporomandibular joint following surgical treatment of temporomandibular joint ankylosis is not uncommon and can be seen as early as two weeks post-operatively[13].

Reports of bilateral mandibular fractures in cats vary in location and frequency, being more common in the caudal mandible and rarely in the rostral mandibular body and angular process[14]; furthermore, bilateral temporomandibular joint injuries have also been significantly associated with HRS[37]. In contrast, other reports cite mainly bilateral rostral mandibular fractures, which were also higher in frequency compared to unilateral rostral mandibular fractures[15]. Comminuted mandibular fractures are associated with high velocity injuries such as MVA and projectiles, although fighting has also been reported as a cause[7,10,48]. This type of fracture is considered less common, being reported in only 19%[10] of cats with mandibular fractures.

Open mandibular fractures are commonly seen, with one study reporting up to 67.7%[10] of cats with open fractures, of which 53.2% occurred at the mandibular symphysis and 14.5% in the mandibular body. The thin layer of gingiva and thin skin with poor muscle coverage surrounding the mandible as well as fracture fragment displacement, sharp fractures fragments and the traumatic force associated with fracture aetiology, are factors hypothesised to predispose these regions to an open presentation.

In feline craniomaxillofacial trauma, multiple fractures have predominantly been reported as being more common (62.5%[15] to 74.4%[14]) than single fractures (30.8%[14] to 37.5%[15]). This is illustrated by a statistically significant association of multiple mid face fractures involving the nasopharynx, orbit, nose, upper jaw, intermaxillary suture and zygomatic arch, as well as an 84.6%[14] chance of another mandibular fracture and 73.1%[14] chance of another skull fracture occurring in the presence of a symphyseal separation or parasymphyseal fracture. In contrast, one study reported predominantly single mandibular fractures occurring in 79%[10] of cats.

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2.6 Classification of mandibular fractures according to involvement of the dental structures

Six different configurations of mandibular fractures in dogs and humans, but not cats, have previously been described relative to the root apex and periodontal ligament, namely type A – F (I – VI) (Fig. 2.4)[1,17-19].

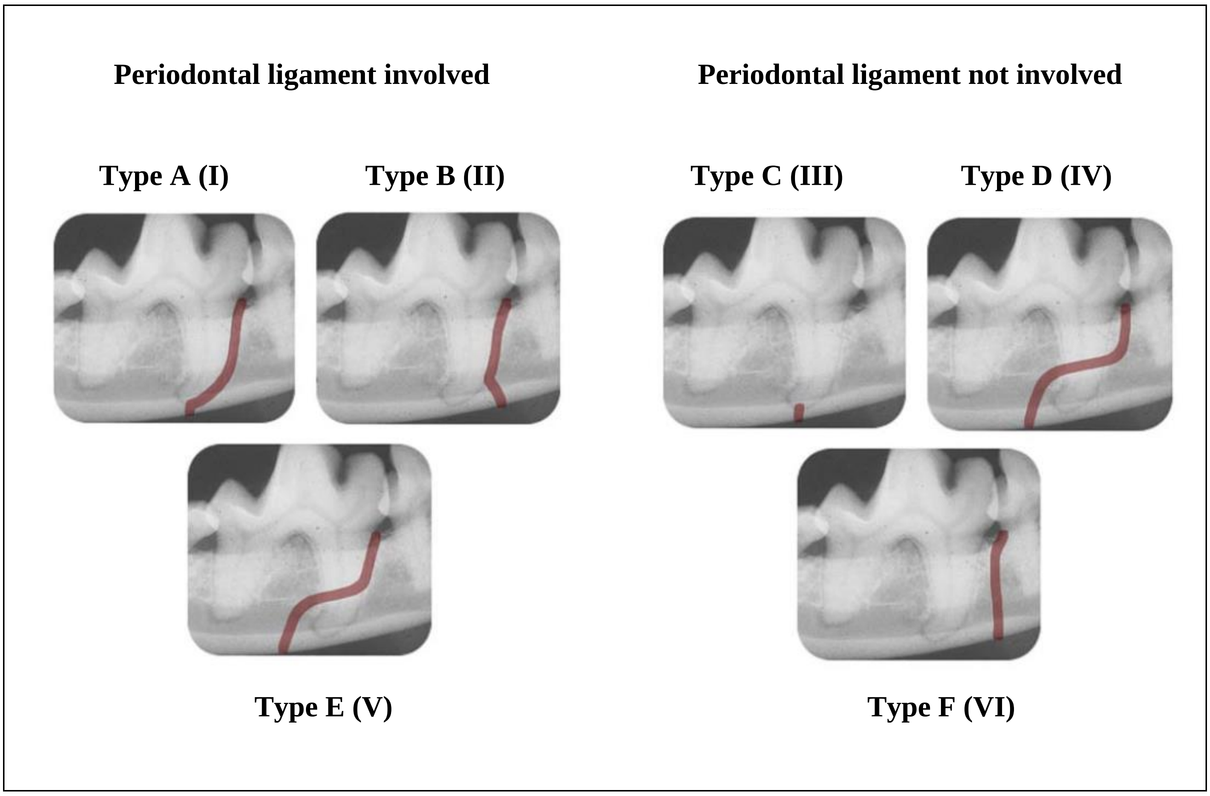

Figure 2.4: Classification of mandibular fractures type A–F (I–VI) relative to root apex and periodontal ligament involvement[1]. (Figure adapted from Guzu *et al.* Mandibular body fracture repair with wire-reinforced interdental composite splint in small dogs. *Veterinary Surgery*. 2017;46: 1068 – 1077).

A type A (I) fracture is described as a fracture line coursing along the entire periodontal ligament, from the alveolar margin of the mandible to the root apex, and continuing to the ventral mandibular cortical margin[1,17]; due to the involvement of the root apex the neurovascular supply of the tooth is likely compromised resulting in a non-vital tooth[1,17]. Fracture type B (II) is described similar to type A (I), however the fracture line deviates away from the tooth root (before reaching the apex) to the ventral margin with limited apical neurovascular injury[1,17]. Fracture type C (III) courses from the root apex to the ventral mandibular margin with likely compromise of the neurovascular supply and secondary pulp necrosis[1,17]. Fracture type D (IV) does not follow the periodontal space, coursing from an interalveolar region of the mandible alveolar margin to the ventral interradicular mandibular margin, crossing the mid-point of the tooth root[1,17]; even though the apical region is not involved in the fracture line, the neurovascular supply coursing from the distal aspect of the tooth root may be compromised[1,17]. Type E (V) is similar to type D (IV), however the initial fracture line courses along the periodontal ligament

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before deviating across the mid-point of the root[1,17]; similar to type D (IV), the neurovascular tissues distal to the tooth root may be compromised[1,17]. Fracture type F (VI) originates at the mandible alveolar margin along the cervical aspect of the tooth, from where it deviates away from the periodontal ligament and continues ventrally through the interalveolar bone to the ventral mandibular margin[1,17]. The neurovascular supply mesial to the fracture line in all the above fracture types may be compromised, however, rostral collateral vascular supply may be established[1,17].

Type A–F (I–VI) fractures are correlated with the prognosis of endodontic viability due to varying degrees of aforementioned neurovascular and peri-apical supporting tissue injury[1,7,17-19]. Accordingly, fracture types A (I), C (III) result in tooth compromise and require treatment, whilst type B (II), does not necessarily result in vascular compromise with endodontic treatment not required[1]. Type D (IV), E (V) and F (VI) may or may not require treatment[1]. Consideration of the type of fracture is crucial to clinical decisions as to whether to retain teeth involved in the fracture line as it will impact post-operative complications and fracture reduction[17].

2.7 Diagnosis of maxillomandibular trauma

Traditionally, radiographic imaging of the skull was routinely employed to evaluate maxillofacial trauma due to ease of access, low level technical operation ability and low cost[13]. However, the complex anatomy of the skull with superimposition of structures, due to anatomy and technical positioning errors, hindered accurate radiographic identification of lesions[12-14,22,31]. Intra-oral radiography improves radiography detail, however, the size of the intra-oral imaging plates compared to the small size of the feline mouth prevents accurate positioning[31]. Computed tomography allows three dimensional multiplanar reconstructions of the skull which facilitates accurate soft tissue and bone lesion identification, as well as interpretation of displacement and surgical planning with no superimposition of anatomy[12-14,22,40,49]. The need for multiple radiographic views is considered a disadvantage due to the need for excessive movement of a traumatised patient, as well as increased general anaesthetic time compared to CT[50].

A radiographic and CT study dividing canine and feline skulls into 26 anatomic regions reported only 42.3%[12] of regions with a mean score of "good visibility" on one or more routine radiographic views. The regions that were difficult or impossible to identify on any radiographic view included maxillary midline, nasomaxillary suture, horizontal lamina palatine bone, vomer, sphenoid, pterygoid bones[12]. Compared to radiography, CT facilitated identification of all anatomic regions with 92.3%[12] regions scoring "easy to very easily identified". The CT score for the mandibular body and dental occlusion were lower than the radiographic score, most likely due to the fact that CT images were viewed as unidimensional saved images with no multiplanar reconstruction[12]. The same study evaluated the

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frequency of maxillofacial traumatic lesions between CT and radiography, where CT identified 4.7 times more lesions than radiographs, with a mean of 7.7 and 3.8 lesions identified per cat, respectively[12]. Computed tomography identified more findings than radiographs for 81.5%[12] of predetermined listed injuries, with a significant difference noted in 29.6%[12] of the listed injuries. The latter includes, maxillary midline separation, intra-articular fractures, palatine bone fractures, palatine process of maxilla fractures, vomer fractures, pterygoid fractures and nasomaxillary suture separation[12]. Lower radiographic lesions scores were likely due to the fact that only routine views and not special views (skyline, sagittal oblique) were acquired[12]. Two lesions, namely mandibular body and ramus fractures, were more commonly diagnosed on radiographs than CT, most likely due to only unidimensional CT images with no multiplanar image reconstructions being available, as well as the acquisition of sub-optimal slice thickness on the CT scans[12]. Three lesions, namely symphyseal separation, temporomandibular joint luxation and incisive bone fractures were equally diagnosed on radiographs and CT[12]. Computed tomography dental imaging is considered more useful than radiography for visualising apical root fractures secondary to maxillofacial trauma[31].

2.8 Treatment of maxillomandibular fractures

Maintaining teeth in the fracture line helps to reduce fractures and maintain normal occlusion, allowing the use of teeth in non-invasive techniques[15,31]. The alveolar margin of the mandible is considered the tension surface, however, the application of certain surgical techniques may be limited by the small head size of cats and the presence of the teeth roots[15].

Mandibular body repair techniques include acrylic external fixators, interdental wiring, interfragmentary wiring and intra-oral splint applications (acrylic, composite, lingual arch bar) with additional caudal mandibular body repair techniques including maxillomandibular fixation, modified button technique and internal rigid fixation (miniplate and screws)[15,22,31]. Temporomandibular joint fractures are most commonly treated conservatively, with condylectomy considered as a last resort. Temporomandibular joint ankylosis is a possible complication of trauma, as well as a complication of prolonged maxillomandibular fixation[31].

Several limitations for aforementioned techniques have been reported due to limited available bone area for implantation, the proximity of sensitive neurovascular and dental structures and fractures involving edentulous regions, deciduous teeth and tooth loss[15,22,31]. Rostral mandibular body fracture repair techniques are hindered by the mandibular symphysis, as well as the large canine roots with relatively limited surrounding cortical bone[15]. Interfragmentary wiring and external fixator application are complicated by the thin fragile mandibular ramus with premature pin loosening and instability due to insufficient surface area for device application[22]. Local complications of repair devices include

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periodontitis, gingivitis, iatrogenic tooth damage (during intra-oral repair technique placement and acrylic splint removal), traumatic gingival lesions along wire tracts and contact regions with the device[15]. Extensive soft tissue trauma and loss of teeth contributes to the incidence of malocclusion and secondary infection as post-operative complications[10]. Compared to other intra-oral splinting techniques, the lingual arch bar is associated with the least amount of complications, with one study reporting only traumatic contact gingival lesions as a complication[15]. Internal rigid fixation has been reported as most advantageous due to accurate anatomical fracture reduction, dental occlusion and rapid return to function[22]. Epoxy/acrylic connecting bars facilitate device application to best fit the fracture area and allow cross pins to be positioned in any way as to avoid dental and neurovascular structures[51]. Additional advantages of epoxy/acrylic includes radiolucency allowing unhindered radiological evaluation of the fracture site as well as its light weight improving patient tolerance[51]. Use of extracorporal bars allow increased device stability without the need to place transfixing pins which increase oral soft tissue trauma[51].

As mentioned previously, the high degree of mandibular morphological symmetry with strong correlation between mandibular height, length and width, facilitates improved surgical outcome and surgical times as unilateral fracture fixation devices can be pre-contoured and customised according to the intact contralateral mandible[22].

Computed tomography investigations of mandibular buccal cortical thickness in dogs identified safe corridors for surgical implant placement, as well as regions to avoid, such as the thinner buccal cortical bone overlying the roots of the fourth premolar and mesial root of the first molar[52]. Placement of miniplate osteosynthesis with monocortical screws, which are ideal to avoid potential damage to underlying sensitive structures, has successfully been reported in humans and dogs in regions of buccal cortical bone greater or equal to 1 mm thickness[52,53]. Contact between screws and underlying dental structures results in inflammation which leads to cementum and dentin damage, root ankylosis, loss of cortical bone, reduced implant stability, poor tooth healing and predisposes to bacterial infection[54-56]. A statistically significant percentage of complications in mandible body fractures is reportedly likely due to vascular damage within the mandibular canal with negative post-operative consequences[10,15,31]. The aforementioned is compounded by the fact that the mandibular alveolar bone receives 30%[1] less arterial blood flow compared to the maxillary alveolar bone. Therefore, intra-oral splinting and non-invasive fracture repair techniques should always be prioritised as they facilitate repair without additional trauma to the mandible, mandibular soft tissues and associated dental and neurovascular structures[10,15,31]. If non-invasive techniques cannot be applied, correct placement of surgical implants avoiding the underlying vascular structures, as well as preventing further trauma to the periosteal and intraosseous vasculature is vital for bone healing[1,51,57].

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2.9 Conclusion drawn from the literature review

The aetiology and distribution of feline mandibular fractures are variable. There is a paucity of literature describing feline mandibular fracture conformation, associated predisposing factors and association of mandibular fractures with dental structures. In light of the relatively common occurrence of feline mandibular fractures, investigations into the above will improve the clinical and surgical approach as well as outcome of these patients.

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Chapter 3: Problem statement

3.1 Research questions

- What are the associations of demographic variables with mandibular fractures in two populations of cats reported by two referral centres from January 2010 to 31 December 2020?
- What is the distribution of mandibular fractures in two populations of cats reported by two referral centres from 1 January 2010 to 31 December 2020?
- What is the conformation of mandibular fractures in two populations of cats reported by two referral centres from 1 January 2010 to 31 December 2020?
- What is the conformation of mandibular fractures associated with teeth in two populations of cats reported by two referral centres from 1 January 2010 to 31 December 2020?
- What is the association of specific teeth with mandibular fractures in two populations of cats reported by two referral centres from 1 January 2010 to 31 December 2020?

3.2 Aims and objectives of the study

- To compare the signalment of two populations of cats with mandibular fractures.
- To categorise and compare the distribution of feline mandibular fractures in two populations of cats.
- To describe and compare mandibular fracture conformation in two populations of cats.
- To describe and compare mandibular fracture conformation associated with teeth in two populations of cats.
- To investigate and compare the association of mandibular fracture conformation with involvement of teeth in two populations of cats.
- To investigate and compare overall associations between mandibular fracture aetiology, fracture conformation, fracture distribution and tooth involvement in mandibular fractures in two populations of cats.

3.3 Hypotheses

- Null hypothesis 1: There will be no difference in demographic variables between the two populations of cats.

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- Alternative hypothesis 1: There will be a difference in demographic variables between the two populations of cats.
- Null hypothesis 2: There will be a difference in mandibular fracture aetiology between the two populations of cats.
- Alternative hypothesis 2: There will be no difference in mandibular fracture aetiology between the two populations of cats.
- Null hypothesis 3: There will be a difference in the proportion of single/multiple fractures (and mean number of fractured regions) between the two groups.
- Alternative hypothesis 3: There will be no difference in the proportion of single/multiple fractures (and mean number of fractured regions) between the two groups.
- Null hypothesis 4: There will be a difference in mandibular fracture distribution between the two populations of cats.
- Alternative hypothesis 4: There will be no difference in mandibular fracture distribution between the two populations of cats.
- Null hypothesis 5: Mandibular fractures will be predominantly displaced in the two groups.
- Alternative hypothesis 5: Mandibular fractures will not be predominantly displaced in the two groups.
- Null hypothesis 6: There will be a difference in mandibular fracture conformation between the two populations of cats.
- Alternative hypothesis 6: There will be no difference in mandibular fracture conformation between the two populations of cats.
- Null hypothesis 7: There will be no difference in the type of tooth predominantly involved with a fracture line between the two populations of cats.
- Alternative hypothesis 7: There will be a difference in the type of tooth predominantly involved with a fracture line between the two populations of cats.
- Null hypothesis 8: There will be no difference in the type of fracture (type A – F) associated with teeth between the two populations of cats.
- Alternative hypothesis 8: There will be a difference in the type of fracture (type A – F) associated with teeth between the two populations of cats.

3.4 Benefits arising from the study

- Gain further understanding of feline mandibular fracture conformation with reference to signalment and cause in two populations of cats from a referral centre in South Africa and Canada.

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- Identification of fracture patterns and risk factors will improve clinical anticipation, treatment, and prognostication, as well as facilitate studies investigating superior repair techniques.
- Investigation and description of feline mandibular fracture conformation and association with dental structures will improve the clinical and surgical approach as well as the outcome of these patients.
- As concluded from the literature review, the aetiology and distribution of feline mandibular fractures are variable and likely influence fracture conformation. Additionally, environmental factors influencing the presentation of patients with mandibular fractures are likely different for separate populations. Therefore, the study justifies comparison of two geographically separate populations of cats with mandibular fractures in order to investigate and identify fracture patterns specifically associated with each population.
- Depending on the findings of the study, given the high degree of mandibular morphological symmetry in mesaticephalic cats, the data could be used to develop pre-contoured mandibular fracture fixation plates modelled according to the predominant fracture configurations seen in the study which would facilitate surgical repair.
- The research conducted will serve as fulfilment of the principal investigator's MSc degree.

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Chapter 4: Materials and Methods

4.1 Experimental design

The study was approved by the University of Pretoria's Animal Ethics Committee. The study was conducted as a retrospective descriptive case series using patient data collected from two referral centres, the Dentistry and Maxillofacial Surgery Clinic, Onderstepoort Veterinary Academic Hospital (OVAH), Pretoria, South Africa, and West Coast Veterinary Dental Services Ltd (WCVDS), Vancouver, Canada. The case records of cats that presented to these facilities from 1 January 2010 – 31 December 2020 with mandibular fractures and having undergone pre-operative radiographic and/or CT imaging were evaluated retrospectively. Given the retrospective nature of the study, patient data and imaging studies could not be standardized and a compromise regarding diagnostic imaging inclusion criteria had to be reached to maximize the number of included cases. Included patients were required to have undergone either pre-operative radiographic imaging of the mandible (intra-oral mandible, extra-oral mandible, skull) or CT imaging of the mandible and/or skull. Given the specialist level of veterinary consultation in these cases, patients with incomplete radiographic studies were also included as accurate clinical localization of fractures was assumed. Patients without pre-operative mandibular fracture imaging were excluded.

4.2 Experimental procedure

4.2.1 Radiographic and computed tomography procedure

OVAH radiographic studies were acquired with an Apelum Baccara imaging unit (Apelum Baccara 90/20, Italy) using a Fuji CR console system (Fujifilm Medical Systems, Stamford, USA) and a CR 7 unit (DÜRR NDT, Germany). OVAH CT images were acquired using a Siemens Emotion Duo with sliding gantry (Siemens Medical Systems, Forchheim, Germany). WCVDS radiographic studies were acquired with an Instrumentarium Focus (Instrumentarium Dental, PaloDEx Group Oy, Nahkelantie 160, FI-04300 Tuusula, Finland) and a CR 7 unit (DÜRR NDT, Germany). A dedicated imaging workstation with a 2 mega-pixel black-and-white medical grade screen (Lumimed MM20, Heeyoung Co., Ltd. Ansan, South Korea) was used during image analysis. Given the retrospective nature of the case series and mainly descriptive aim of the study, details regarding radiographic and CT parameters and exposure settings of each case were not included in the study. Similarly, details regarding patient sedation and general anaesthesia protocols used during the acquisition of imaging studies were not included in this study.

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4.2.2 Clinical data and image analysis

Clinical patient data and diagnostic imaging data was recorded in a table by the researcher (MC), which was separated into two groups consisting of patients from OVAH and patients from WCVDS.

Clinical patient data included patient location (OVAH, WCVDS), breed, age (years), sex (male, female), sterilization status (neutered/spayed, intact) and weight (kg). Clinical notes regarding presence of open or closed fractures was used to determine whether fractures were open or closed. If the presence of open or closed fractures was not recorded in the clinical notes, fractures with radiographic or CT evidence of soft tissue emphysema in the region of the fracture site were classified as open fractures. Fracture aetiology was classified into seven categories, namely: motor vehicle accident, falling from a height, animal encounter (animal attack), human encounter (non-veterinary related malicious/accidental human induced trauma), iatrogenic (fracture during veterinary dental procedures, such as tooth extraction), pathological (fracture in region of predisposing osseous pathology, such as bone lysis, osteopenia, osteomyelitis, periodontitis, neoplasia) and unknown aetiology.

A brief image analysis calibration study was conducted on a random sample of cases by the researcher (MC), supervisor (GS) and co-supervisor (JCAR) to establish consensus regarding image analysis. Following the calibration study, all extra-oral, intra-oral and skull radiographic images (DICOM, JPEG) as well as skull CT images (DICOM) were evaluated individually by the researcher (MC) and supervisor (GS) using a dedicated imaging workstation desktop computer with RadiAnt DICOM viewer (Medixant, Promienista 25, 60-288 Poznań, Poland), adjustable brightness, contrast, and magnification to optimize image evaluation. CT multiplanar bone and soft tissue window reconstruction was used as necessary. Cases with observer discrepancy were re-evaluated by both observers to establish consensus. Detailed descriptions of the recorded data are represented in Table 4.1. Recorded data included anatomical fracture location (Fig. 4.1), fracture conformation, relative fracture stability of mandibular body fractures, fracture displacement, laterality of fractures, single or multiple fractures, open or closed fractures, tooth involvement in a fracture line, fracture classification associated with teeth (type A - F), and evidence of pre-existing pathology associated with the fracture.

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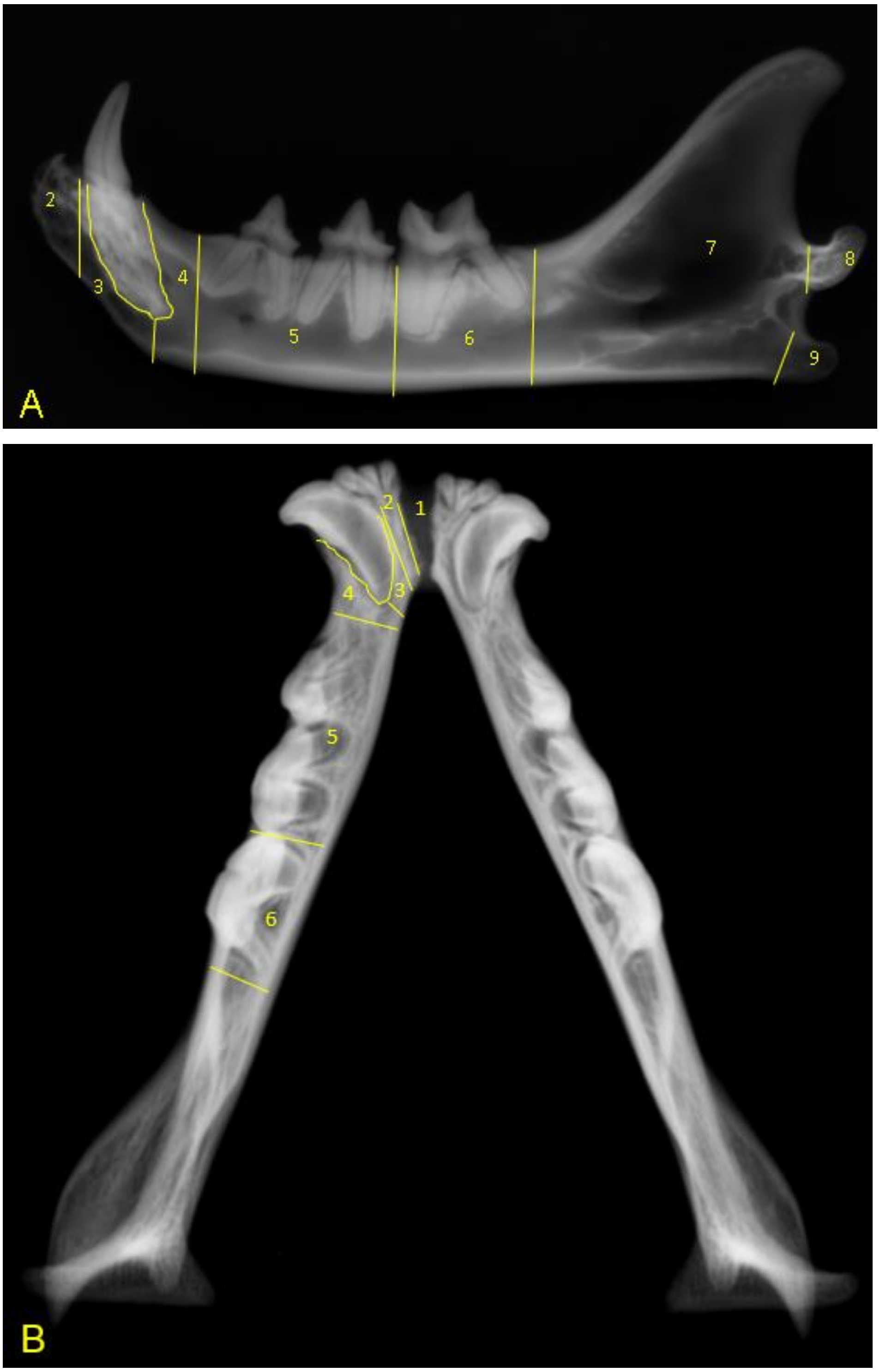

Figure 4.1 A - B: Anatomical fracture location. A) Laterolateral View, B) Ventrodorsal View. 1 – Symphyseal, 2 – Parasymphyseal Incisor, 3 – Parasymphyseal Canine, 4 – Canine, 5 – Premolar, 6 – Molar, 7 – Mandibular Ramus Coronoid Process, 8 – Mandibular Ramus Condylar Process, 9 – Mandibular Ramus Angular Process. Note: the mandible is a cadaver mandible used as an illustration of anatomical fracture location only, disregard the abnormal mandibular symphysis (symphyseal separation).

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Table 4.1: Image analysis guide of feline mandibular fracture classification and description.

Classification	**Description**
Fracture location	
The mandible was divided into three grouped anatomical sections (symphyseal, mandibular body and caudal mandible) comprising nine individual anatomical regions as indicated in this table and shown in Figure 4.1. Each anatomical region containing a fracture was identified and recorded. If a single fracture involved multiple anatomical regions, all regions were recorded as being fractured and the fracture conformation was recorded separately for each region.	
Symphyseal section	
Symphyseal	• Separation of the mandibular symphysis
Mandibular body section	
Parasymphyseal incisor	• Fracture involving *pars incisive* of the mandible distal to the mandibular symphysis up to but excluding the mesial canine periodontal ligament
Parasymphyseal canine	• Fracture involving *pars incisive* of the mandible from the mesial canine periodontal ligament to the apical alveolar bone of the canine root
Canine	• Fracture involving *pars incisive and molaris* of the mandible from the apical alveolar bone of the canine root up to but excluding mesial third premolar periodontal ligament
Premolar	• Fracture involving *pars molaris* of the mandible from mesial third premolar periodontal ligament up to and including distal fourth premolar periodontal ligament
Molar	• Fracture involving the *pars molaris* of the mandible from mesial to distal first molar periodontal ligament
Caudal mandible section	
Mandibular ramus / coronoid process	• Fracture involving the mandibular ramus distal to first molar periodontal ligament and excluding the *processus angularis* and *processus condylaris*
Mandibular ramus / condylar process	• Fracture involving the *processus condylaris*
Mandibular ramus / angular process	• Fracture involving the *processus angularis*
Fracture conformation	

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Complete fracture	• Fracture line extending through the entire bone with total disruption of bone continuity[58,59] • All fractures can be assumed to be complete fractures even though not specifically designated as complete
Incomplete fracture	• Fracture line involving a single bone cortex or small portion of a bone, not resulting in separation of a bone into fracture fragments[58,59] • If present, incomplete fractures will specifically be described
Transverse	• Fracture line orientated perpendicular to the long axis of the mandible in a dorso-ventral or bucco-lingual direction
Oblique	• Fracture line orientated at an angle to the long axis of the mandible in a dorso-ventral or bucco-lingual direction • Long oblique fracture measures more than twice the diameter of the mandible • Short oblique fracture measures less than twice the diameter of the mandible • Oblique fractures will be named in a rostro-caudal direction. Depending on the respective lateral or VD/DV view, these configurations include caudo-ventral, caudo-dorsal, caudo-lingual, and caudo-buccal fractures
Parasagittal	• Fracture line orientated along the long axis of the mandible, lingual or buccal to the midline of the mandible
Comminuted	• Fracture consisting of at least three bone fragments with communication of fracture lines
<u>Relative fracture stability of mandibular fractures</u> Relative fracture stability of mandibular body fractures was classified according to fracture orientation as well as association with masticatory muscle biomechanical forces[5,7].	
Relatively stable mandibular body fractures	• Caudo-dorsal oblique fractures on lateral/sagittal views

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	• Caudo-lingual oblique fractures on DV/VD/dorsal views
Relatively unstable mandibular body fractures	• Caudo-ventral oblique fractures on lateral/sagittal views • Caudo-buccal oblique fractures on DV/VD/dorsal views • Dorso-ventral and bucco-lingual transverse fractures on lateral and DV/VD/dorsal views • Comminuted fractures • Parasagittal fractures
Fracture displacement	
Displaced	• Defined as fracture fragments not lined up in a normal anatomical position, over-riding fracture fragments, or a step/gap present between fracture fragments
Non-displaced	• Fractures edges are in contact and lined up in a normal anatomical position
Fracture laterality Described as either unilateral right, unilateral left, bilateral, with or without symphysis, or symphysis alone.	
Unilateral right/left	• Fracture or fractures involving either the right or left mandible
Bilateral	• Fracture or fractures involving both left and right mandibles
Symphysis	• Separation of the mandibular symphysis
Single or multiple fractures	
Single	• Cases where only a single fracture line was identified, which may or may not extend through multiple anatomical regions
Multiple	• Cases where more than one fracture line was identified, which may or may not extend through multiple anatomical regions
Open or closed fractures	
Open	• Clinical notes referencing an open fracture

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	• Radiographic and/or CT presence of subcutaneous emphysema associated with a fracture
Closed	• Clinical notes referencing a closed fracture • Radiographic and/or CT absence of subcutaneous emphysema associated with a fracture
Fracture classification associated with teeth: type A - F (I - VI) Fractures involving teeth, categorized as previously described type A – F (I – VI)[17,18].	
Fractures involving a tooth/teeth and/or PDL	• Fractures involving a tooth/teeth and/or PDL as previously described type A - F (I - VI)
Fractures not involving a toot/teeth and/or PDL	• Fractures not involving a tooth/teeth and/or PDL
Pathological fractures Fractures are non-pathological unless stated otherwise.	
	• Fracture secondary to no or minimal trauma with associated radiographic or CT presence of bone lysis, osteopenia, infection (periodontitis, osteomyelitis), neoplasia

4.3 Statistical analysis

All data was captured in Microsoft Excel and imported into JMP Pro, version 16, SAS Institute Inc., Cary, NC, 1989-2021 statistical analysis program. The identification of each cat was recorded together with corresponding clinical and demographic data. Radiographic and/or CT studies were evaluated, and all abnormalities were recorded as categorical data according to predefined criteria. The results were initially evaluated using descriptive statistics. Categorical data was evaluated using chi-square tests with one degree of freedom. Statistical significance was set at $p < 0.05$.

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Chapter 5: Results

5.1 Study population demographics

5.1.1 Study population demographics according to referral centre

A total of 104 case records from cats with mandibular fractures were evaluated for the study; of these, 41 were seen at the OVAH and 63 at WCVDS. Only 46 cases fulfilled the requirements to be included in the study, comprising 15 OVAH and 31 WCVDS cases. The OVAH cases consisted of 8 radiographic studies, 3 combined radiographic and CT studies, and 4 CT studies, whilst all of the WCVDS cases were radiographic studies.

The domestic shorthair was the most common breed in both populations, representing 73.3% of OVAH cases and 74.2% of WCVDS cases (Fig. 5.1). The breed distribution of the remaining cases included a variety of other breeds, represented in small numbers.

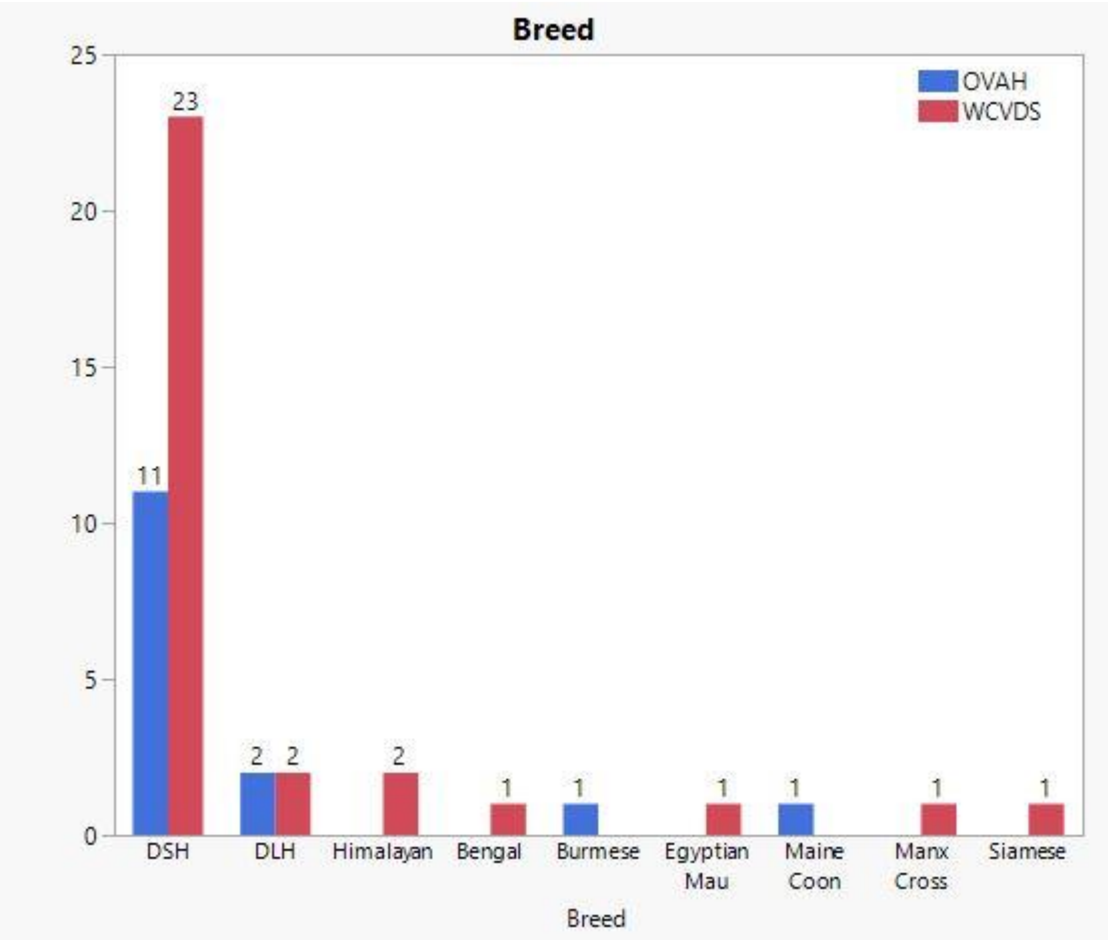

Figure 5.1: Breed distribution and number of cats with mandibular fractures according to referral centre. Abbreviations: DLH, domestic longhair; DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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The age range and sex distribution of the OVAH and WCVDS cats are shown in Figure 5.2. There was no significant difference in age (P = 0.111) and sex (P = 0.063) between the two groups. Male cats were predominant in both groups (80% of the OVAH cases and 54.8% of the WCVDS cases). The majority of male cats were neutered in both groups (75% of OVAH and 94% of WCVDS male cats). All the female cats in both populations were sterilised. In the OVAH group, the 7-years-of-age group had the highest number of mandibular fracture cases (26.44%) whilst the WCVDS group had no one age group predominating (Fig. 5.2).

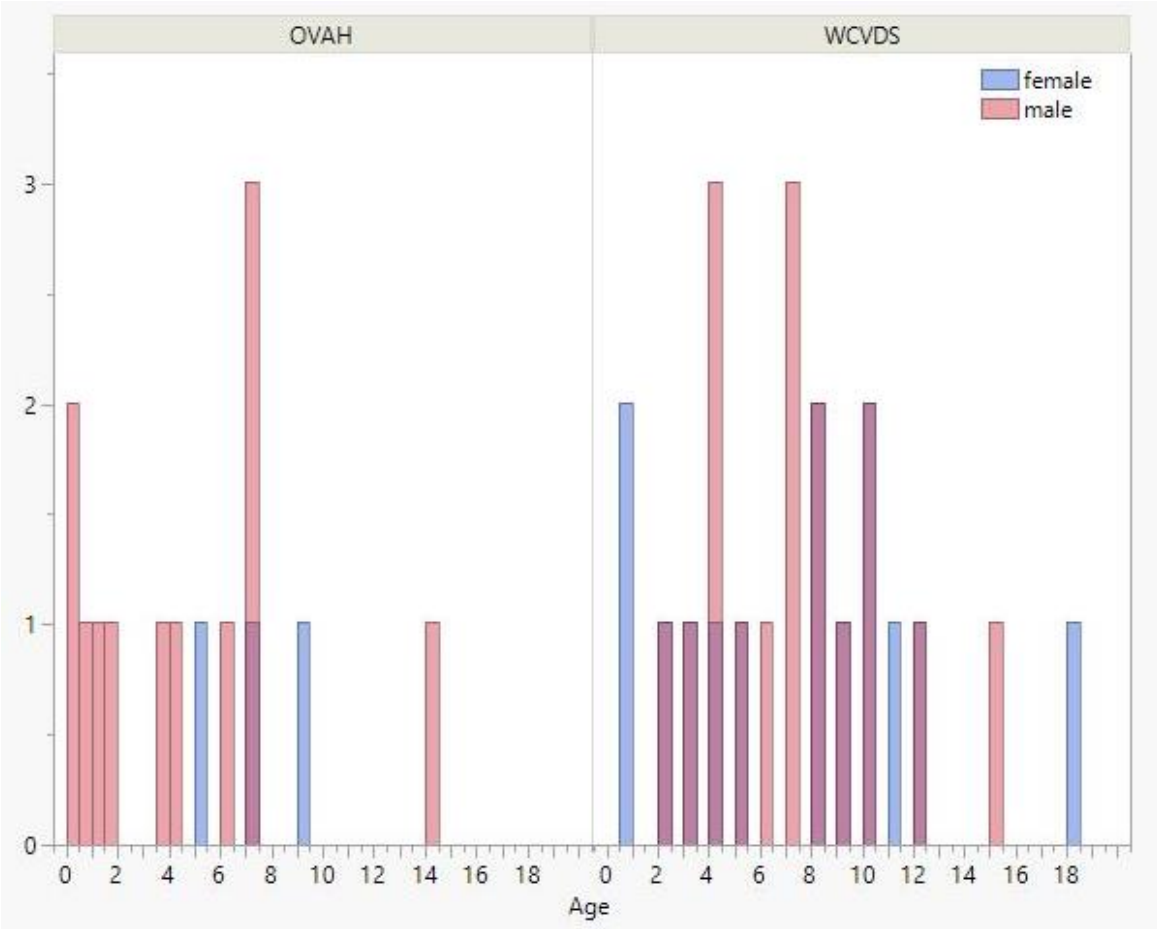

Figure 5.2: Age (years) and sex distribution of cats with mandibular fractures according to referral centre. Purple bar indicates male and female cat overlap. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

The weight distribution of the OVAH and WCVDS cats are shown in Table 5.1. There was no significant difference between the two groups (P = 0.276).

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Table 5.1: Weight distribution (kg) of cats with mandibular fractures according to referral centre.

Sex	Weight variable (kg)	OVAH	WCVDS
Combined (male and female)	Weight range	2 – 9.2	2.2 – 7.8
	Mean weight	4.3	4.8
	Median weight	4	4.8
Male	Weight range	2 – 9.2	3.5 – 7.8
	Mean weight	4.3	5.3
	Median weight	4.3	5.5
Female	Weight range	3 – 6.4	2.2 - 6
	Mean weight	4.3	4.1
	Median weight	3.5	4

Abbreviations: kg, kilogram; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

5.1.2 Study population demographics according to fracture aetiology

Mandibular fracture aetiology and associated population demographics of the OVAH and WCVDS cases are shown in Tables 5.2 – 5.8. The majority of mandibular fractures in both groups were caused by unknown aetiology (53.3% of the OVAH cases and 71% of the WCVDS cases). Of the known aetiology categories, iatrogenic aetiology was most common in the OVAH group (20%) and animal encounter most common in the WCVDS group (12.9%). Due to the low number of known aetiology cases, statistical analysis was not possible.

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Table 5.2: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the unknown aetiology category.

Demographic variables	OVAH	WCVDS
Number of cats	8/15 (53.3%)	22/31 (71%)
Number of males Sterilised Intact	8/8 (100%) 6/8 (75%) 2/8 (25%)	11/22 (50%) 10/11 (91%) 1/11 (9%)
Number of females Sterilised Intact	0	11/22 (50%) 11/11 (100%) 0
Male age range (years) Mean Median	0.3 – 7 3.13 2.5	2 – 15 6.54 6
Female age range (years) Mean Median	0	0.8 – 18 7.25 8
Male weight range (kg) Mean Median	2 – 5.5 3.95 4.25	3.5 – 7.8 (*) 5.56 5.75
Female weight range (kg) Mean Median	0	2.2–6 4.26 4
Breed (number)	DSH (7) DLH (1)	DSH (17) Manx Cross (1) DLH (1) Himalayan (1) Siamese (1) Bengal (1)

Abbreviations: DLH, domestic longhair; DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services. *, One cat with no weight.

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Table 5.3: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the motor vehicle accident category.

Demographic variables	**OVAH**	**WCVDS**
Number of cats	1/15 (6.7%)	3/31 (9.7%)
Number of males Sterilised Intact	1/1 (100%) 1/1 (100%) 0	2/3 (66.7%) 2/2 (100%) 0
Number of females Sterilised Intact	0	1/3 (33.3%) 1/1 (100%) 0
Male age range (years) Mean Median	7 7 7	7 – 12 9.5 9.5
Female age range (years) Mean Median	0	11 11 11
Male weight range (kg) Mean Median	4.6 4.6 4.6	4 – 6 5 5
Female weight range (kg) Mean Median	0	4 4 4
Breed (number)	DLH (1)	DSH (1) Himalayan (1) Egyptian Mau (1)

Abbreviations: DLH, domestic longhair; DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5.4: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the falling from a height category.

Demographic variables	OVAH	WCVDS
Number of cats	2/15 (13.3%)	0
Number of males Sterilised Intact	0	0
Number of females Sterilised Intact	2/2 (100%) 2/2 (100%) 0	0
Male age range (years) Mean Median	0	0
Female age range (years) Mean Median	5.3 – 9 7.15 7.15	0
Male weight range (kg) Mean Median	0	0
Female weight range (kg) Mean Median	3 – 3.5 3.25 3.25	0
Breed (number)	DSH (2)	0

Abbreviations: DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5.5: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the animal encounter category.

Demographic variables	**OVAH**	**WCVDS**
Number of cats	1/15 (6.7%)	4/31 (12.9%)
Number of males	1/1 (100%)	2/4 (50%)
Sterilised	0	2/2 (100%)
Intact	1/1 (100%)	0
Number of females	0	2/4 (50%)
Sterilised		2/2 (100%)
Intact		0
Male age range (years)	0.4	3 – 8
Mean	0.4	5.5
Median	0.4	5.5
Female age range (years)	0	0.5 – 10
Mean		5.25
Median		5.25
Male weight range (kg)	2.6	5.5
Mean	2.6	5.5
Median	2.6	5.5
Female weight range (kg)	0	3 – 4
Mean		3.5
Median		3.5
Breed (number)	DSH (1)	DSH (3) DLH (1)

Abbreviations: DLH, domestic longhair; DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5.6: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the human encounter category.

Demographic variables	OVAH	WCVDS
Number of cats	0	1/31 (3.2%)
Number of males Sterilised Intact	0	1/1 (100%) 1/1 (100%) 0
Number of females Sterilised Intact	0	0
Male age range (years) Mean Median	0	9 9 9
Female age range (years) Mean Median	0	0
Male weight range (kg) Mean Median	0	4.5 4.5 4.5
Female weight range (kg) Mean Median	0	0
Breed (number)	0	DSH (1)

Abbreviations: DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5.7: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the iatrogenic category.

Demographic variables	**OVAH**	**WCVDS**
Number of cats	3/15 (20%)	0
Number of males Sterilised Intact	2/3 (66.7%) 2/2 (100%) 0	0
Number of females Sterilised Intact	1/3 (33.3%) 1/1 (100%) 0	0
Male age range (years) Mean Median	6 – 14 10 10	0
Female age range (years) Mean Median	7 7 7	0
Male weight range (kg) Mean Median	3.9 – 9.2 6.55 6.55	0
Female weight range (kg) Mean Median	6.4 6.4 6.4	0
Breed (number)	DSH (1) Maine Coon (1) Burmese (1)	0

Abbreviations: DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5.8: Study population demographics of OVAH and WCVDS cats with mandibular fractures in the pathological category.

Demographic variables	**OVAH**	**WCVDS**
Number of cats	0	1/31 (3.2%)
Number of males Sterilised Intact	0	1/1 (100%) 1/1 (100% 0
Number of females Sterilised Intact	0	0
Male age range (years) Mean Median	0	10 10 10
Female age range (years) Mean Median	0	0
Male weight range (kg) Mean Median	0	3.5 3.5 3.5
Female weight range (kg) Mean Median	0	0
Breed	0	DSH (1)

Abbreviations: DSH, domestic shorthair; OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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5.2 Number of fractured regions and distribution

5.2.1 Number of fractured regions and anatomical distribution according to referral centre

In the OVAH group, 35 anatomical regions were fractured in 15 cats. Six cases (40%) were single fracture cases and 9 cases (60%) were multiple fracture cases. In the WCVDS group, 49 anatomical regions were fractured in 31 cats. Twenty cases (64.5%) were single and 11 (35.5%) were multiple fracture cases. The proportion of single and multiple fracture cases were not significantly different between the two groups (P = 0.115), however the mean number of fractured regions per cat was significantly higher for the OVAH group compared to the WCVDS group (2.3 and 1.6 respectively) (P = 0.022). In the OVAH group, 4 of the single fracture cases were open and 2 were closed, whilst 7 of the multiple fracture cases were open and 2 were closed. In the WCVDS group, 6 single fracture cases were open and 14 were closed, whereas 8 multiple fracture cases were open and 3 were closed. Even though fractures were classified as open and closed it was difficult to accurately classify based on the presence of gas alone, therefore the results are considered inconclusive (further explanation in discussion).

The variation of mandibular fracture distribution according to referral centre is shown in Figures 5.3-5.4. When considering the overall number of cases, the mandibular body was most commonly fractured in the OVAH group (60% of cases), whilst the symphysis was most commonly affected in the WCVDS group (64.5% of cases), although neither were significantly different between the two groups (P = 0.250, P = 0.115 respectively). When considering the overall number of fractured regions, the mandibular body was the most fractured region in both groups (48.6% of OVAH and 42.8% of WCVDS fractured regions). Overall, the symphyseal region was least affected in the OVAH group whereas the caudal mandible was least affected in the WCVDS group. In both groups most of the fractures within the mandibular body were centered around the canine tooth, specifically the parasymphyseal canine region in the OVAH group, involving 40% of cases (representing 20% of fractured regions), and the canine region in the WCVDS group, involving 19.3% of cases (representing 12.2% of fractured regions). The proportion of parasymphyseal canine fracture cases were significantly different between the OVAH (40%) and WCVDS groups (12.9%) (P = 0.036) whilst the proportion of canine region fracture cases were not significantly different (P = 0.297). In the OVAH group, the symphyseal region was affected in 40% of cases, however represented a lower proportion of affected regions (17.1%) compared to the parasymphyseal canine region. Overall, there was no significant difference in the proportion of cases with only symphyseal separation, symphyseal separation with concomitant fractures, and cases without symphyseal separation between the two groups (P = 0.243).

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The proportion of caudal mandible fracture cases were not significantly different between the two groups (OVAH 46.7%, WCVDS 22.6%) (P = 0.096). Within the caudal mandible of the OVAH group, the coronoid and condylar processes were each fractured in 26.7% of cases, however, the condylar process had a higher number of fractured regions (17.1%); whereas in the WCVDS group, coronoid process fractures were predominant in the caudal mandible (22.6% of cases, 14.3% of fractured anatomical regions). The proportion of OVAH condylar process fracture cases (26.7%) were significantly higher compared to the WCVDS group (3.2%) (P = 0.016). Temporomandibular joint subluxation was seen in 20% of the OVAH cases (one bilateral and two unilateral). One of the unilateral temporomandibular joint subluxation cases also had a contralateral temporomandibular joint luxation.

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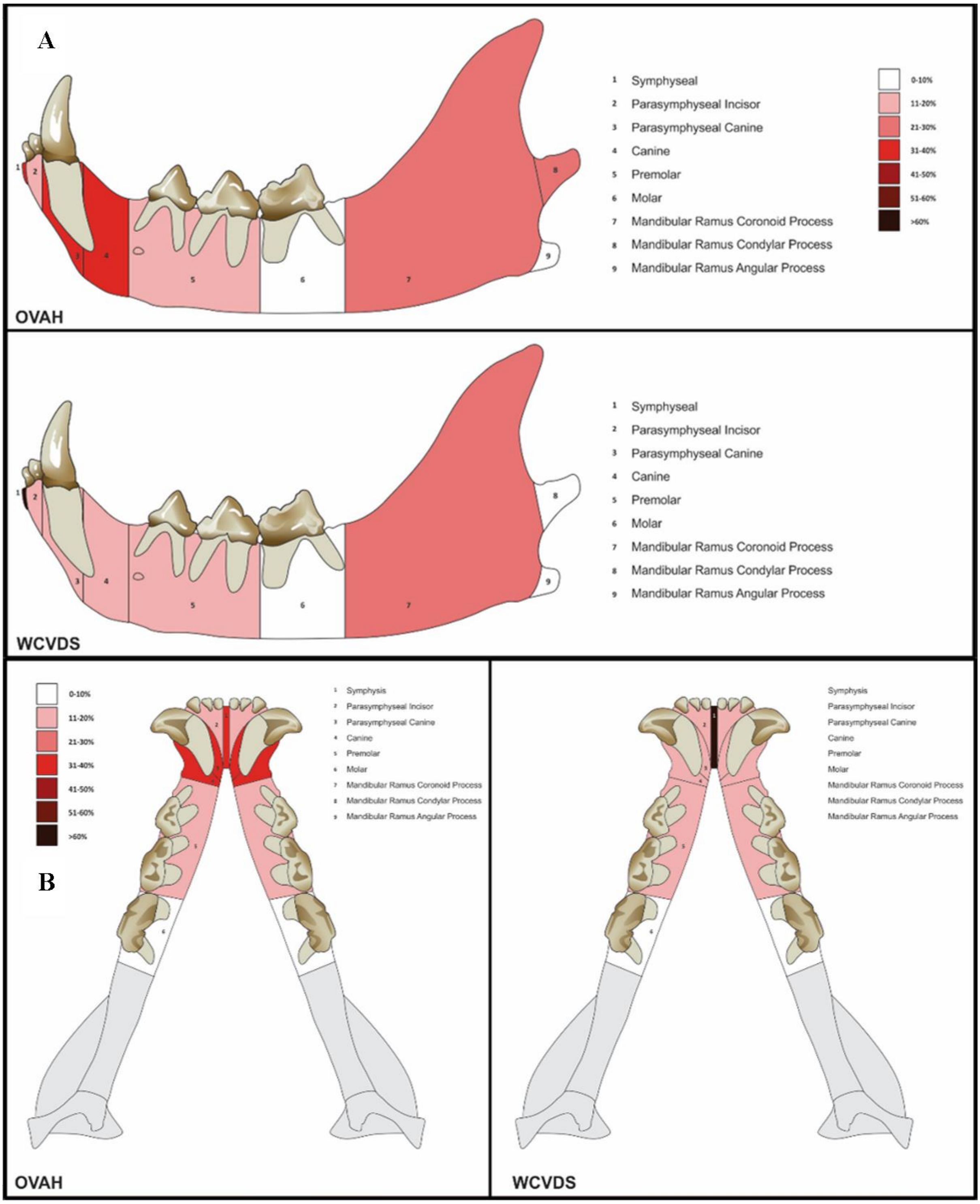

Figure 5.3: Heat map demonstrating the overall case percentage of OVAH and WCVDS cats (cases) sustaining a fracture in each region. (A) The mandible shown from a lateral perspective with the symphysis purposefully enlarged to be visible on the heat map. (B) The mandible shown from a dorsal perspective with the symphysis purposefully widened in order to clearly show the symphyseal area. The detail of the caudal mandible is not accurate due to overlapping structures. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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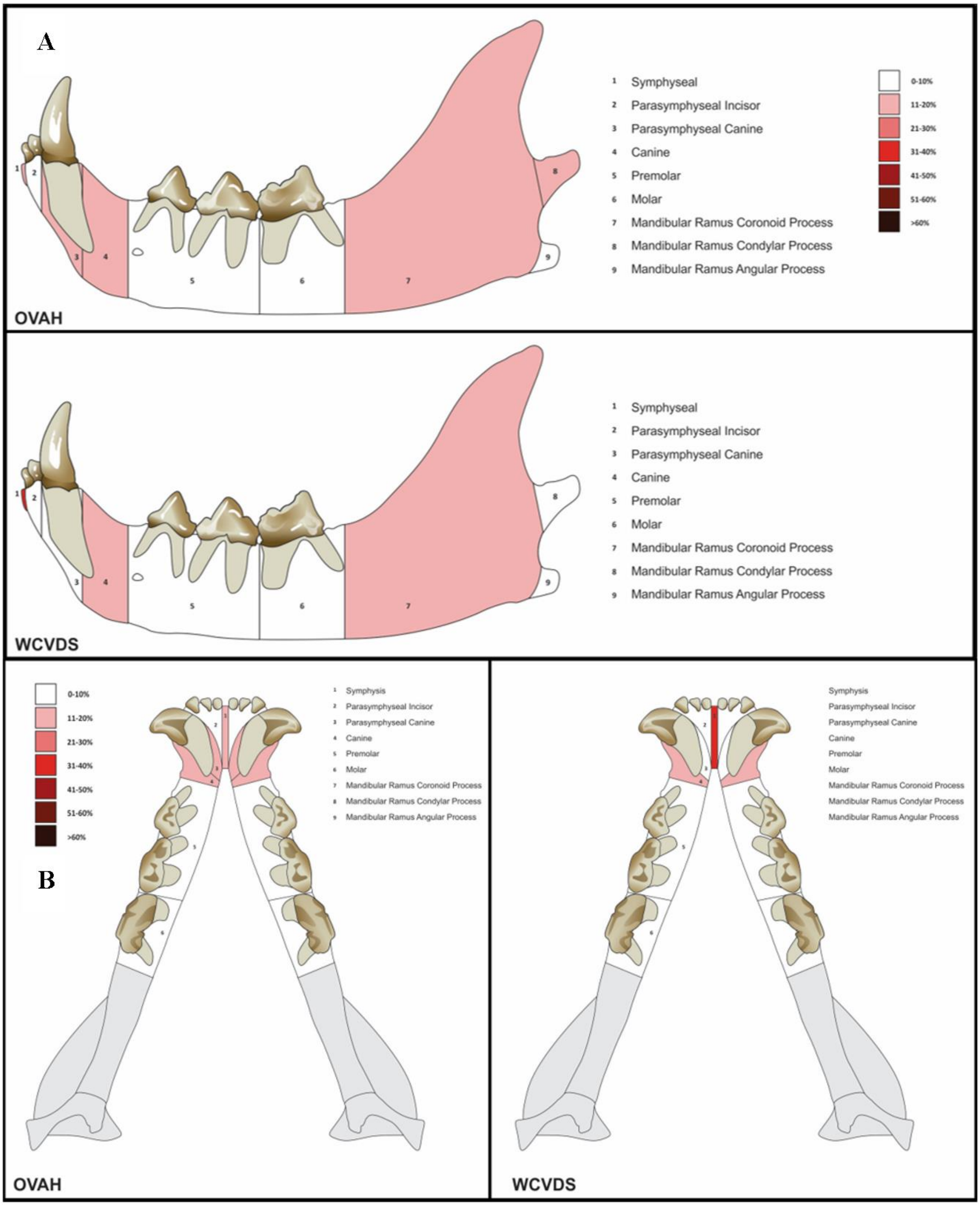

Figure 5.4: Heat map demonstrating the percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats. (A) The mandible shown from a lateral perspective with the symphysis purposefully enlarged to be visible on the heat map. (B) The mandible shown from a dorsal perspective with the symphysis purposefully widened in order to clearly show the symphyseal area. The detail of the caudal mandible is not accurate due to overlapping structures. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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5.2.2 Number of fractured regions and anatomical distribution according to aetiology

The number of fractured anatomical regions in OVAH and WCVDS cats according to aetiology is shown in Table 5.9. The variation of mandibular fracture distribution in OVAH and WCVDS cats according to aetiology is shown in Annexure A (Tables 1 - 7). The variation of single and multiple fractures cases according to aetiology is shown in Annexure A (Table 8). The number of known aetiology cases were too low to draw clear conclusions between the two groups.

Table 5.9: Number (percent) of fractured anatomical regions in OVAH and WCVDS cats according to aetiology.

Referral centre	Number (percent) of cats	Number (percent) of fractured anatomical regions	Mean number of fractured regions per cat
Unknown aetiology			
OVAH	8/15 (53.3%)	15/35 (42.8%)	1.9
WCVDS	22/31 (71%)	35/49 (71.4%)	1.6
Motor vehicle accident			
OVAH	1/15 (6.7%)	5/35 (14.3%)	5
WCVDS	3/31 (9.7%)	4/49 (8.2%)	1.3
Falling from height			
OVAH	2/15 (13.3%)	5/35 (14.2%)	2.5
WCVDS	0/31 (0%)	0/0 (0%)	0
Animal encounter			
OVAH	1/15 (6.7%)	3/35 (8.6%)	3
WCVDS	4/31 (12.9%)	6/49 (12.2%)	1.5
Human encounter			
OVAH	0/15 (0%)	0/0 (0%)	0
WCVDS	1/31 (3.2%)	1/49 (2%)	1
Iatrogenic			
OVAH	3/15 (20%)	7/35 (20%)	2.3
WCVDS	0/31 (0%)	0/0 (0%)	0
Pathological			
OVAH	0/15 (0%)	0/0 (0%)	0
WCVDS	1/31 (3.2%)	3/49 (6.1%)	3

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

5.2.3 Fracture laterality according to referral centre

The proportion of bilateral, unilateral and symphyseal only fracture cases were significantly different between the OVAH and WCVDS groups (P = 0.004) (Fig. 5.5). In the OVAH group, both unilateral and bilateral fracture cases were predominant (40% of cases), whilst in the WCVDS group, unilateral

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fracture cases were most common (54.8% of cases) with only 3.3% bilateral fracture cases. Cases featuring only symphyseal separation were present in 20% of the OVAH cases compared to 41.9% of the WCVDS cases. Both OVAH and WCVDS groups had more unilateral right sided fracture cases, with 33.3% right and 6.7% left unilateral fracture cases in the OVAH group, and 32.3% right and 22.6% left unilateral fracture cases in the WCVDS group.

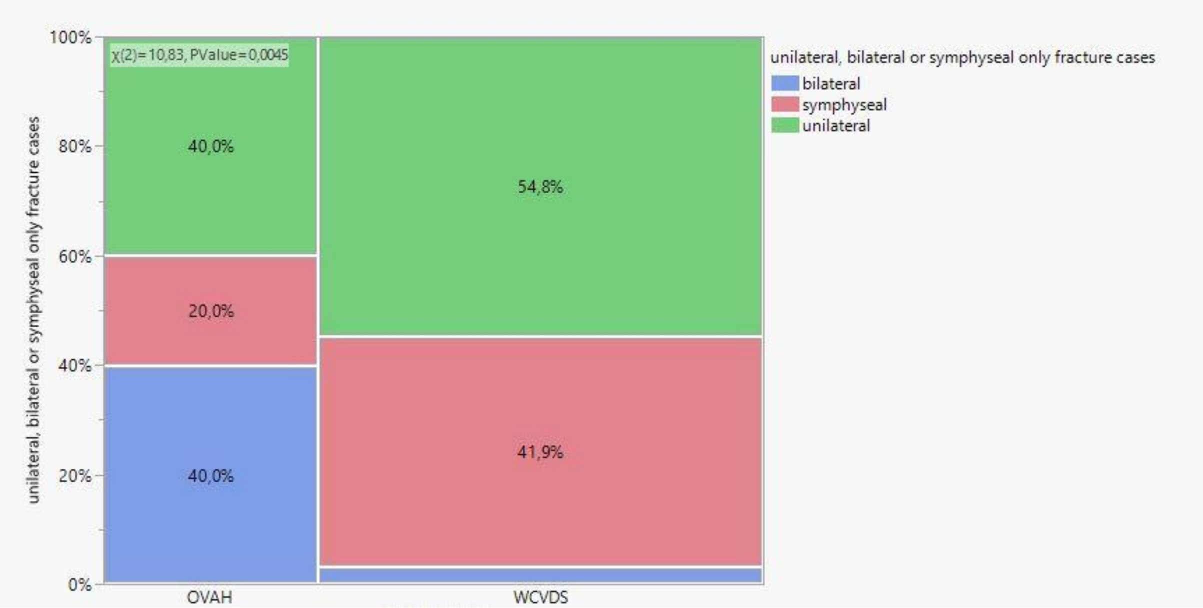

Figure 5.5: A stacked bar graph showing the distribution of unilateral, bilateral and symphyseal only mandibular fracture cases (case percentage) according to referral centre. Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

5.2.4 Fracture laterality according to aetiology

The distribution of unilateral, bilateral and symphyseal only cases of OVAH and WCVDS cats according to aetiology is shown in Table 5.10. The proportion of OVAH and WCVDS unknown aetiology bilateral, unilateral and symphyseal only fracture cases were similarly distributed to the overall proportion per referral centre. The number of known aetiology cases were too low to draw clear conclusions on the difference in fracture laterality between the two groups.

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Table 5.10: Distribution of OVAH and WCVDS unilateral, bilateral and symphyseal only mandibular fracture cases (number, percent of cases) according to aetiology.

Referral centre	Number (percentage) of unilateral, bilateral and symphyseal only fracture cases		
	Symphyseal only	Unilateral	Bilateral
Unknown aetiology			
OVAH	2/8 (25%)	3/8 (37.5%)	3/8 (37.5%)
WCVDS	9/22 (40.9%)	12/22 (54.5%)	1/22 (4.5%)
Motor vehicle accident			
OVAH	0/1 (0%)	0/1 (0%)	1/1 (100%)
WCVDS	2/3 (67.7%)	1/3 (33.3%)	0/3 (0%)
Animal encounter			
OVAH	0/1 (0%)	0/1 (0%)	1/1 (100%)
WCVDS	1/4 (25%)	3/4 (75%)	0/4 (0%)
Human encounter			
OVAH	0/0 (0%)	0/0 (0%)	0/0 (0%)
WCVDS	1/1 (100%)	0/1 (0%)	0/1 (0%)
Falling from a height			
OVAH	1/2 (50%)	0/2 (0%)	1/2 (50%)
WCVDS	0/0 (0%)	0/0 (0%)	0/0 (0%)
Iatrogenic			
OVAH	0/3 (0%)	3/3 (100%)	0/3 (0%)
WCVDS	0/0 (0%)	0/0 (0%)	0/0 (0%)
Pathological			
OVAH	0/0 (0%)	0/0 (0%)	0/0 (0%)
WCVDS	0/1 (0%)	1/1 (100%)	0/1 (0%)

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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5.3 Fracture conformation

5.3.1 Mandibular fracture conformation and regional anatomic distribution according to referral centre

Symphyseal separation was seen in all OVAH and WCVDS cases with symphyseal involvement. Caudo-ventral oblique fractures were predominant (34.6%) in the body of the mandible in the OVAH group compared to caudo-lingual oblique fractures in the WCVDS group (31.8%) (Table 5.11). Caudo-lingual oblique fractures were also second most common in the OVAH group and caudo-ventral oblique fractures second most common in the WCVDS group. Within the most affected region of the mandibular body in the OVAH group (parasymphyseal canine) and WCVDS group (canine), bucco-lingual transverse fractures were most common (30% and 33.3% respectively) (Table 5.12). However, when combining the fracture conformations centered around the canine tooth, which includes the parasymphyseal canine and canine regions, caudo-ventral oblique fractures were still most common in the OVAH group (33.3%) whilst bucco-lingual transverse fractures remained predominant in the WCVDS group (30%). All OVAH mandibular body fractures were displaced irrespective of fracture conformation and relative fracture stability (84.6% unstable and 15.4% stable fractures). In the WCVDS group, 90.9% of the mandibular body fractures were displaced irrespective of fracture conformation and relative fracture stability (68% unstable and 31.8% stable fractures).

In the caudal mandible, comminuted fractures were most common in the OVAH group (30.8%) compared to caudo-ventral oblique fractures in the WCVDS group (50%). All the OVAH caudal mandible comminuted fractures occurred in the coronoid process. All the WCVDS caudal mandible caudo-ventral oblique fractures occurred in the coronoid process. In the OVAH group, 92.3% of caudal mandible fractures were displaced irrespective of fracture conformation. In the WCVDS group all caudal mandible fractures were displaced. In both OVAH and WCVDS groups, the transverse condylar process fractures involved the neck of the condylar process. All the OVAH condylar process parasagittal fractures involved the mandibular head of the condylar processes.

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Table 5.11: Mandibular fracture conformation (number, percentage) and anatomical distribution according to referral centre with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal	6 cases: Separation (6/6, 100%)	20 cases: Separation (20/20, 100%)
Mandibular body	5 cases: Caudo-ventral oblique (9/26, 34.6%) - Long (7/9, 77.8%) - Short (2/9, 22.2%) 4 cases: Caudo-lingual oblique (4/26, 15.4%) - Long (2/4, 50%) - Short (2/4, 50%) 3 cases: Bucco-lingual transverse (4/26,15.4 %) 2 cases: Parasagittal (3/26, 11.5%) 1 case: Comminuted (3/26, 11.5%) 1 case: Dorso-ventral transverse (2/26, 7.7%) 1 case: Caudo-buccal oblique (1/26, 3.8%) - Short (1/1, 100%)	5 cases: Caudo-lingual oblique (7/22, 31.8%) - Long (3/7, 42.8%) - Short (4/7, 57.1%) 4 cases: Caudo-ventral oblique (5/22, 22.7%) - Long (3/5, 60%) - Short (2/5, 40%) 3 cases: Bucco-lingual transverse (3/22, 13.6%) 2 cases: Comminuted (3/22, 13.6 %) 1 case: Parasagittal (3/22, 13.6 %) 1 case: Dorso-ventral transverse (1/22, 4.5%)
Caudal mandible	3 cases: Comminuted (4/13, 30.8%)	4 cases: Caudo-ventral oblique (4/8, 50%) - Long (3/4, 75%) - Short (1/4, 25%)

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	2 cases: Transverse (3/13, 23%) 2 cases: Parasagittal (3/13, 23%) - Medial (2/3, 66.7%) - Lateral (1/3, 33.3%) 1 case: Caudo-lingual oblique (1/13, 7.7%) - Long (1/1, 100%) 1 case: Caudo-ventral oblique (1/13, 7.7%) - Long (1/1, 100%) 1 case: Chip (1/13, 7.7%)	2 cases: Comminuted (2/8, 25%) 1 case: Transverse (1/8, 12.5%) 1 case: Caudo-dorsal oblique (1/8, 12.5%) - Short (1/1, 100%)

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5.12: Mandibular fracture conformation (number, percentage) and anatomical distribution according to referral centre with the mandible divided into nine individual anatomical regions.

Anatomical region affected	**Number of cases with number (percent) of fracture conformations in each anatomical region**	
	OVAH	**WCVDS**
Symphyseal	6 cases: Separation (6/6, 100%)	20 cases: Separation (20/20, 100%)
Parasymphyseal incisor	1 case: Caudo-lingual oblique (1/3, 33.33%) - Long (1/1, 100%) 1 case: Caudo-ventral oblique (1/3, 33.33%) - Long (1/1, 100%) 1 case: Comminuted (1/3, 33.33%)	3 cases: Caudo-lingual oblique (3/4, 75%) - Long (1/3, 33.3%) - Short (2/3, 66.7%) 1 case: Parasagittal (1/4, 25%)
Parasymphyseal canine	2 cases: Bucco-lingual transverse (3/10, 30%) 2 cases: Caudo-ventral oblique (2/10, 20%) - Long (2/2, 100%) 1 case: Dorso-ventral transverse (2/10, 20%) 1 case: Caudo-lingual oblique (1/10, 10%) - Long (1/1, 100%) 1 case: Comminuted (1/10, 10%)	1 case: Bucco-lingual transverse (1/4, 25%) 1 case: Caudo-lingual oblique (1/4, 25%) - Short (1/1, 100%) 1 case: Comminuted (1/4, 25%) 1 case: Parasagittal (1/4, 25%)

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	1 case: Parasagittal (1/10, 10%)	
Canine	4 cases: Caudo-ventral oblique (4/8, 50%) - Long (2/4, 50%) - Short (2/4, 50%) 2 cases: Caudo-lingual oblique (2/8, 25%) - Short (2/2, 100%) 1 case: Comminuted (1/8, 12.5%) 1 case: Parasagittal (1/8, 12.5%)	2 cases: Bucco-lingual transverse (2/6, 33.3%) 1 case: Caudo-ventral oblique (1/6, 16.7%) - Long (1/1, 100%) 1 case: Caudo-lingual oblique (1/6, 16.7%) - Long (1/1, 100%) 1 case: Comminuted (1/6, 16.7%) 1 case: Parasagittal (1/6, 16.7%)
Premolar	2 cases: Caudo-ventral oblique (2/5, 40%) - Long (2/2, 100%) 1 case: Bucco-lingual transverse (1/5, 20%) 1 case: Caudo-buccal oblique (1/5, 20%) - Short (1/1, 100%) 1 case: Parasagittal (1/5, 20%)	3 cases: Caudo-ventral oblique (3/5, 60%) - Long (1/3, 33.3%) - Short (2/3, 66.7%) 2 cases: Caudo-lingual long oblique (2/5, 40%) - Long (1/2, 50%) - Short (1/2, 50%)

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Molar		1 case: Caudo-ventral oblique (1/3, 33.3%) - Long (1/1, 100%) 1 case: Comminuted (1/3, 33.3%) 1 case: Dorso-ventral transverse (1/3, 33.3%)
Coronoid process	3 cases: Comminuted (4/6, 66.7%) 1 case: Caudo-lingual oblique (1/6, 16.7%) - Long (1/1, 100%) 1 case: Caudo-ventral oblique (1/6, 16.7%) - Long (1/1, 100%)	4 cases: Caudo-ventral oblique (4/7, 57.1%) - Long (3/4, 75%) - Short (1/4, 25%) 2 cases: Comminuted (2/7, 28.6%) 1 case: Caudo-dorsal oblique (1/7, 14.3%) - Short (1/1, 100%)
Condylar process	2 cases (neck of condylar process): Transverse (3/6, 50%) 2 cases (head of condylar process): Parasagittal (3/6, 50%) - Medial (2/3, 66.7%) - Lateral (1/3, 33.3%)	1 case (neck of condylar process): Transverse (1/1, 100%)
Angular process	1 Case: Chip (1/1, 100%)	

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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5.3.2 Association of masticatory muscle biomechanical forces and relative fracture stability of oblique mandibular body fractures according to referral centre

When only considering oblique fractures, unstable oblique fracture conformations of the mandibular body were predominant in the OVAH group, with caudo-ventral oblique fractures occurring most commonly (64.3%). In contrast, stable oblique fracture conformations were predominant in the WCVDS group, of which caudo-lingual fractures were most common (58.3%) (Fig. 5.6).

All of the OVAH stable and unstable oblique mandibular body fractures were displaced, while in the WCDS group, all of the unstable and 85.7% of the stable oblique mandibular body fractures were displaced. A combination of unstable caudo-ventral oblique and stable caudo-lingual oblique orthogonal fracture conformations were noted in three of the OVAH cases and one WCVDS case.

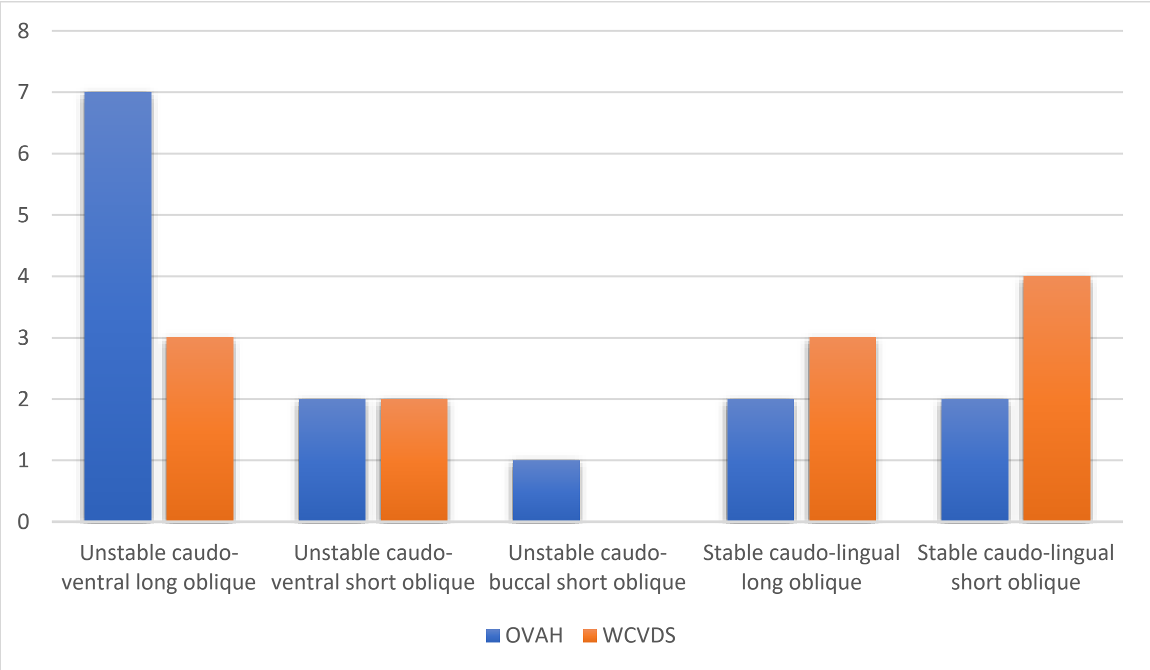

Figure 5.6: Bar graph showing the number of oblique mandibular body fracture conformations and relative fracture stability according to referral centre (OVAH: blue; WCVDS: orange) . Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

5.3.3 Mandibular fracture conformation and regional anatomic distribution according to aetiology

Mandibular fracture conformation and anatomical distribution in OVAH and WCVDS cats according to aetiology is shown in Annexure B (Tables 1 - 14). The number of known aetiology cases were too

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low to identify meaningful conclusions on the difference in mandibular fracture conformation and anatomical distribution according to aetiology between the two groups.

5.3.4 Association of masticatory muscle biomechanical forces and relative fracture stability of oblique mandibular body fractures according to aetiology

The number of oblique mandibular body fracture conformations and relative fracture stability according to aetiology is shown in Annexure C (Fig. 1 - 4). The number of known aetiology cases were too low to identify meaningful conclusions on the difference in relative fracture stability of oblique mandibular body fractures according to aetiology between the two groups.

5.4 Dental structure involvement of mandibular fractures

5.4.1 Classification of mandibular fracture involvement of dental structures according to referral centre

The OVAH (53.3%) group had a higher proportion of cases with teeth involved in a fracture line compared to the WCVDS group (38.7%). In the OVAH group, 90.9% of teeth involved in a fracture were canine teeth (Table 5.13) compared to 56.2% in the WCVDS group (Table 5.14). Of the fractures associated with tooth roots, type A was most common in both groups (72.7% OVAH, 56.2% WCVDS). The canine tooth was commonly affected by type A fractures (80% of canine teeth in a fracture in the OVAH group, 55.5% in the WCVDS group). Canine tooth type A fractures were mostly seen in the parasymphyseal canine region in the OVAH group (62.5%) and the canine region in the WCVDS group (60%).

In the OVAH group, caudo-ventral oblique mandibular fractures were most commonly seen with a canine tooth in a fracture (Table 5.13), whereas multiple fracture orientations of equal number were seen in the WCVDS group (Table 5.14). One mandibular body fracture involving a tooth in the OVAH group and three in the WCVDS group could not be classified using the type A – F classification; these fractures were seen associated with a variety of teeth (canine, third premolar, first molar), and were designated as “unclassified type” fractures.

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Table 5.13: Dental fracture type (A - F) of the OVAH according to tooth involvement, region affected and fracture conformation.

Tooth involved in fracture (number)	Fracture type A - F (number)	Mandibular region (Number)	Mandibular fracture conformation (Number)
First incisor tooth (1)	B (1)	Parasymphyseal incisor (1)	Comminuted (1)
Canine tooth (10)	A (8)	Parasymphyseal canine (5)	Bucco-lingual transverse (2) Dorso-ventral transverse (2) Caudo-lingual long oblique (1) Caudo-ventral long oblique (1) Comminuted (1) Parasagittal (1)
		Canine (3)	Caudo-lingual short oblique (1) Caudo-ventral long oblique (1) Caudo-ventral short oblique (1) Comminuted (1)
	B (1)	Canine (1)	Caudo-ventral long oblique (1) Parasagittal (1)
	Unclassified (1)	Parasymphyseal canine (1)	Bucco-lingual transverse (1)

Abbreviation: OVAH, Onderstepoort Veterinary Academic Hospital.

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Table 5.14: Dental fracture type (A - F) of the WCVDS according to tooth involvement, region affected and fracture conformation.

Tooth involved in fracture (number)	Fracture type A - F (number)	Mandibular region (Number)	Mandibular fracture conformation (Number)
First incisor tooth (1)	A (1)	Parasymphyseal incisor (1)	Caudo-lingual short oblique (1)
Second incisor tooth (1)	A (1)	Parasymphyseal incisor (1)	Parasagittal (1)
Canine tooth (9)	A (5)	Parasymphyseal canine (2)	Comminuted (1) Parasagittal (1)
		Canine (3)	Caudo-lingual long oblique (1) Comminuted (1) Parasagittal (1)
	B (2)	Parasymphyseal canine (2)	Bucco-lingual transverse (1) Caudo-lingual short oblique (1)
	C (1)	Canine (1)	Bucco-lingual transverse (1)
	Unclassified (1)	Canine (1)	Caudo-ventral long oblique (1)
Third premolar tooth (1)	Unclassified (1)	Premolar (1)	Caudo-ventral short oblique (1) Caudo-lingual short oblique (1)
Fourth premolar tooth (1)	A (1)	Premolar (1)	Caudo-ventral short oblique (1)
First molar tooth (3)	A (1)	Molar (1)	Dorso-ventral transverse (1)
	B (1)	Molar (1)	Comminuted (1)
	Unclassified (1)	Molar (1)	Caudo-ventral long oblique (1)

Abbreviation: WCVDS, West Coast Veterinary Dental Services.

Other mandibular dental pathology (excluding teeth in a fracture line) noted in 46.7% of OVAH and 38.7% of WCVDS cats included a combination of missing incisors, incisor root fractures, incisor root fracture and avulsions, incisor crown root fractures, incisor complicated crown fractures, canine periapical pathology, canine subluxation, canine complicated crown fractures, canine root fractures and periodontal disease. Overall, when including the cases with teeth involved in fracture lines, 60% of the OVAH and 58% of the WCVDS cases presented with traumatic dentoalveolar injuries.

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5.4.2 Classification of mandibular fracture involvement of dental structures according to aetiology

The involvement of specific teeth in a fracture with associated fractured anatomical region and mandibular fracture conformation in OVAH and WCVDS cats according to aetiology is shown in Annexure D (Table 1). Clear conclusions of mandibular fracture involvement of dental structures between the two groups could not be drawn due to the small sample size per fracture aetiology.

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Chapter 6: Discussion

This study investigated the aetiology and demographics of feline mandibular fracture cases from two referral practices in opposite hemispheres of the world, the distribution and conformation of feline mandibular fractures, and the conformation of feline mandibular fractures associated with dental structures. Due to the low number of cases of which the cause of mandibular fractures was known, numerous associations between the aforementioned could not be statistically analysed and clear conclusions could not be drawn. However, where possible, trends and data patterns were analysed and discussed.

6.1 Aetiology and demographic variables

Motor vehicle accidents are a major cause of feline mandibular fractures (37.5-75.5%[10,14,15] of cases) and temporomandibular joint injuries (30.5-32.9%[13,37] of cases), whilst falling from a height has been reported with variable predominance (2.2-62.5%[13-15,37] of cases). Mandibular fractures and traumatic temporomandibular joint injuries sustained during animal altercations is less commonly reported (1.2-16.5%[13,14,37]). Unknown aetiology of feline mandibular fractures and traumatic temporomandibular joint injuries range from a lower prevalence (13.4-17.7%[10,13,14] of cases), to a higher prevalence in a recent study (31.6%[37]). Contrary to the aforementioned studies, the most common cause of mandibular fractures from both referral centres in our study was unknown aetiology (53.3% OVAH and 71% of WCVDS cases, respectively). The most common known aetiology in our study differed from the literature, with iatrogenic aetiology being most common in the OVAH group (20%) and animal encounter most common in the WCVDS group (12.9%). Since we had such a large unknown aetiology component to this study, it is not possible to draw many conclusions compared to previously published studies.

Multiple factors have been reported as possible reasons for the variation in the aetiology of mandibular fractures, which could have also played a role in the two groups studied. Some of these factors include human population density, human socioeconomic factors and lifestyle, animal population density (domestic/feral cats and dogs, wildlife), sex, sterilisation status, urban or rural locations, urban-rural interface, number of vehicles on the road, degree of environmental lighting and seasonality[10,13,14,37,60-68].

The reason for the higher proportion of unknown aetiology cases in our study compared to previous studies is unclear. It is possible that differences in regional and geographic socioeconomic factors, working from home or from a remote office, and lifestyle of people associated with the location of different studies may have influenced the number of traumatic events being witnessed.

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The proportion of animal encounter cases was higher in both the OVAH and WCVDS groups in comparison to previous studies, and the proportion of WCVDS animal encounter cases was also higher compared to the OVAH group. Apart from the low number of cases in our study with a high proportion of unknown aetiology cases which likely influenced our results, the animal population density around OVAH and WCVDS may have been higher in comparison to the locations in previous studies, resulting in a higher number of animal encounter cases. Animal altercation (dog fights) has been reported as the main cause of mandibular fractures in dogs presenting to the OVAH, which may also be a factor increasing animal altercations involving OVAH cats[16]. Additionally, the fact that the OVAH is situated on the outskirts of a suburban region of a city bordering a rural landscape with vervet monkey and chacma baboon troops in close proximity, and WCVDS is situated in a suburban region of a large city with a coyote population present, which has been reported to attack and prey on domestic animals within the city [69,70], may have resulted in increased traumatic incidents due to animal encounters. In support of the previously mentioned, 50% of the WCVDS animal encounter cases were known to be coyote attacks. The higher proportion of animal encounter cases in the WCVDS group compared to the OVAH group is also not unexpected given the coyote population residing within the city and suburban areas.

Young cats with mandibular fractures and temporomandibular joint injuries are over-represented in comparison to older cats, with previous studies reporting 53.2%[10] of cats less than or equal to 1 year of age, 63.4%[13] of cats less than or equal to 2 years of age, 87%[10] less than or equal to 4 years of age, 71.1%[14] less than 5 years of age, and only 4.9%[13] older than 6 years. The reason for the higher percentage of young cats could be explained due to their inexperience with dangerous situations, reckless playing behaviour, and the higher probability of roaming activity in younger sexually intact animals[10,35]. Young dogs have lower bone mineral content and density compared to mature dogs, which has been hypothesised as a possible reason for the predisposition of young dogs to mandible fractures during traumatic incidents[16,71,72]. It is possible that similar bone physiology in cats may also be a factor involved in the over-representation of young cats with mandible fractures in previous studies. However, in contrast to previous studies, the age groups of cats in our study were relatively uniformly spread, with young cats not over-represented and the inclusion of a larger proportion of older cats (33.3% of OVAH and 12.9% of WCVDS cases less than or equal to 2 years of age, 40% of OVAH and 58% of WCVDS cases older than 6 years). The lower number of younger cats seen in our study may be due to several reasons: 1) due to the fact that both the OVAH and WCVDS are referral centres, it is possible that many of the less severe cases are treated by primary veterinarians, whilst the severe cases are either euthanised or succumb to associated injuries before referral, which may influence the age distribution; 2) it is the author's opinion that a minority of the OVAH clientele have pet medical insurance which would also preclude referral; 3) the OVAH is located in a poor socioeconomic location. In comparison,

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a larger proportion of older cats in the WCVDS group is likely due to WCVDS being situated within an affluent city where most owners are able to afford referral care.

Similar to previous studies of cats with mandibular fractures and temporomandibular joint injuries which reported a higher number of male cats[10,13-15,37], our study also included more males than females, however, this difference in sex was not statistically significant. The predominant sterilisation status of cats with mandibular fractures varies between studies, with reports describing predominantly sterilised males and females[14], predominantly intact males and females[13], predominantly intact males and sterilised females[15] and relatively similar numbers of sterilised and intact males and females[34]. In both groups, all the females, 75% of OVAH males and 94% of WCVDS males were sterilised. It has been hypothesised that intact males (and intact cats) are over-represented due to a higher probability of roaming activity, territorial behaviour and aggression[10,13,68]. However, other studies involving predominantly sterilised cats, or a similar number of sterilised and intact cats, concluded that sex hormone influence is not an important predisposing factor for feline mandibular fractures[34]. The variation in the predominant sterilisation status of cats with mandibular fractures is likely related to the fact that studies evaluating the effect of sterilisation on feline behaviour have also reported conflicting results. One of these studies found a pronounced decline (not elimination) in fighting, roaming and urine spraying in over half of the cases after sterilisation, with a gradual decline to no change in these behavioural displays in the remaining cases[66]. It was also noted that some individuals displayed a reduction in some, not all, of these behaviours[66]. Another study reported a reduction of aggressive behaviour in sterilised cats in the absence of food, whilst in the presence of food similar pre-sterilisation aggressive behaviour was displayed[63]. Territorial behaviour is not influenced by sterilisation, with a study reporting no significant difference in the size or overlap of territories of intact and sterilised cats[65]. In the same study, movement of cats between natural habitats and human populated areas was commonly recorded, regardless of sex or sterilisation status[65]. Therefore, we can propose that there is a complex interplay between sexually driven/hormonally influenced behaviour, the effect of social structure, and environmental influences in the behaviour of cats predisposing involvement of both sterilised and intact cats in traumatic incidents.

The most common breed involved in our study was the domestic shorthair, which represented similar proportions of cases in the OVAH and WCVDS groups (73.3% and 74.2% respectively). Domestic shorthair cats were also reported as the most common breed in other studies of cats with mandibular fractures (86.7-98.9%[14,30] of cases). The domestic shorthair breed is a common breed, hence, it is the author's opinion that this breed was over-represented in our study due to the number of domestic shorthair cats within the hospital population and not due to a breed predisposition to mandibular fractures per se. Statistical analysis comparing the entire hospital patient population for the study time

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period to the breeds of cats presenting with mandibular fractures would be needed to confirm this statement.

6.2 Single and multiple fractures

The proportion of single and multiple fracture cases were respectively lower and higher in the OVAH group (40% and 60%) compared to the WCVDS group (64.5% and 35.5%), although the difference was not statistically significant. However, given the higher proportion of multiple fractures in the OVAH group, the mean number of fractured anatomical regions per OVAH cat (2.3) was significantly higher (P = 0.022) compared to the WCVDS group (1.6). The proportional difference in the number of single and multiple fracture cases in the OVAH group is relatively similar to a previous study which reported 30.8%[14] single fracture cases, and 74.4%[14] multiple fracture cases, whilst the proportional difference in the WCVDS group is relatively similar to another study which reported 79%[10] single, and 21%[10] multiple fracture cases. Several reasons are proposed as explanations for the difference in the proportion of single and multiple fracture cases and the difference in the number of fractured anatomical regions. Three-dimensional multiplanar reconstruction of CT studies, without anatomical superimposition of complex skull anatomy, facilitates accurate identification of bone lesions, whereas superimposition of anatomy in radiographic studies may hinder accurate identification of bone lesions and subtle fractures might be overlooked[12-14,22,31,37]. Therefore, the results of the former study[14] reporting a higher proportion of multiple fractures is expected as CT scans of included cats were evaluated, whilst the latter study[10] reporting a lower proportion of multiple fractures is also expected as radiographic studies of included cats were evaluated. In our study, 46.7% of OVAH cases had CT scans whilst all WCVDS cases were radiographic studies, which is possibly a reason for more fractures being recorded in the OVAH group. Additionally, in both groups the majority of radiographic cases did not include radiographs of the entire mandible or orthogonal views. As these cases presented to referral centres it is presumed that all fractures were accurately localised during clinical examination and appropriate radiographic studies were acquired. However, in the presence of more serious fractures it is possible that subtle fractures in other regions of the mandible were not included in the radiographic views. It is also possible that minor or non-surgical fractures, even if identified clinically, were not radiographed due to the fact that it would not alter the treatment plan or due to financial constraints. One of the main factors possibly influencing the number of fractured regions is the nature of the traumatic event (aetiology as well as direction, force, velocity and severity of impact); motor vehicle accidents result in a higher probability of more anatomical regions being fractured in comparison to other fracture aetiologies due to greater impact velocity and force of impact[73]. A relatively high probability of multiple fractures due to animal bites has also been reported[73]. Single mandibular fractures are predominantly reported in cats falling from a height[34,35,39]. Reasons for a reduced degree of mandibular trauma during falling include, 1) cats having the ability to change position during a fall to land feet first; 2) when falling from greater heights reaching

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terminal velocity the limbs are orientated horizontally (similar to a flying squirrel) resulting in the body striking the ground first, absorbing most of the impact which is distributed over a larger surface area, and the head hitting the ground second[34,35,39]. Whilst the aforementioned concepts are sound, it could be argued that a motor vehicle accident may at times be low velocity, for example a pet driven over in the driveway of a home, and other traumatic events such as animal altercations, being kicked or assaulted with a blunt object may vary in levels of aggression and strength resulting in either high or low-velocity injuries. The severity of injury when falling from a height is also difficult to predict as it depends on the height of the fall, objects in the path of the fall, the landing surface and the dexterity of the cat[35,39]. When falling from a height, the distance may be such that the cat does not have enough time to orientate into a position of maximum impact protection or feet landing first position[34,38]. Obstacles in the path of the fall (fire escapes, balcony railings, awnings, trees, pot plants, metal structures used for hanging laundry) may break a fall or may result in an untimely spin, tumbling fall and awkward landing[38,39]. Therefore, it is considered that multiple aetiologies have the potential of being low or high-impact traumatic events with a resultant varying probability of single or multiple fractures. Due to the low number of known aetiology cases in our study, this theory could not be reliably assessed, however, the motor vehicle accident and animal encounter cases in the WCVDS group, as well as the falling from a height cases in the OVAH group, had both single and multiple fracture cases which is in agreement with the aforementioned theory. Additionally, further support to the theory that multiple trauma aetiologies may result in single or multiple fractures lies in the fact that, 1) the mean number of fractured regions per cat in the motor vehicle accident and animal encounter categories ranged from 1.3 (WCVDS) to five (OVAH) and from 1.5 (WCVDS) to three (OVAH) respectively; 2) a previous study of dogs and cats with maxillofacial trauma due to a variety of causes also reported a relatively high average number of fractures per animal[12]. The author, therefore, postulates that even though the OVAH group likely included more higher velocity traumatic events such as motor vehicle accidents and animal bites resulting in a higher number of multiple fractures, and the WCVDS group more lower velocity traumatic events such as falling from a height resulting in a higher number of single fractures, multiple fractures aetiologies may result in single or multiple fractures.

6.3 Open and closed fractures

The classification of open and closed fractures by assessing radiographs and/or CT scans proved challenging for the following reasons: 1) In some of the OVAH cases which had radiographic and CT images, gas was noted associated with the fracture site on the CT images, however, not on the radiographic images; 2) The radiographic studies did not always include orthogonal views for all fracture sites which would affect the orientation of gaseous foci being struck by the x-ray beam, and in turn, affecting visualisation, especially if small or subtle gas foci were present; 3) Some cases with severe maxillofacial trauma and fractures presented with diffuse soft tissue emphysema associated with

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the entire maxillofacial and mandibular region, which made it difficult to reliably identify the origin of gas associated with a specific fracture, either being truly due to an open fracture or due to gas tracking from other lesions and fractures; 4) The origin of gas in soft tissues adjacent to multiple fractures was difficult to interpret as being from a specific open fracture site, or a combination of open fracture sites; 5) It is also possible that gas within the soft tissues adjacent to or associated with a fracture was not specifically due to an open fracture but rather a soft tissue lesion sustained during the traumatic event; and 6) Lastly, the clinical data records did not include which fractures were open or closed as noted on clinical examination, which would have facilitated the imaging conclusion by being the “gold standard” of identification of open or closed fractures. Due to these challenges no results were possible for this part of the study.

6.4 Mandibular fracture distribution with the mandible divided into three grouped anatomical sections

When dividing the mandible into three grouped anatomical sections (symphyseal, mandibular body, caudal mandible), results from our study indicated that the mandibular body was most commonly fractured in the OVAH group (60% of cases), whilst the symphysis was most commonly affected in the WCVDS group (64.5% of cases), although not statistically significant. The results of the WCVDS group are relatively similar to two previous studies which also identified symphyseal separation as being most common (73.3%[10] of fractures, 64.1%[14] of cases). The number of mandibular body fracture cases of the OVAH group (60%) was higher than in previous studies (16%[10] of fractures, 38.5%[14] of cases). Contrary to the OVAH group, the WCVDS group had a similar number of mandibular body fracture cases (40.9%) as seen in the latter study[14]. A possible reason for the lower percentage of symphyseal separation cases in the OVAH group may be the small sample size in our study. The difference in fracture aetiologies in our study, between the two groups and compared to other studies would also influence the distribution of fractures. Traditionally, falling from a height has been reported as a common cause of symphyseal separation[10]; however, more recently numerous studies of HRS have reported a much lower proportion of cats with symphyseal separation (2.9 - 7.1%[30,34,35]). Therefore, it is debatable whether the WCVDS unknown aetiology cases might have been due to more cases of cats falling from a height, resulting in a higher number of symphyseal separations. The higher percentage of mandibular body fractures in the OVAH group compared to the previous two studies[10,14] could be due to differences in anatomical division of the mandible. The study by *Tundo et al*. (2019) grouped the symphyseal and parasymphyseal regions together. In this study, the symphysis, due to the fact that it is a fibrocartilage structure, was grouped on its own and the parasymphyseal region grouped with the mandibular body. The addition of the parasymphyseal region fracture cases to either the symphyseal separation cases or the mandibular body fracture cases, would therefore be a relevant factor. In the study by *Umphlet et al*. (1988) the distribution diagram of mandibular body fractures annotates the premolar

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and molar region without specifying if fractures of the rostral mandible (corresponding to the parasymphyseal and canine regions in our study) were also grouped together, which may be a reason for the markedly lower proportion of mandibular body fractures seen in that study. It is the opinion of the author that future mandibular fracture studies should use the same regions, as described in this study, in order to allow for better comparison.

Caudal mandible fracture cases were more common in the OVAH group (46.7%) in comparison to the WCVDS group (22.6%), although not statistically significant. Caudal mandible fractures were also more common than symphyseal separation in the OVAH group. The results of the OVAH group are comparable to the results of other studies which reported higher percentages of caudal mandible fractures in cats (56.4%[14] cats with condylar fractures, 50.9%[13] of cats with traumatic temporomandibular joint lesions). In contrast, one study reported a low percentage of caudal mandible fractures (10.7%[10]) comparable to the WCVDS group. Possible reasons for a higher proportion of caudal mandibular fractures being identified in the OVAH group compared to the WCVDS group include the previously mentioned limitations of the radiographic studies and the superiority of CT at identifying mandibular fractures, especially in the region of the caudal mandible[12-14,22,31,37]. Fracture aetiology is also a factor that could result in a proportional difference of caudal mandible fractures. The OVAH cats were likely subjected to higher velocity and higher force traumatic events (see previously) compared to the WCVDS cats. None of the WCVDS cats had skull CT scans which may also have reduced the number of caudal mandible fractures identified.

6.5 Mandibular fracture distribution with the mandible divided into nine individual anatomical regions

When dividing the mandible into nine anatomical regions the results indicated that the most commonly fractured region of the mandibular body centered around the canine tooth in both groups, with the parasymphyseal canine region significantly more fractured in the OVAH group ($P = 0.036$) and the canine region predominantly fractured in the WCVDS group. The canine region was also the second most commonly fractured region in the OVAH group. When combined, the parasymphyseal canine and canine regions were fractured in 60% of OVAH cases, representing 34.2% of fractured regions. In the WCVDS group, it was fractured in 25% cases, representing 20.4% of fractured regions.

In small dogs, the roots of the first mandibular molar tooth are relatively larger with a significantly reduced mandible to first molar height ratio, which has been regarded as a weak point, predisposing the mandible to mandibular molar region fractures[23]. The “weak point” is hypothesised on the fact that the large molar tooth is embedded in a comparatively smaller amount of bone with a large amount of supporting soft tissues (periodontal ligament)[23]. Due to the fact that the mandible of the dog is relatively

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longer, which creates the potential of a lever effect on the mandible by a traumatic force, the ratio of increased root size is also suggested to act as a stress riser predisposing the mandible to fractures in the molar region of small dogs[16]. In cats, the mandible is relatively shorter and stubby, therefore, the potential of a lever-action on the mandible by a traumatic force is reduced. It is proposed that a traumatic force is more likely focussed rostrally, around the canine tooth. Due to the relatively large canine tooth, a similar concept can be proposed, which possibly predisposes the canine tooth region (parasymphyseal canine and canine anatomical regions) in cats to a higher risk of fractures compared to the other regions during traumatic events. Furthermore, studies investigating dentoalveolar trauma in cats and dogs have also reported the canine teeth being commonly associated with and predisposed to dentoalveolar injuries secondary to traumatic events, likely due to their vulnerable anatomical location and use during prehension and defence[30-32,36]. With this in mind, it is possible that a traumatic force applied to the crown of a canine tooth would have a lever-action force directed into the alveolus that can potentially result in a mandibular fracture. Therefore, the increased association of canine tooth dentoalveolar injuries with traumatic events may also be a reason for the higher proportion of mandibular fractures in this region.

In the caudal mandible, condylar process fractures were slightly more common than coronoid process fractures in the OVAH group, whilst coronoid process fractures were predominant in the WCVDS group. Overall, the proportion of mandibular condylar process fractures were significantly higher in the OVAH group ($P = 0.016$) compared to the WCVDS group. Temporomandibular joint lesions were seen in 46.7% of the OVAH cats compared to other studies of cats with maxillofacial injuries reporting 50.9%[13] and 66.7%[14] cats with temporomandibular joint lesions. Of the temporomandibular joint lesions, condylar process fractures were most common in our study with subluxation/luxations second most common, which is similar to findings in other studies[13,14,37]. In contrast, condylar process fractures have also been reported as rare (6.7%[10] of mandibular fractures), which is comparable to the WCVDS group recording a lower proportion of temporomandibular joint lesions (3.2% of cases). Reasons for a lower proportion of temporomandibular joint lesions and condylar process fractures seen in our study (specifically in the WCVDS group) include, 1) the previously mentioned potential differences in fracture aetiology, with higher velocity, greater traumatic force events likely occurring in the OVAH group and lower velocity, lower traumatic events likely occurring in the WCVDS group; and 2) the previously mentioned imaging limitations. All the mandibular head of the condylar process fractures were parasagittal in orientation with no to minimal displacement and only identified in the CT studies of the OVAH group, which would be difficult to identify on a lateral radiograph; therefore, the limitations of the included radiographic studies, specifically the absence of ventro-dorsal views of the condylar processes and the absence of CT imaging could have affected the results. Additionally, as mandibular head condylar process fractures may not result in malocclusion and may be difficult to detect on physical examination, especially in the presence of other more serious or prominent fractures, it is possible that radiographs of the condylar processes were not deemed clinically necessary which

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may have resulted in a lower presentation in our study[13,74]. Furthermore, due to the fact that condylar process fractures may be treated conservatively, a full radiographic workup may not have been acquired, whilst rather being focussed/limited to a region of potential surgical interest[13]. However, in light of the aforementioned it is in the clinician's interest to motivate the client to permit imaging of the temporomandibular joints as clinically significant complications of temporomandibular joint lesions could result in joint pain, degenerative joint disease, reduced range of motion and ankylosis, which could be more accurately communicated and prognosticated after thorough imaging[73].

Fractures of the mandibular condylar process have been reported as being associated with separation of the mandibular symphysis as well as associated with fractures of the rostral mandibular body and mandibular ramus[13,41]. A statistically significant association of the mandibular condylar process with other regions was not seen in our study, however, a similar trend was seen with all condylar process fractures occurring with at least one other fracture in the other regions. A moderate positive correlation between condylar neck fractures and fractures of the vertical ramus of the mandible has also been reported[14]. The results of this study also showed a similar trend with all of the condylar neck fractures occurring with coronoid process fractures, however, due to the low number of cases (three) statistical analysis was not possible. The anatomical proximity and continuity of the mandibular condylar process with the coronoid process is proposed as a mechanism which facilitates the association of fractures in these regions. Another proposed mechanism explaining the association of condylar process fractures with symphyseal separation, and rostral mandibular fractures, involves the transmission of a traumatic force from the rostral aspect of the mandible along the mandibular body to the caudal mandible, from which the impact of the condylar process against the mandibular fossa and retroarticular process could result in a fracture. A lower incidence of coronoid and condylar process fractures in another study[10] has been hypothesised to be due to the protection afforded by the masseter muscle and zygomatic arch, which might explain the lower number of condylar process fractures in the WCVDS group, however, does not explain the relatively higher number of WCVDS coronoid process fractures, or the fact that most of the OVAH coronoid process fractures were comminuted. In the previous study, 53%[10] of cases were due to motor vehicle accidents, which are traditionally considered high-velocity traumatic incidents, however, could also be low-velocity traumatic incidents as previously discussed. Hence, whilst this protection theory may be true for a relatively lower velocity lateral or oblique directed force of impact, it is possible that a higher velocity lateral force or the propagation of a traumatic force along the longitudinal axis of the mandible, from rostral to caudal, will not be reduced by the masseter muscle or zygomatic arch. In comparison, given the higher percentage of caudal mandible fractures in both the OVAH and WCVDS groups, the aforementioned protection was not considered a major factor in our study.

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An important additional point of discussion is the comparison of the percentage of fracture cases to the percentage of fractured regions represented by the anatomical divisions of the mandible. The reason for this is that the mandibular body and caudal mandible may incur complex multiple fractures of greater extent, and clinical significance, in comparison to the symphyseal region (which is effectively a single lesion region) yet would be underscored in proportion as reported in a case percentage basis. This may in turn influence clinical anticipation, surgical planning, treatment and prognosis. The point is illustrated by the WCVDS group; even though the symphysis was the most affected when considering the number of cases (64.5%), when considering the number of fractured anatomical regions, the mandibular body had a higher number of fractured regions (42.8%) compared to the symphysis (40.8%). Even though the proportions in the previous example are only slightly different, the principle is still illustrated. It is feasible that more robust examples occur in other populations of cats with mandibular fractures which would highlight the relevance of comparing the percentage of fractured regions to the percentage of fracture cases.

6.6 Fracture laterality

The number of unilateral and bilateral fracture cases were the same in the OVAH group (40% respectively) whilst the WCVDS group had a higher percentage of unilateral fracture cases (54.8%) and very few bilateral fracture cases (3.2%). The proportion of unilateral cases, bilateral cases and cases with symphyseal separation only were significantly different between the OVAH and WCVDS groups ($P = 0.004$). The reason for this is most probably the higher velocity/forces that the OVAH group of cats experienced (as previously stated) as well as the limited radiographic evaluations of the WCVDS cats. A previous study reported 18%[14] bilateral mandibular fractures in cats, however, it is understood that this study defined bilateral fractures as affecting the same regions of the mandible (symmetrical sides of the mandible), which is likely a reason for the lower percentage compared to the OVAH group as bilateral fractures in our study were defined as the presence of any fractures on both mandibles, irrespective of symmetry. When defining bilateral fractures and anatomical regions in the same fashion as the aforementioned study[14], the OVAH group recorded 13.3% bilateral fracture cases, whilst there were no bilateral fractures in the WCVDS group. One of the bilateral symmetrical fractures in the OVAH group involved the parasymphyseal region, which was grouped with the symphysis in the previous study, and was thus not counted as bilateral in this comparison; if it were to be included, the bilateral fracture cases in the OVAH group would be 20%, which is similar to the referenced study[14]. The study also reported that bilateral rostral mandibular fractures and angular process fractures are rare, and bilateral caudal mandible fractures more common[14]. Despite our low case numbers, when describing OVAH bilateral fracture cases according to the method of the previous study[14], a similar trend of bilateral fractures more commonly involving the caudal mandible was seen. Bilateral temporomandibular joint injuries have been significantly associated with falling from a height due to a

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frontal force being simultaneously directed from rostral to caudal along the mandible into the temporomandibular joints[37]. Due to low case numbers, this association with aetiology could not be evaluated in our study, however, one of the two OVAH cases with bilateral temporomandibular joint fractures was due to falling from a height, whilst the other was due to an animal encounter.

Cases without any laterality were those involving only symphyseal separation without other concomitant fractures. A large proportion of only symphyseal separation cases (41.9%) were seen in the WCVDS group, which is not surprising, as 64.5% of the WCVDS cases had symphyseal separations. A reason for the high number of cases with symphyseal separation only could be explained as follows, because the fibrocartilage mandibular symphysis has been hypothesised to represent a weak point in the mandible[10,16], it is proposed that the symphysis separates first during a traumatic event before structurally harder bone fractures, which results in the dissipation of trauma energy with less residual energy available to be transmitted throughout the rest of the mandible causing other fractures. The WCVDS results support this theory, with only 22.6% of cases that had symphyseal separation and concomitant fractures, in comparison to 41.9% of cases that only had a symphyseal separation without concomitant fractures. The results of the OVAH group did not support this theory due to equal numbers of cases only involving symphyseal separation and cases involving symphyseal separation with concomitant fractures (20% respectively). It must be borne in mind that the OVAH group is under-powered in sample size compared to the WCVDS group which may influence the results due to inaccurate case representation, however, overall, there was no statistically significant difference between the proportion of OVAH and WCVDS cases with symphyseal separation only, symphyseal separation with other fractures, and fractures without symphyseal separation. Contrary to the aforementioned theory and the supporting results of the WCVDS group, a previous study reported all cats with symphyseal separation and/or parasymphyseal fractures had additional fractures, with an 84.6% chance of another fracture occurring in the mandible, and a 73.1% chance of another fracture occurring in the skull[14]. There was no statistically significant association between symphyseal and/or parasymphyseal fractures with another mandibular fracture in our study. Due to the study being focussed on mandibular fractures, an association with skull fractures was not evaluated. The difference in findings of our study, compared to the previous study, is possibly related to the nature of the traumatic event. As previously mentioned, high-velocity trauma with high impact force has been reported to result in a high probability of multiple fractures, of which motor vehicle accidents are most commonly reported, with animal bites also implicated[73]. Thus, it is likely that the previous study had more high velocity impact events in comparison to our study, which is supported by the fact that 75% of the cases were due to motor vehicle accidents[14].

An interesting finding is the fact that both the OVAH and WCVDS groups presented with a higher proportion of unilateral right-sided fracture cases in comparison to unilateral left-sided fracture cases (OVAH: right 33.3%, left 6.7%; WCVDS 32.3% right, 22.6% left). The reason for this is unclear,

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however, may be reasoned based on studies of human maxillofacial trauma due to violence; it has been suggested that cerebral hemispheric dominance plays a role in reflex manoeuvres leading to trauma victims turning to a specific direction to avoid injury[75]. Cerebral lateralisation has also been suggested in cats with results of a feline study investigating paw preference indicating a 49.5%[76] right sided preference compared to 40.4%[76] left sided preference. Even though the aforementioned paw preference was not statistically significant, their findings, in combination with the results of human studies may be of value when extrapolated to our study. It is considered that a possible right-sided preference may suggest a stronger, more agile and dexterous side, resulting in these cats bracing the right side against impact or leading with the right side in an attack or defence, which could explain the higher proportion of right sided fracture regions. Despite our low case numbers of known aetiology fractures, our results also suggest a compatible trend with the unknown aetiology, motor vehicle accident and animal encounter cases from both referral centres featuring a higher proportion of right-sided fractures. Only the iatrogenic and pathological fracture cases were predominantly left-sided. This theory is proposed with a degree of caution as further studies with larger sample sizes are needed to evaluate its validity.

6.7 Mandibular fracture conformation and regional anatomic distribution

The typical transverse conformation of symphyseal separation was expected given the dorso-ventral orientation of the fibrocartilage mandibular symphysis. Several fracture conformations occurred throughout the body of the mandible in both groups, however, due to numerous conformations being recorded in relatively low numbers, statistical analysis was not possible. Caudo-ventral oblique fractures (specifically long oblique) were predominant in the OVAH group whereas caudo-lingual oblique fractures (specifically short oblique) were predominant in the WCVDS group. Interestingly, the second most common fractures in the body of the mandible in the OVAH and WCVDS groups were also caudo-lingual oblique and caudo-ventral oblique respectively, therefore, overall these two orthogonal fracture conformations were predominant in the mandibular body of both groups. In both groups the predominantly fractured region centered around the canine tooth, represented by the parasymphyseal canine region in the OVAH group, which was significantly higher in proportion to the WCVDS group, and the canine region in the WCVDS group. Within these regions multiple fracture conformations occurred, with bucco-lingual transverse fractures being most common in both groups. However, when combining the fracture conformations centered around the canine tooth (parasymphyseal canine and canine regions) caudo-ventral oblique fractures were still most common in the OVAH group, whilst bucco-lingual transverse remained most common in the WCVDS group. Fracture conformation depends on intrinsic and extrinsic factors[7,16]. Intrinsic factors include patient factors such as anatomical characteristics of the bone involved (shape, strength, size), attached and surrounding soft tissues, and associated dental structures, whereas extrinsic factors include trauma aetiology and the force of the trauma[7,16]. As the demographic profile of the cats in our study were

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relatively similar, with no significant difference in sex, age and weight between the two groups, it suggests that the intrinsic factors between the two groups would also be relatively similar. Therefore, it would be intuitive to assume that the extrinsic factors, which should vary between cases, could have a predominant effect on mandibular fracture conformation. However, given that the two most common fracture conformations in the body of the mandible in both groups were relatively similar it is considered that the intrinsic factors may play a larger role in dictating the response of the mandible to trauma leading to overall similar fracture conformations in the two groups in that region. Further studies with a larger cohort of known aetiology cases would be needed to further investigate this theory. In one study of molar region mandibular fractures in dogs, caudo-ventral oblique and caudo-lingual oblique fractures were also most common[7]. Similarly, another study of mandibular body fractures in dogs reported caudo-ventral oblique fractures as most common[1]. The tension surface of the mandible which is located on the dorsal surface or alveolar margin was proposed as a reason for the predominance of caudo-ventral oblique fracture propagation in the previous study[7]. The biomechanical forces exerted on the mandible by the masticatory muscles, especially the dorso-caudal force applied to the caudal mandible when closing the mouth, may also predispose to this fracture conformation during a traumatic event due to possible intentional or reflex activation of these muscles at the time of fracture propagation. In a similar manner, reflex or intentional opening of the mouth during a traumatic event at the time of fracture propagation will result in a caudo-ventrally directed force exerted on the mandibular body by the digastricus muscle, which could also predispose to caudo-ventral oblique fracture orientation. In addition, or independent to the aforementioned, trauma force direction may also result in a caudo-ventrally directed force being exerted on the mandibular body with the propagation of similar fracture conformation. In the previous study[7], the presence of the large mandibular first molar tooth and other anatomical factors leading to fracture propagating along a path of least resistance, such as possible thinning of the lingual cortical bone plate, were also proposed as reasons for the predominant oblique fracture conformation. In our study, the predominant OVAH oblique fracture conformation seen with a canine tooth in a fracture was caudo-ventral oblique. In comparison, in the WCVDS group multiple fracture orientations of equal number were seen with the canine tooth included in a fracture line. Therefore, the results of the OVAH group follow a similar trend to the aforementioned study[7], proposing a similar association of a larger tooth (canine tooth in our study) creating a weak point for fracture propagation in a caudo-ventral direction. The natural caudo-ventrally directed position of the canine tooth root is also a possible factor predisposing to this fracture conformation. It is feasible that the non-standardised imaging studies of the included cases in the two groups influenced the distribution, number and predominant types of fracture conformations seen as most of the radiographic studies did not consist of a full set of radiographs with orthogonal views. A more consistent fracture conformation identified in the OVAH group may also be due to some of the cases having undergone CT imaging which allowed multiplanar reconstruction, thereby overcoming the limitation imposed by incomplete radiographic studies.

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Displaced mandibular body fractures were more common than non-displaced fractures, with all the OVAH and 90.9% of the WCVDS mandibular body fractures being displaced irrespective of fracture conformation. The high proportion of displaced fractures was expected due to overall unstable mandibular body fracture conformations being predominant in both groups, representing 84.6% and 68% of all fracture conformations, respectively. Oblique mandibular body fractures have specifically been described in the literature as being stable (favourable) or unstable (unfavourable) depending on the association of fracture conformation and effect of biomechanical forces exerted on the mandible by the masticatory muscles, either resulting in fracture fragment compression or distraction and displacement[5,7]. In this study, all the unstable and stable oblique mandibular body fractures in the OVAH group were displaced irrespective of fracture conformation, and all of the WCVDS unstable and 85.7% of stable oblique mandibular body fractures were displaced irrespective of fracture conformation. Given the high proportion of displaced fractures, which included almost all the stable (favourable) fractures, our study did not identify any clinical relevance in the classification of oblique mandibular body fractures (or any other fracture conformation) as stable (favourable) or unstable (unfavourable). Furthermore, a combination of unstable caudo-ventral oblique and stable caudo-lingual oblique orthogonal fractures, which were all displaced, were noted in three of the OVAH cases and one of the WCVDS cases, which highlights the fact that compressive forces are overcome by distraction forces, resulting in displacement even when stable fracture conformations are involved. The high proportion of displaced fractures could be explained by the following: 1) the absence of large stabilising muscles associated with the body of the mandible; 2) the movement and dynamics of opposing compression and distraction forces exerted on the mandible by the mandibular muscles; and 3) movement and distraction of mandibular fragments influenced by normal dental occlusion as well as malocclusion. Due to the low number of known aetiology cases, an association between fracture displacement and fracture aetiology could not be investigated, however, given the high number of displaced mandibular body fractures the general trend of our data suggests that aetiology did not influence the proportion of displaced or non-displaced fracturs of the mandibular body.

Several fracture conformations also occurred throughout the caudal mandible in both groups, however, due to numerous conformations being recorded in relatively low numbers, statistical analysis was not possible. Of these, comminuted fractures were predominant in the OVAH cases, and all involved the coronoid process, whereas caudo-ventral oblique fractures were predominant in the WCVDS cases with all involving the coronoid process as well. As previously mentioned, the predominance of caudo-ventral fractures in the WCVD group is possibly due to the combination of biomechanical forces exerted on the caudal mandible and the mandibular body by the masticatory muscles, which may have been activated by intention or reflex during a traumatic event at the time of fracture propagation. Depending on the direction of trauma, rostral impact forces may also exert a caudo-ventrally directed force on the

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mandibular body. Due to the low number of cases, statistical analysis of mandibular condyle process fractures was not possible, however, a general trend was identified from the results. All the mandibular condyle neck fractures were transverse in orientation and all of the mandibular head of the condylar process fractures were parasagittal in orientation. The anatomy of the mandibular head of the condylar process is proposed as a predisposing factor to parasagittal fractures. The head of the mandibular condyle is a transversely elongated cylindrical to bar shaped structure with thinner tapering medial and lateral aspects, and a thinner cross-sectional area at the level of the condylar process neck[8,37,77]. Therefore, as the feline temporomandibular joint is a hinge joint which does not permit lateral movement[44], it is feasible that a traumatic force causing compression or impaction of the head of the mandibular condyle into the mandibular fossa and retroarticular process, especially when applied asymmetrically either along the medial or lateral aspect of the condyle, would result in the thinner medial and lateral extremities fracturing in a parasagittal orientation. In agreement with our study, similar fractures have been noted and described in the literature, reported as lateral condyle fractures in the sagittal plane (transverse to the mandibular head of the condylar process)[37,78]. Symphyseal separation may result in trauma forces being applied unilaterally to the mandible and temporomandibular joint resulting in abnormal angulation or movement of the mandibular head of the condylar process[78], which is likely an additional predisposing factor to either medial or lateral parasagittal fractures in this region. Despite the low number of cases with fractures of the mandibular head of the condylar process in our study it was interesting to note that, like other studies, medial parasagittal fractures were more common than lateral parasagittal fractures[13,15,37]. The insertion of the lateral pterygoid muscle onto the *fovea pterygoidea* of the head of the mandibular condyle may increase tension on the medial aspect, which could be a reason for more medial parasagittal fractures in comparison to the lateral aspect. This theory is supported by a study describing fractures of the medial aspect of the head of the mandibular condyle as an avulsion[15]. Displaced caudal mandibular fractures were more common than non-displaced fractures, with 92.3% of OVAH and all WCVDS caudal mandible fracture orientations being displaced. Similarly to previously mentioned, the biomechanical forces exerted on the caudal mandible, as well as the movement of the mandible, is likely the reason for the high proportion of displaced fractures.

Fracture displacement was not quantified in this study due to the inherent subjectivity of this feature, which can either be measured according to the degree of overlap or distraction of fracture fragments. Additionally, the degree of displacement is also relative to the size of the patient and the size of the bone involved, for example: a 1 mm fracture gap in the mandible of a large dog might be considered negligible and non-displaced, whereas a 1 mm fracture gap in the mandible of a cat, being only a few millimetres thick, could be considered as significant and displaced. Due to the low number of known aetiology cases, an association between caudal mandible fracture displacement and fracture aetiology could not be investigated, however, given that almost all fractures were displaced, the general trend of

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our data suggests that aetiology did not influence the proportion of displaced or non-displaced caudal mandibular fractures.

6.8 Dental structure involvement of mandibular fractures

The OVAH group (53.3%) had a higher proportion of cases with teeth involved in a fracture line compared to the WCVDS group (38.7%). In both OVAH and WCVDS groups, the canine tooth was the most common tooth involved in a fracture, 90.9% and 56.2% of teeth in a fracture line, respectively. To the best of the author's knowledge there is currently no comparable literature describing the association of feline mandibular fractures with teeth or identification of the most commonly involved tooth in a fracture line. A study of dogs reported almost three-quarters of mandibular fractures involving the alveolus of a tooth, of which the larger first molar was most frequently involved[16]. As mentioned previously, the predominant involvement of the large canine tooth in cats in a mandibular fracture can be hypothesised based on the same concept reported in small dogs, where a large molar tooth creates a weak point and a stress riser effect predisposing to fractures in that region[16,23]. Additionally, the predisposition of canine teeth to dentoalveolar injuries due to traumatic events is also a possible reason for the increased involvement of canine teeth in a fracture line[30-32,36]. Human studies investigating the prognosis of teeth in a fracture line reported type A fractures as being most common[18,19]. Studies in dogs with mandibular fractures also reported type A fractures as being most common, associated with 56%[1] of teeth involved in a fracture line, and associated with the mesial root of the mandibular first molar in 80%[7] of cases, and with the distal root in 62.2%[7] of cases. Consistent with the literature, type A fractures were predominant in our study representing 72.7% and 56.2% of fractures associated with a tooth in a fracture line, of which 100% of type A fractures involved canine teeth in the OVAH group and 55.5% in the WCVDS group. A reason for the higher number of type A fractures associated with a canine tooth can be explained based on the transmission of a traumatic force applied to the crown of the canine tooth which moves through the larger root resulting in a lever-action force directed into the alveolus, with resultant tearing of the periodontal ligament as the fracture propagates. As a healthy viable tooth in a fracture line reduces post-operative complications and aids in fracture reduction and preventing fracture displacement, the significance of type A fractures (or any fracture affecting the neurovascular bundle) lies in the fact that neurovascular bundle and apical trauma will likely result in pulpal compromise leading to pulp necrosis, peri-apical infection and questionable endodontic viability[1,7,17-19]. Accordingly, the influence of fractures associated with teeth on long term endodontic viability is an important factor to consider when selecting surgical repair techniques which incorporate teeth to facilitate fracture stabilisation[15,31].

A thorough dental examination of every mandibular fracture patient is warranted as dentoalveolar injuries due to maxillofacial trauma in dogs and cats is common (72.1%[32]) with the mandibular teeth

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mostly affected (54.8%[32]). Maxillary and mandibular canine teeth (35.5%[36]) as well as incisor teeth have also been reported as being most commonly injured[30-32,36]. Dentoalveolar injury due to HRS has been reported in 73.1%[30] of cats, with a lower incidence of dental fractures reported (17%[34]). Another study investigating craniomaxillofacial trauma in cats also reported a high incidence of dental trauma, with 64.4%[14] of the study population sustaining tooth fractures. Similar to previous studies, dentoalveolar trauma was identified in a large proportion of cases in our study (60% of OVAH cats, 58% of WCVDS cats). Whilst the proportion of cases presenting with dentoalveolar injury in our study is comparable to other studies which focussed on maxillofacial trauma, the range and number of dentoalveolar injuries is interpreted with caution because the included radiographic studies focussed on mandibular fractures and were not conducted to document and optimise visualisation of all dentoalveolar injuries. Furthermore, accompanying clinical examinations would have been conducted to document dentoalveolar injury where further imaging was not required or not considered to be of benefit. The detailed dental examination charts were not reviewed for the purposes of the study as traumatic dentoalveolar injuries were not the main focus of the investigation and have already been described in detail elsewhere[30-32,36]. Since the focus of the study was only the mandible, the author had no knowledge of dentoalveolar trauma affecting the maxilla. Motor vehicle accidents and being hit by an object are trauma aetiologies reported to be significantly associated with dentoalveolar injuries[32]. Due to the low number of known aetiology cases an association between fracture aetiology and dentoalveolar trauma could not be evaluated in our study.

6.9 Study Limitations

The retrospective nature of the study has all the limitations of previous retrospective clinical studies. Incomplete clinical records accounted for the loss of 58 potential cases, which could have made a difference to the outcome of this study. The retrospective design did not allow for the imaging studies to be standardised, therefore, a full set of radiographic images and CT studies optimised for feline dental imaging were not available for each patient. Due to the small sample size, statistical or objective analysis with clear conclusions drawn from all the data was not possible. Similarly, the trends or patterns reported in the data (which may vary by only very few cases) are possibly inaccurate or misleading due to the low case numbers. Therefore, the results and conclusions stated without statistical significance are intended to be received in a similar fashion as a pilot study, with further studies involving larger sample sizes needed to draw more accurate conclusions. The fact that the included cases are from referral facilities is another limitation which could have affected the number and types of cases included and, therefore, influenced the accuracy of the data. Less severe cases may not have been referred due to treatment initiated by primary veterinarians whilst more severe cases may have been euthanised due to a very poor prognosis. Lastly, from a surgical standpoint, the anatomical division of the vertical ramus of the mandible in this study may be a limitation as treatment of fractures affecting the ventral

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half and the dorsal half of the mandibular ramus may be different. Therefore, in hindsight, it would have been beneficial to divide the mandibular ramus into a dorsal and ventral part to facilitate distinction of fractures affecting these regions.

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Chapter 7: Conclusion

The study provides description of the conformation of feline mandibular fractures, however, also highlights the overall unpredictability of predominant mandibular fracture distribution and conformation in cats when comparing different populations in two different hemispheres. The study provides insight into the difference by quantifying the most commonly affected regions according to the proportion of cases, or proportion of affected anatomical regions, which may affect clinical decisions, planning, treatment and prognosis depending on the complexity or severity of the fracture/s.

Demographic variables were not significantly different between the two groups, therefore, null hypothesis 1 that there will be no difference in the demographics of the cats in this study is accepted. The most common aetiology of mandibular fractures was unknown in both groups, therefore, there was not enough data to evaluate hypothesis 2 that there will be a difference in mandibular fracture aetiology between the two groups.

The OVAH group had a higher proportion of multiple fracture cases with a significantly higher mean number of fractured regions per cat, therefore, null hypothesis 3 is accepted. There was a difference in mandibular fracture distribution between the two groups (null hypothesis 4 accepted) with the mandibular body affected in most OVAH cases and the symphysis least affected in the OVAH cases, compared to the symphysis being affected in most WCVDS cases and the caudal mandible least affected in the WCVDS cases. There were significantly more parasymphyseal canine and mandibular condylar process fracture cases in the OVAH group. Considering the overall number of fractured regions, the mandibular body represented the most fractured regions in both groups. Most of the WCVDS group were single fracture cases with symphyseal separation. The hypothesis that mandibular fractures will be predominantly displaced in the two groups is accepted (hypothesis 5) as almost all mandibular body and caudal mandible fractures in both groups were displaced irrespective of fracture conformation. Even though caudo-ventral oblique fractures of the mandibular body were most common in the OVAH group and caudo-lingual oblique fractures were predominant in the WCVDS group, the difference in fracture conformation was considered too low in number, therefore, the alternate hypothesis 6 that there will be no difference in mandibular fracture conformation between the two groups is accepted.

Within the body of the mandible, most fractures were centred around the canine tooth in both groups, with caudo-ventral oblique fractures being most common in the OVAH group. The canine tooth represented 90.9% (OVAH) and 56.2% (WCVDS) of all teeth in a fracture line, therefore, null hypothesis 7 that there will be no difference in the type of tooth predominantly involved in a fracture

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line between the two groups is accepted. Of the fractures associated with teeth, type A was most common in both groups (72.7% OVAH, 56.2% WCVDS), therefore null hypothesis 8 is accepted.

In conclusion, this study shows that mandibular fracture distribution and conformation is relatively unpredictable. This emphasizes the importance of acquiring complete imaging studies of feline mandible trauma cases. Computed tomography with multiplanar reconstruction is an invaluable diagnostic imaging modality to assess the nature and extent of the trauma. Two important findings in this study are the predominance of canine tooth inclusion in fracture lines and the predominance of type A fractures with a canine tooth. The identification of these two fracture patterns improves clinical anticipation in feline mandible trauma cases. Future studies with larger sample sizes should be conducted to determine the clinical significance of these fracture patterns, as well as investigate superior repair techniques. Future studies with larger sample sizes should also be conducted to identify statistically significant mandibular fracture distribution and conformation. Given the high degree of mesaticephalic feline mandibular morphological symmetry, the data from such studies could be used to develop customised mandibular fracture fixation plates according to the predominant fracture conformations which would facilitate surgical repair and improved outcome.

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Annexure A

The variation of mandibular fracture distribution in OVAH and WCVDS cats according to aetiology are shown in Tables 1 - 7.

Table 1: Unknown aetiology category case percentage of OVAH and WCVDS cats sustaining a fracture in each region and percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats.

Anatomical region	Number (percent) of cases and affected anatomical regions	
	OVAH	WCVDS
Symphyseal	Cases: 3/8 (37.5%) Anatomical regions: 3/15 (20%)	Cases: 13/22 (59%) Anatomical regions: 13/35 (37.1%)
Parasymphyseal incisor		Cases: 3/22 (13.6%) Anatomical regions: 3/35 (8.6%)
Parasymphyseal canine	Cases: 3/8 (37.5%) Anatomical regions: 4/15 (26.7%)	Cases: 3/22 (13.6%) Anatomical regions: 3/35 (8.6%)
Canine	Cases: 1/8 (12.5%) Anatomical regions: 1/15 (6.7%)	Cases: 5/22 (22.7%) Anatomical regions: 5/35 (14.3%)
Premolar	Cases: 2/8 (25%) Anatomical regions: 2/15 (13.3%)	Cases: 3/22 (13.6%) Anatomical regions: 3/35 (8.6%)
Molar		Cases: 2/22 (9%) Anatomical regions: 2/35 (5.7%)
Coronoid process	Cases: 3/8 (37.5%) Anatomical regions: 3/15 (20%)	Cases: 5/22 (22.7%) Anatomical regions: 5/35 (14.3%)
Condylar process	Cases: 2/8 (25%) Anatomical regions: 2/15 (13.3%)	Cases: 1/22 (4.5%) Anatomical regions: 1/35 (2.8%)
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 2: Motor vehicle accident category case percentage of OVAH and WCVDS cats sustaining a fracture in each region and percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats.

Anatomical region	**Number (percent) of cases and affected anatomical regions**	
	OVAH	**WCVDS**
Symphyseal	Cases: 1/1 (100%) Anatomical regions: 1/5 (20%)	Cases: 3/3 (100%) Anatomical regions: 3/4 (75%)
Parasymphyseal incisor	Cases: 1/1 (100%) Anatomical regions: 1/5 (20%)	
Parasymphyseal canine	Cases: 1/1 (100%) Anatomical regions: 1/5 (20%)	
Canine	Cases: 1/1 (100%) Anatomical regions: 1/5 (20%)	Cases: 1/3 (33.3%) Anatomical regions: 1/4 (25%)
Premolar		
Molar		
Coronoid process		
Condylar process		
Angular process	Cases: 1/1 (100%) Anatomical regions: 1/5 (20%)	

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 3: Animal encounter category case percentage of OVAH and WCVDS cats sustaining a fracture in each region and percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats.

Anatomical region	**Number (percent) of cases and affected anatomical regions**	
	OVAH	**WCVDS**
Symphyseal		Cases: 2/4 (50%) Anatomical regions: 2/6 (33.3%)
Parasymphyseal incisor		
Parasymphyseal canine		
Canine	Cases: 1/1 (100%) Anatomical regions: 1/3 (33.3%)	
Premolar		Cases: 1/4 (25%) Anatomical regions: 1/6 (16.7%)
Molar		Cases: 1/4 (25%) Anatomical regions: 1/6 (16.7%)
Coronoid process		Cases: 2/4 (50%) Anatomical regions: 2/6 (33.3%)
Condylar process	Cases: 1/1 (100%) Anatomical regions: 2/3 (66.6%)	
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 4: Human encounter category case percentage of OVAH and WCVDS cats sustaining a fracture in each region and percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats.

Anatomical region	**Number (percent) of cases and affected anatomical regions**	
	OVAH	**WCVDS**
Symphyseal		Cases: 1/1 (100%) Anatomical regions: 1/1 (100%)
Parasymphyseal incisor		
Parasymphyseal canine		
Canine		
Premolar		
Molar		
Coronoid process		
Condylar process		
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5: Falling from a height category case percentage of OVAH and WCVDS cats sustaining a fracture in each region and percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats.

Anatomical region	Number (percent) of cases and affected anatomical regions	
	OVAH	WCVDS
Symphyseal	Cases: 1/2 (50%) Anatomical regions: 1/5 (20%)	
Parasymphyseal incisor		
Parasymphyseal canine		
Canine		
Premolar		
Molar		
Coronoid process	Cases: 1/2 (50%) Anatomical regions: 2/5 (40%)	
Condylar process	Cases: 1/2 (50%) Anatomical regions: 2/5 (40%)	
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 6: Iatrogenic category case percentage of OVAH and WCVDS cats sustaining a fracture in each region and percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats.

Anatomical region	Number (percent) of cases and affected anatomical regions	
	OVAH	WCVDS
Symphyseal	Cases: 1/3 (33.3%) Anatomical regions: 1/7 (14.3%)	
Parasymphyseal incisor	Cases: 1/3 (33.3%) Anatomical regions: 1/7 (14.3%)	
Parasymphyseal canine	Cases: 2/3 (66.7%) Anatomical regions: 2/7 (28.6%)	
Canine	Cases: 2/3 (66.7%) Anatomical regions: 2/7 (28.6%)	
Premolar	Cases: 1/3 (33.3%) Anatomical regions: 1/7 (14.3%)	
Molar		
Coronoid process		
Condylar process		
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 7: Pathological category case percentage of OVAH and WCVDS cats sustaining a fracture in each region and percentage of individual fractured regions in relation to the overall number of fractured regions of the OVAH and WCVDS cats.

Anatomical region	**Number (percent) of cases and affected anatomical regions**	
	OVAH	**WCVDS**
Symphyseal		Cases: 1/1 (100%) Anatomical regions: 1/3 (33.3%)
Parasymphyseal incisor		Cases: 1/1 (100%) Anatomical regions: 1/3 (33.3%)
Parasymphyseal canine		Cases: 1/1 (100%) Anatomical regions: 1/3 (33.3%)
Canine		
Premolar		
Molar		
Coronoid process		
Condylar process		
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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The variation of single and multiple fracture cases according to aetiology is shown in Table 8.

Table 8: Number of OVAH and WCVDS single/multiple fracture cases according to aetiology.

Aetiology	Single/Multiple	OVAH	WCVDS
Unknown aetiology	Single	3	14
	Multiple	5	8
Motor vehicle accident	Single	0	2
	Multiple	1	1
Falling from a height	Single	1	0
	Multiple	1	0
Animal encounter	Single	0	3
	Multiple	1	1
Human encounter	Single	0	1
	Multiple	0	0
Iatrogenic	Single	2	0
	Multiple	1	0
Pathological	Single	0	0
	Multiple	0	1
Total	Single	6	20
	Multiple	9	11

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Annexure B

Mandibular fracture conformation and anatomical distribution in OVAH and WCVDS cats according to aetiology are shown in Tables 1 - 14.

Table 1: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the unknown aetiology category with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal	3 cases: Separation (3/3, 100%)	13 cases: Separation (13/13, 100%)
Mandibular body	2 cases: Caudo-ventral oblique (3/12, 25%) - Long (3/3, 100%) 2 cases: Parasagittal (3/12, 25%) 1 case: Bucco-lingual transverse (2/12, 16.7%) 1 case: Dorso-ventral transverse (2/12, 16.7%) 1 case: Caudo-buccal oblique (1/12, 8.3%) - Short (1/1, 100%) 1 case: Caudo-lingual oblique (1/12, 8.3%) - Long (1/1, 100%)	4 cases: Caudo-lingual oblique (5/17, 29.4%) - Long (3/5, 60 %) - Short (2/5, 40%) 2 cases: Caudo-ventral oblique (3/17, 17.6%) - Long (2/3, 66.7%) - Short (1/3, 33.3%) 1 case: Parasagittal (3/17, 17.6%) 2 cases: Bucco-lingual transverse (2/17, 11.8%) 2 cases: Comminuted (3/17, 17.6%) 1 case: Dorso-ventral transverse (1/17, 5.9%)
Caudal mandible	2 cases: Comminuted (2/6, 33.3%)	2 Cases: Caudo-ventral oblique (2/6, 33.3%)

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	1 case: Transverse (1/6, 16.7%) 1 case: Caudo-lingual oblique (1/6, 16.7%) - Long (1/1, 100%) 1 case: Caudo-ventral oblique (1/6, 16.7%) - Long (1/1, 100%) 1 case: Parasagittal (1/6, 16.7%) - Medial (1/1, 100%)	- Long (1/2, 50%) - Short (1/2, 50%) 2 cases: Comminuted (2/6, 33.3%) 1 case: Transverse (1/6, 16.7%) 1 case: Caudo-dorsal oblique (1/6, 16.7%) - Short (1/1, 100%)

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 2: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the unknown aetiology category with the mandible divided into nine individual anatomical regions.

Anatomical region affected	**Number of cases with number (percent) of fracture conformations in each anatomical region**	
	OVAH	**WCVDS**
Symphyseal	3 cases: Separation (3/3, 100%)	13 cases: Separation (13/13, 100%)
Parasymphyseal incisor		2 cases: Caudo-lingual oblique (2/3, 66.7%) - Long (1/2, 50%) - Short (1/2, 50%) 1 case: Parasagittal (1/3, 33.3%)
Parasymphyseal canine	1 case: Bucco-lingual transverse (2/7, 28.6%) 1 case: Dorso-ventral transverse (2/7, 28.6%) 1 case: Caudo-lingual oblique (1/7, 14.3%) - Long (1/1, 100%) 1 case: Caudo-ventral oblique (1/7, 14.3%) - Long (1/1, 100%) 1 case: Parasagittal (1/7, 14.3%)	1 case: Bucco-lingual transverse (1/3, 33.3%) 1 case: Comminuted (1/3, 33.3%) 1 case: Parasagittal (1/3, 33.3%)
Canine	1 case: Caudo-ventral oblique (1/2, 50%) - Long (1/1, 100%)	1 case: Bucco-lingual transverse (1/5, 20%) 1 case:

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	1 case: Parasagittal (1/2, 50%)	Caudo-lingual oblique (1/5, 20%) - Long (1/1, 100%) 1 case: Caudo-ventral oblique (1/5, 20%) - Long (1/1, 100%) 1 case: Comminuted (1/5, 20%) 1 case: Parasagittal (1/5, 20%)
Premolar	1 case: Caudo-buccal oblique (1/3, 33.33%) - Short (1/1, 100%) 1 case: Caudo-ventral oblique (1/3, 33.33%) - Long (1/1, 100%) 1 case: Parasagittal (1/3, 33.33%)	2 Cases: Caudo-lingual oblique (2/4, 50%) - Long (1/2, 50%) - Short (1/2, 50%) 2 cases: Caudo-ventral oblique (2/4, 50%) - Long (1/1, 100%) - Short (1/1, 100%)
Molar		1 case: Comminuted (1/2, 50%) 1 case: Dorso-ventral transverse (1/2, 50%)
Coronoid process	2 cases: Comminuted (2/4, 50%) 1 case: Caudo-ventral oblique (1/4, 25%) - Long (1/1, 100%)	2 cases: Caudo-ventral oblique (2/5, 40%) - Long (1/2, 50%) - Short (1/2, 50%) 2 cases: Comminuted (2/5, 40%)

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	1 case: Caudo-lingual oblique (1/4, 25%) - Long (1/1, 100%)	1 case: Caudo-dorsal oblique (1/5, 20%) - Short (1/1, 100%)
Condylar process	1 case (neck of condylar process): Transverse (1/2, 50%) 1 case (head of condylar process): Parasagittal (1/2, 50%) - Medial (1/1, 100%)	1 case (neck of condylar process): Transverse (1/1, 100%)
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 3: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the motor vehicle accident category with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal	1 case: Separation (1/1, 100%)	3 cases: Separation (3/3, 100%)
Mandibular body	1 case: Comminuted (3/3, 100%)	1 case: Bucco-lingual transverse (1/1, 100%)
Caudal mandible	1 case: Chip (1/1, 100%)	

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 4: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the motor vehicle accident category with the mandible divided into nine individual anatomical regions.

Anatomical region affected	**Number of cases with number (percent) of fracture conformations in each anatomical region**	
	OVAH	**WCVDS**
Symphyseal	1 case: Separation (1/1, 100%)	3 cases: Separation (3/3, 100%)
Parasymphyseal incisor	1 case: Comminuted (1/1, 100%)	
Parasymphyseal canine	1 case: Comminuted (1/1, 100%)	
Canine	1 case: Comminuted (1/1, 100%)	1 case: Bucco-lingual transverse (1/1, 100%)
Premolar		
Molar		
Coronoid process		
Condylar process		
Angular process	1 case: Chip (1/1, 100%)	

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 5: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the animal encounter category with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal		2 cases: Separation (2/2, 100%)
Mandibular body	1 case: Caudo-lingual oblique (1/2, 50%) - Short (1/1, 100%) 1 case: Caudo-ventral oblique (1/2, 50%) - Short (1/1, 100%)	2 cases: Caudo-ventral oblique (2/2, 100%) - Long (1/2, 50%) - Short (1/2, 50%)
Caudal mandible	1 case: Parasagittal (2/2, 100%) - Medial (1/2, 50%) - Lateral (1/2, 50%)	2 cases: Caudo-ventral oblique (2/2, 100%) - Long (2/2, 100%)

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 6: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the animal encounter category with the mandible divided into nine individual anatomical regions.

Anatomical region affected	Number of cases with number (percent) of fracture conformations in each anatomical region	
	OVAH	WCVDS
Symphyseal		2 cases: Separation (2/2, 100%)
Parasymphyseal incisor		
Parasymphyseal canine		
Canine	1 case: Caudo-ventral oblique (1/2, 50%) - Short (1/1, 100%) 1 case: Caudo-lingual oblique (1/2, 50%) - Short (1/1, 100%)	
Premolar		1 case: Caudo-ventral oblique (1/1, 100%) - Short (1/1, 100%)
Molar		1 case: Caudo-ventral oblique (1/1, 100%) - Long (1/1, 100%)
Coronoid process		2 cases Caudo-ventral oblique (2/2, 100%) - Long (2/2, 100%)
Condylar process	1 case (head of condylar process): Parasagittal (2/2, 100%) - Medial (1/2, 50%) - Lateral (1/2, 50%)	

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Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 7: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the human encounter category with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal		1 case: Separation (1/1, 100%)
Mandibular body		
Caudal mandible		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 8: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the human encounter category with the mandible divided into nine individual anatomical regions.

Anatomical region affected	Number of cases with number (percent) of fracture conformations in each anatomical region	
	OVAH	**WCVDS**
Symphyseal		1 case: Separation (1/1, 100%)
Parasymphyseal incisor		
Parasymphyseal canine		
Canine		
Premolar		
Molar		
Coronoid process		
Condylar process		
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 9: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the falling from a height category with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal	1 case: Separation (1/1, 100%)	
Mandibular body		
Caudal mandible	1 case: Transverse (2/4, 50%) 1 case: Comminuted (2/4, 50%)	

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 10: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the falling from a height category with the mandible divided into nine individual anatomical regions.

Anatomical region affected	**Number of cases with number (percent) of fracture conformations in each anatomical region**	
	OVAH	**WCVDS**
Symphyseal	1 case: Separation (1/1, 100%)	
Parasymphyseal incisor		
Parasymphyseal canine		
Canine		
Premolar		
Molar		
Coronoid process	1 case: Comminuted (2/2, 100%)	
Condylar process	1 case (neck of condylar process): Transverse (2/2, 100%)	
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 11: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the iatrogenic category with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal	1 case: Separation (1/1, 100%)	
Mandibular body	2 cases: Caudo-ventral long oblique (5/9, 55.5%) - Long (4/5, 80%) - Short (1/5, 20%) 2 cases: Bucco-lingual transverse (2/9, 22.2%) 2 cases: Caudo-lingual oblique (2/9, 22.2%) - Long (1/2, 50%) - Short (1/2, 50%)	
Caudal mandible		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 12: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the iatrogenic category with the mandible divided into nine individual anatomical regions.

Anatomical region affected	Number of cases with number (percent) of fracture conformations in each anatomical region	
	OVAH	WCVDS
Symphyseal	1 case: Separation (1/1, 100%)	
Parasymphyseal incisor	1 case: Caudo-lingual oblique (1/2, 50%) - Long (1/1, 100%) 1 case: Caudo-ventral long oblique (1/2, 50%) - Long (1/1, 100%)	
Parasymphyseal canine	1 case: Bucco-lingual transverse (1/2, 50%) 1 case: Caudo-ventral oblique (1/2, 50%) - Long (1/1, 100%)	
Canine	2 cases: Caudo-ventral oblique (2/3, 66.7%) - Long (1/2, 50%) - Short (1/2, 50%) 1 case: Caudo-lingual oblique (1/3, 33.3%) - Short (1/1, 100%)	
Premolar	1 case: Bucco-lingual transverse (1/2, 50%) 1 case: Caudo-ventral oblique (1/2, 50%) - Long (1/1, 100%)	

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Molar		
Coronoid process		
Condylar process		
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 13: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the pathological category with the mandible divided into three grouped anatomical sections.

Anatomical section affected	**Number of cases with number (percent) of fracture conformations in each anatomical section**	
	OVAH	**WCVDS**
Symphyseal		1 case: Separation (1/1, 100%)
Mandibular body		1 case: Caudo-lingual oblique (2/2, 100%) - Short (2/2, 100%)
Caudal mandible		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Table 14: Mandibular fracture conformation (number, percent) and anatomical distribution in OVAH and WCVDS cats in the pathological category with the mandible divided into nine individual anatomical regions.

Anatomical region affected	**Number of cases with number (percent) of fracture conformations in each anatomical region**	
	OVAH	**WCVDS**
Symphyseal		1 case: Separation (1/1, 100%)
Parasymphyseal incisor		1 case: Caudo-lingual oblique (1/1, 100%) - Short (1/1, 100%)
Parasymphyseal canine		1 case: Caudo-lingual oblique (1/1, 100%) - Short (1/1, 100%)
Canine		
Premolar		
Molar		
Coronoid process		
Condylar process		
Angular process		

Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Annexure C

The number of oblique mandibular body fracture conformations and relative fracture stability according to aetiology are shown in Figures 1 - 4.

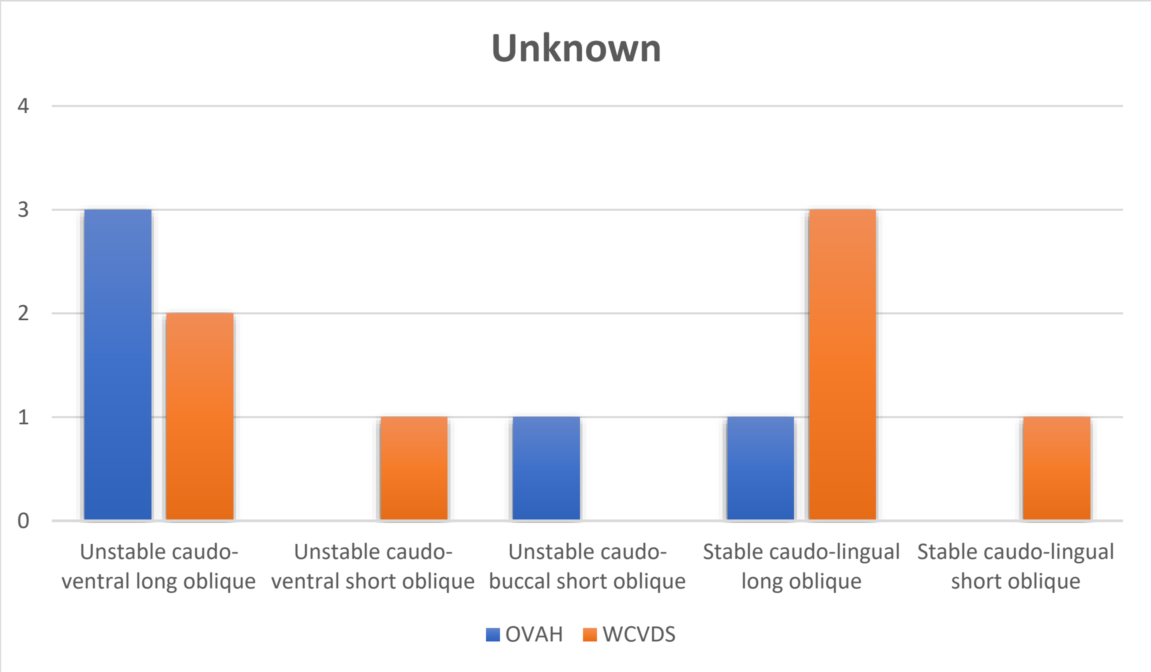

Figure 1: Bar graph showing the number of oblique mandibular body fracture conformations and relative fracture stability in OVAH and WCVDS cats in the unknown aetiology category (OVAH: blue, WCVDS: orange). Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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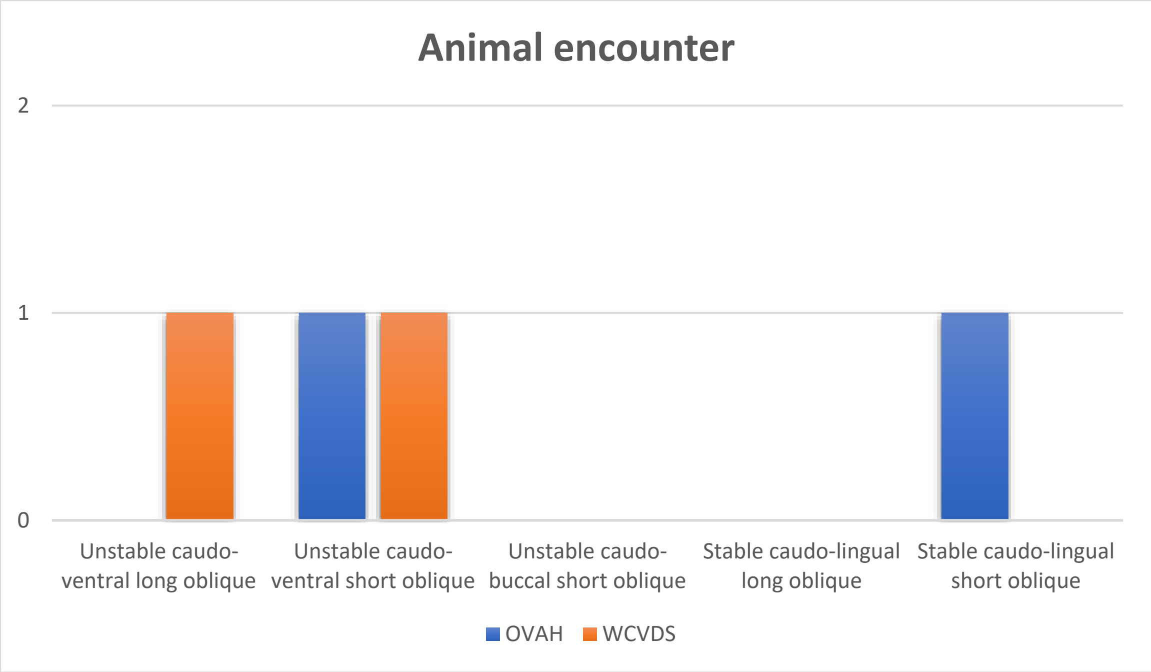

Figure 2: Bar graph showing the number of oblique mandibular body fracture conformations and relative fracture stability in OVAH and WCVDS cats in the animal encounter category (OVAH: blue, WCVDS: orange). Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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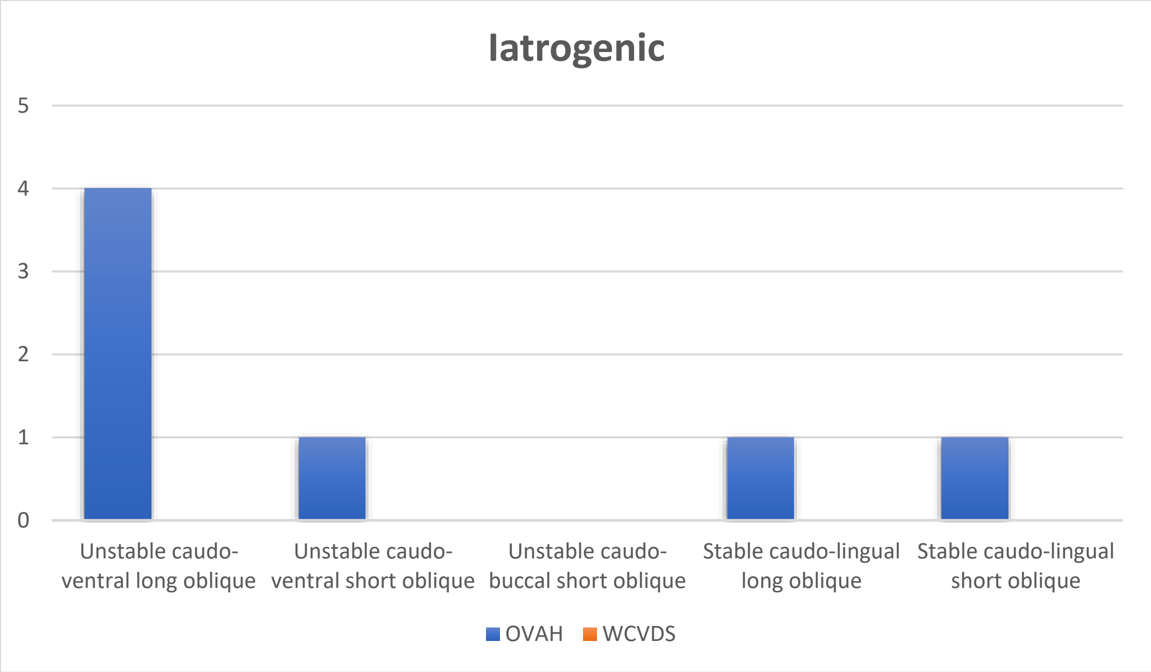

Figure 3: Bar graph showing the number of oblique mandibular body fracture conformations and relative fracture stability in OVAH and WCVDS cats in the iatrogenic category (OVAH: blue, WCVDS: orange). Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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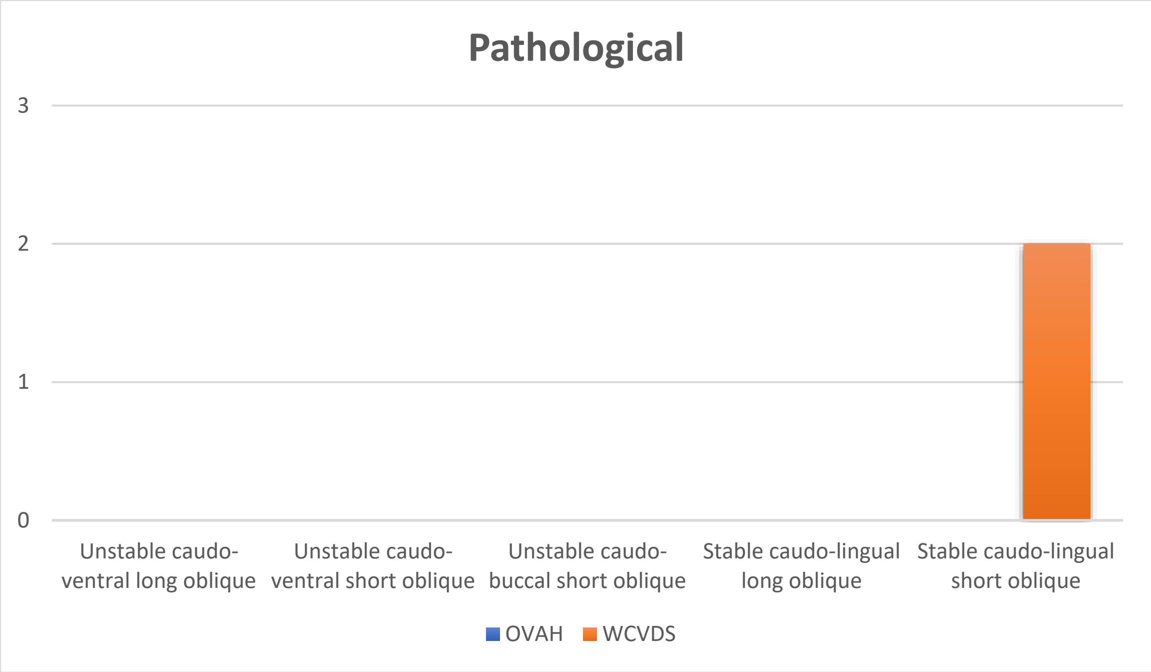

Figure 4: Bar graph showing the number of oblique mandibular body fracture conformations and relative fracture stability in OVAH and WCVDS cats in the pathological category (OVAH: blue, WCVDS: orange). Abbreviations: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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Annexure D

The involvement of specific teeth in fracture with associated fractured anatomical region and mandibular fracture conformation in OVAH and WCVDS cats according to aetiology is shown in Table 1.

Table 1: Dental fracture type (A - F) of OVAH and WCVDS cats according to aetiology, tooth involvement, region affected and fracture conformation.

Referral centre	**Tooth involved in fracture (number)**	**Fracture type A - F (number)**	**Mandibular region (number)**	**Mandibular fracture conformation (number)**
Unknown aetiology				
OVAH	Canine (5)	A (4)	Parasymphyseal canine (4)	Bucco-lingual transverse (2) Dorso-ventral transverse (2) Caudo-lingual long oblique (1) Caudo-ventral long oblique (1) Parasagittal (1)
		B (1)	Canine (1)	Caudo-ventral long oblique (1) Parasagittal (1)
WCVDS	First incisor (1)	A (1)	Symphyseal (1)	Separation (1)
	Second incisor (1)	A (1)	Parasymphyseal incisor (1)	Parasagittal (1)
	Canine (8)	A (5)	Parasymphyseal canine (2)	Comminuted (1) Parasagittal (1)
			Canine (3)	Caudo-lingual long oblique (1) Comminuted (1) Parasagittal (1)
		B (1)	Parasymphyseal canine (1)	Bucco-lingual transverse (1)
		C (1)	Canine (1)	Bucco-lingual transverse (1)
		Unclassified (1)	Canine (1)	Caudo-ventral long oblique (1)
	Third premolar (1)	Unclassified (1)	Premolar (1)	Caudo-lingual short oblique (1) Caudo-ventral short oblique (1)

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	First Molar (1)	A (1)	Molar (1)	Dorso-ventral transverse (1)
Motor vehicle accident				
OVAH	First incisor (1)	B (1)	Parasymphyseal incisor (1)	Comminuted (1)
	Canine (2)	A (2)	Parasymphyseal canine (1)	Comminuted (1)
			Canine (1)	Comminuted (1)
Animal encounter				
OVAH	Canine (1)	A (1)	Canine (1)	Caudo-lingual short oblique (1) Caudo-ventral short oblique (1)
WCVDS	Fourth premolar (1)	A (1)	Premolar (1)	Caudo-ventral short oblique (1)
	First Molar (1)	Unclassified (1)	Molar (1)	Caudo-ventral long oblique (1)
Iatrogenic				
OVAH	Canine (2)	Unclassified (1)	Parasymphyseal canine (1)	Bucco-lingual transverse (1)
		A (1)	Canine (1)	Caudo-ventral long oblique (1)
Pathological				
WCVDS	Canine (1)	B (1)	Parasymphyseal canine (1)	Caudo-lingual short oblique (1)

Abbreviation: OVAH, Onderstepoort Veterinary Academic Hospital; WCVDS, West Coast Veterinary Dental Services.

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