Anatomy and Pathology of the Texel Sheep Larynx

Katie Waine BVSc PhD MRCVS AFHEA

AHDB/MSD Animal Health Senior Clinical Training Scholar (Resident) in

Farm Animal Veterinary Pathology

Thesis submitted for Master of Veterinary Medicine (MVM)

University of Nottingham

Student ID: 4295364

Supervisors: Kerstin Baiker, Fiona Lovatt, Martin Green and Ben Strugnell

Date: January 2020

Acknowledgements

Sincere thanks to my supervisors Kerstin, Ben, Fiona and Martin who helped me to create this residency and have provided unwavering support throughout my studies.

For the larynx project I would like to thank Kirsty McLean at the SRUC CT Scanner Unit, Edinburgh, for the CT scanning; Alex Font and Ross Brodie at Bearl Equine Clinic, Northumberland, and Hallmarq Veterinary Imaging Ltd for the MRI scans and image interpretation; Dr Richard Allibone from The Queen's Medical Centre, Nottingham for assisting with the laryngeal dissection technique; the drivers at the Fallen Stock Collection Centre for carcase collection and movement; and post mortem room technicians Joanne Sanders and Pauline Brind at the University of Nottingham Veterinary Pathology Service.

Thank you to the University of Nottingham Veterinary Pathology team past and present; Simone, Llorenç, Winsome, Ana, Mel, Davide and Antonia. Special thanks to Joanne and Pauline for their assistance in the post mortem room, and to Laura Polledo for setting such a good example and providing never ending help and support.

Finally, thank you to the funders of this project, AHDB and MSD Animal Health, for seeing the value in supporting the training of a farm animal veterinary pathologist.

Declaration

A large portion of this work has been published as:

WAINE, K., STRUGNELL, B., REMNANT, J., LOVATT, F., GREEN, M., RIDEOUT, H., GENEVER, E. and BAIKER, K. (2019) Anatomy and Pathology of the Texel Sheep Larynx. *Veterinary sciences.* 6(1).

Contents

1 Introduction and Background 6

1.1 Laryngeal Chondritis 6

1.1.1 Terminology 6

1.1.2 Species affected 8

1.1.3 Prevalence and signalment 8

1.1.4 Aetiology 10

1.1.5 Clinical signs 12

1.1.6 Pathogenesis 12

1.1.7 Pathology 13

1.2 Anatomy of the larynx 13

1.3 Sheep breed conformation and the reasons for breed differences 15

1.4 Aims of the study 16

2 Materials and Methods 17

2.1 Ethical approval 17

2.2 Larynx selection 17

2.3 Carcase measurements 18

2.4 Larynx collection, measuring and photography 19

2.5 Diagnostic imaging 23

2.6 Statistical analysis 25

3 Results 25

3.1 Anatomy of the larynx 26

3.1.1 General observations 26

3.1.2 Carcase measurements 31

3.1.3 Larynx measurements 32

3.1.4 The glottis 33

3.2 Diagnostic imaging 34

4 Discussion 39

4.1 Imaging 43

4.2 Study limitations 44

4.3 Conclusions 45

5 References 45

Abbreviations

ACVP = American College of Veterinary Pathology

AFBI = Agri-food and Biosciences Institute

APHA = Animal and Plant Health Agency

ECVP = European College of Veterinary Pathology

EPSN = European Pathosurveillance Network

BFL = Bluefaced Leicester

BSVP = British Society of Veterinary Pathology

FPM Ltd = Farm Post Mortems Ltd

SRUC = Scotland's Rural College

SVMS = School of Veterinary Medicine and Science

UoN = University of Nottingham

1 Introduction and Background

Laryngeal chondritis is an upper respiratory tract disease of sheep of unknown aetiology (Faull and Scholes 1987; Lane and others 1987; Sigurðardóttir and others 2016). The prevalence in the United Kingdom (UK) or on an international level is also unknown, but a predisposition of the Texel and Beltex breeds is suggested in the literature (Faull and Scholes 1987; Lane and others 1987; Edmunds and others 2017) and supported through surveillance data (Carson 2017). Laryngeal chondritis has health and welfare implications for the individual sheep affected, as well as economic and logistical impacts on the flock and farm (Sigurðardóttir and others 2016; Rideout 2019).

1.1 Laryngeal Chondritis

1.1.1 Terminology

Cameron and Britton (1943) first described the condition of 'chronic ovine laryngitis', referring to lesions of chronic abscess formation on the arytenoid cartilages that result in inflammatory oedema of the larynx and ultimately death. Authors since have termed the same lesions laryngeal chondritis (Faull and Scholes 1987; Lane and others, 1987; Lovatt and others 2014; SRUC 2014; Sigurðardóttir and others 2016). Synonyms of laryngeal chondritis include necrotic arytenoiditis, arytenoid chondritis and '*Texel throat*' (France and others 1995; Nichols and Anderson 2009). Occasionally the term laryngeal chondrosis is used, but this is technically incorrect as it assumes a degenerative condition. For clarity, throughout this thesis the term laryngeal

chondritis will be used to refer to the pathological condition as originally described by Cameron and Britton (1943) (Figure 1 and 2).



Figure 1 Bilateral, severe, chronic necrosuppurative laryngeal chondritis with severe laryngeal oedema in a Texel ram [Photo: Ben Strugnell]



Figure 2 Moderate, multifocal, chronic suppurative laryngeal chondritis in a Beltex ram [Photo: Ben Strugnell]

Some textbooks discuss laryngeal chondritis alongside other laryngeal conditions, such as laryngeal necrobacillosis (calf diphtheria) or necrotic laryngitis (Constable and others 2017; Lopez and Matinson 2017). Sigurðardóttir et al. (2016) suggests that in cattle, laryngeal contact ulcers predispose to calf diphtheria, which can lead to laryngeal chondritis, and this sequence of pathogenic events may be where some of

the terminological confusion stems from when discussing laryngeal chondritis, with different texts focusing on different stages of the process (Jensen and others 1980; Lopez and Matinson 2017). The peer-reviewed literature refers to laryngeal chondritis in sheep as a standalone condition, and this is the approach adopted by this study.

1.1.2 Species affected

Laryngeal chondritis has been described in sheep, cattle and horses (Lawrence 1967; Haynes and others 1980; Lane and others 1987). In cattle it has been suggested as a hereditary condition of the double-muscled Belgian Blue (Lekeux and Art 1987) while in horses the condition is thought to most commonly affect young Thoroughbred racehorses (Garrett and others 2013). The term arytenoid chondritis is more commonly used to describe the condition in the horse (France and others 1995; Garrett and others 2013; Davis and others 2014).

1.1.3 Prevalence and signalment

The prevalence of the disease in the UK sheep flock is currently unknown. The Animal and Plant Health Agency (APHA) reported 181 cases over a 10-year period and Farm Post Mortems Ltd[1] diagnosed twelve cases over two years (Carson, 2017 *personal communication;* Strugnell, 2017 *personal communication*). It is likely that the condition is under-reported as it may cause sporadic sudden death, and it is easily

[1] An independent farm animal post mortem examination service based in the north of England

confused clinically with pneumonia (Britton 1945; Salisbury 1956; Winter and Clarkson 2012). Farmers also commonly rely on their own diagnosis to treat clinical cases rather than on the diagnosis of a veterinary surgeon; this may affect the number and accuracy of reported cases (Rideout 2019). Within the sheep industry laryngeal chondritis is recognised as a significant problem as the loss of an animal, especially a young ram, can have economic and breeding consequences for a flock (Rideout 2019).

Laryngeal chondritis is thought to mainly affect sheep with short necks and faces such as the Texel and Beltex breeds. Similarities are often drawn between the condition seen in Belgian Blue cattle and Texel sheep as both are bred to produce a heavily muscled meat carcase (Winter and Clarkson 2012; Constable and others 2017). However, in horses the condition is mainly seen in Thoroughbreds, bred for their light frame for racing (Haynes and others 1980). In the literature the Texel breed accounts for the majority of cases reported (Faull and Scholes 1987; Lane and others 1987; Edmunds and others 2017). United Kingdom surveillance data supports a higher incidence seen in the Texel and Beltex breeds; comprised 86% of 181 sheep reported by the APHA over a ten-year period (Carson, 2017 *pers comms*). Farm Post Mortems Ltd also reported 12 cases between April 2014 and March 2016 (AHDB, 2015), all of which were Texel or Beltex animals. Reports in the farming press, discussions on farming forums and the use of the term '*Texel throat'* also supports

the suggestion that cases of laryngeal chondritis are overrepresented in these breeds.

Laryngeal chondritis has also been reported in other breeds, in sheep of all ages and in both ewes and rams (Britton 1945; Salisbury 1956; Lane and others 1987; Winter and Clarkson 2012; Sigurðardóttir and others 2016). Rams are often suggested as being more susceptible but this may be due to the value of these animals resulting in an increased likelihood of presentation for treatment or post mortem examination (Lane and others 1987). Lane and others (1987) and Sigurðardóttir and others (2016) suggest that young animals have a smaller glottis and are therefore more susceptible to developing the lesion. Lekeux and Art (1987) also suggest that double muscled cattle have a higher incidence of the disease due to a narrower glottis.

1.1.4 Aetiology

The underlying cause of laryngeal chondritis is not clear (Sigurðardóttir and others 2016). Early literature suggested that intense feeding of yearling rams prior to sale caused some to inhale oat awns which damaged the mucosa of the larynx followed by secondary infection (Cameron and Britton 1943; Britton 1945). However, Salisbury (1956) reported cases in pastured sheep given no concentrate feeding. Salisbury (1956) also suggested drenching and subsequent dosing-gun injury may be the inciting cause, although 12 out of the 37 animals described by this author were not drenched in the months prior to developing the condition. Bilateral lesions as seen in Figure 1, also make these aetiologies unlikely. In people, vocal fold collision is

considered an important cause of traumatic lesions on the laryngeal mucosa, but it is not clear if this could progress to infection of deeper structures in sheep (Dejonckere and Kob 2009).

A hereditary predisposition to this condition was first suggested in relation to the Southdown breed of sheep in New Zealand (Salisbury 1956). The Texel breed in the UK may be predisposed due to the short head potentially affecting the anatomy of the larynx (Lane and others 1987). The heritability of this condition appears to have caused confusion within the industry where some producers believe the condition is hereditary and can be diagnosed with genetic testing, while some do not think a genetic link is involved (Rideout 2019). There is currently no literature to confirm that genetics do or do not play a significant role in the development of the disease in sheep. Selecting for certain anatomical traits is known to cause inadvertent effects in other domestic animals, such as is seen in Brachycephalic Obstructive Airway Syndrome (BOAS) in flat-faced dogs (Packer and others 2015). A single genetic mutation leading to laryngeal oedema and airway obstruction has been found in the Norwich Terrier which dissociates this particular lesion from head conformation in dogs (Marchant and others 2019). Laryngeal chondritis, composed of more than just a single pathological process such as laryngeal oedema, may be expected to have an underlying polygenetic aetiology.

1.1.5 Clinical signs

Sheep presenting with laryngeal chondritis show an increased respiratory rate and effort which can lead to coughing, choking and roaring (Cameron and Britton 1943). As the oedema of the larynx increases affected animals show dyspnoea, cyanosis and eventually death (Salisbury 1956; Lane and others 1987). It is not an unusual diagnosis to be made in rams found dead without premonitory clinical signs (Lovatt and others 2014). The condition is often treated with antibiotics and steroids, and if necessary, tracheostomy with variable results; often the prognosis is guarded and mortality rates are high.

1.1.6 Pathogenesis

Opportunistic pathogens such as *Trueperella pyogenes*, *Streptococcus spp*, *E.coli*, *Fusobacterium necrophorum*, *Bacteriodes spp* and *Pasteurella spp* proliferate in ulcerated areas of laryngeal mucosa of unknown pathogenesis (Cameron and Britton 1943; Salisbury 1956; Lane and others 1987; Sigurðardóttir and others 2016). The inflammatory response leads to abscessation and necrosis of the laryngeal cartilage with accompanying oedema (Cameron and Britton 1943). Severe oedema can occlude the glottis and lead to suffocation. Occasionally aspiration pneumonia is found, likely caused by pieces of necrotic exudate being inhaled (Lopez and Matinson 2017).

1.1.7 Pathology

Grossly, chronic abscessation of the laryngeal submucosa and the arytenoid cartilages are seen often accompanied by inflammatory oedema with narrowing of the rimma glottis (Cameron and Britton 1943; Lane and others 1987) (Figure 1 and 2). In about 50% of cases both arytenoid cartilages are involved (Britton 1945). Regional lymph nodes may be enlarged and aspiration pneumonia can be an accompanying lesion (Britton 1945; Salisbury 1956). Histopathology of affected larynges shows extensive areas of necrosis with accompanying inflammation and intralesional bacteria (Figure 3).

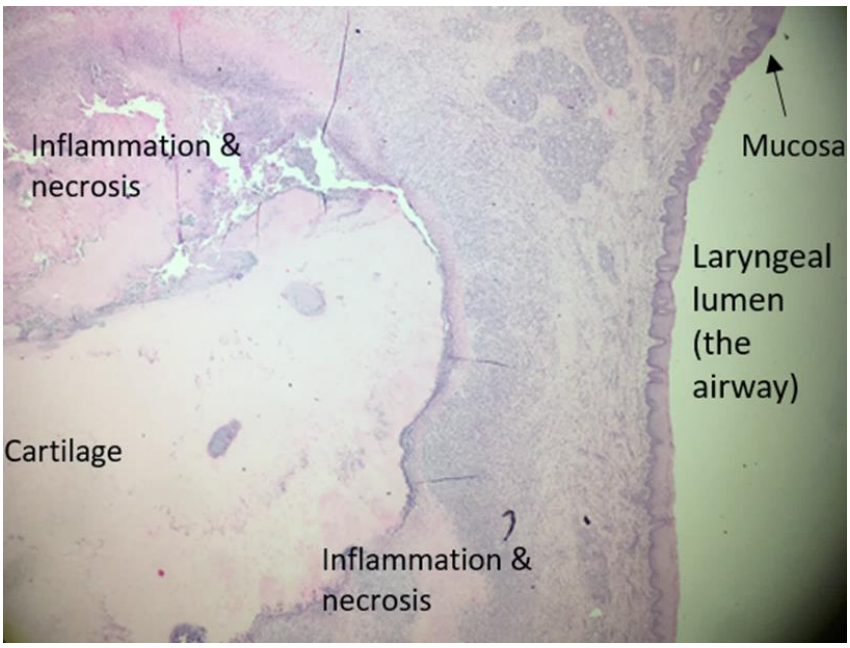


Figure 3 Histopathology of laryngeal chondritis showing extensive necrosis and inflammation of the cartilage and surrounding tissue

1.2 Anatomy of the larynx

The larynx connects the pharynx to the trachea and is suspended from the base of the skull by the hyoid apparatus. The ovine larynx consists of the epiglottic, thyroid,

cricoid and the paired arytenoid cartilages (Dyce and others 2002). A small median ventricle is present in sheep and goats (Dyce and others 2002).

The epiglottis consists of elastic cartilage and functions to protect the entrance to the airways, although the cartilage does not achieve a complete seal. The thyroid cartilage is the largest piece and consists of two lateral plates of hyaline cartilage that meet to form the ventral surface of the larynx, this cartilage is susceptible to ageing changes such as calcification and ossification. The cricoid cartilage is also hyaline and subject to the same ageing changes. The arytenoid cartilages are paired and formed of hyaline cartilage, except the corniculate process which is elastic. The crico-arytenoid joint is a synovial joint (Dyce and others 2002).

The larynx is lined partly by stratified squamous epithelium and partly by ciliated pseudostratified columnar epithelium. There are serous, mucous and mixed glands in the lamina propria and submucosa and the whole structure is supported by skeletal muscle (Bacha and Bacha 2012).

Due to its use as a model for human disease, some literature exists describing the anatomy and size of the sheep larynx (Zrunek and others 1988; Kim and others 2004). Zrunek and others (1988) found that the anatomy of the sheep larynx did not significantly differ between males and females and compared to the human larynx, the arytenoid cartilage is much larger. No literature was found that describes how the anatomy of the larynx differs between breeds of sheep.

1.3 Sheep breed conformation and the reasons for breed differences

To suit the different land and terrain utilised by sheep farmers in the UK different breeds of sheep are used at different points in the production system (National Sheep Association 2019). There are three parts of the stratification system – hill, upland and lowland. There are many breeds used within these systems but one system is discussed below to demonstrate how two different breeds, the Bluefaced Leicester and the Texel, might fit in (Figure 4).

The Bluefaced Leicester is an upland Longwool breed, which is often crossed with hill breeds such as the Swaledale, Welsh Mountain, Cheviot and Scottish Blackface, to produce the prolific North Country Mule ewe. These Mule ewes are used as breeding stock in upland and lowland areas to produce lambs for meat and will be mated to a terminal sire such as the Texel. Texel sheep, originally from a Dutch Island, have been bred to grow fast, be well muscled and prolific. There are many purebred Texel sheep in the UK having a 27% share of the ram market, while Texel crossbred ewes make up 12% of the total ewe flock (Texel Breed Society 2019).

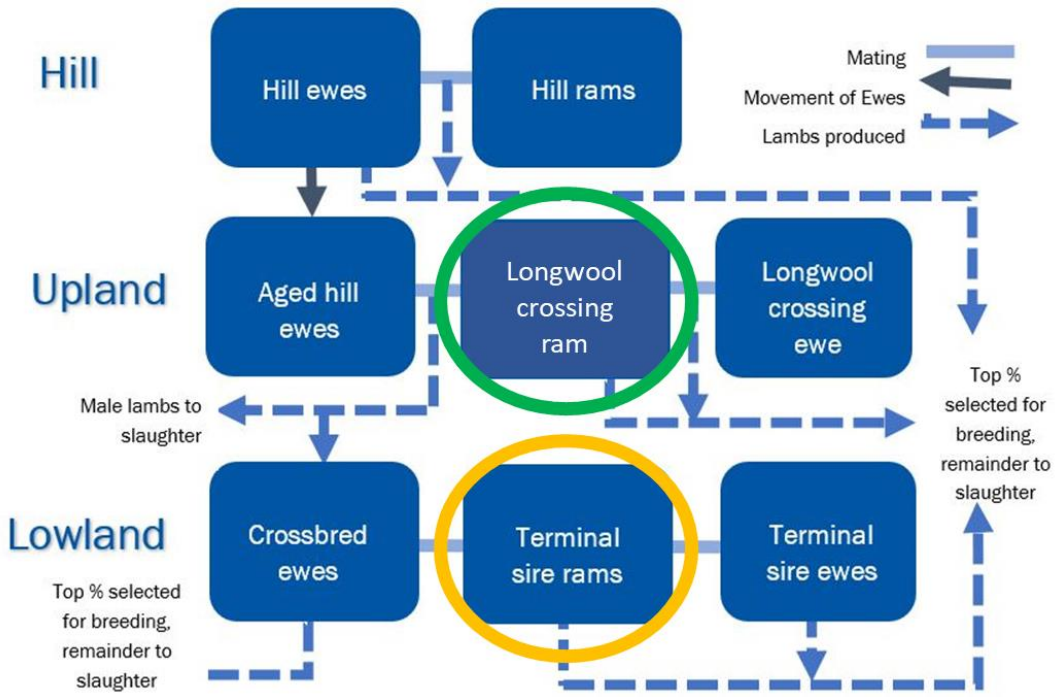


Figure 4 The UK Sheep Stratification System showing where Bluefaced Leicesters (green circle) and Texel (orange circle) breeds fit in [Image: National Sheep Association 2019]

The conformation of the Bluefaced Leicester and the Texel breeds differ reflecting the difference in their utilisation. Texel breed sheep have a near horizontal head carriage, with a short head and neck (Oklahoma State University 2015) and it may be these anatomical and conformational traits that predispose the breed to laryngeal chondritis (Lane and others 1987). There have been no studies to assess how the anatomy of the Texel larynx may differ to that of other breeds of sheep.

1.4 Aims of the study

The Texel is the most commonly used terminal sire in the UK sheep industry and over 1.6 million crossbred ewes are found in the national ewe flock (Texel Breed Society 2019). Although the prevalence of laryngeal chondritis is unknown the impact the disease can have on the animals, flocks, and farmers affected suggests that research

to gain a better understanding of the condition is merited (Rideout 2019). No previous studies have assessed the anatomy of the Texel larynx and how this may predispose to laryngeal chondritis. This study aimed to assess this deficit.

2 Materials and Methods

2.1 Ethical approval

This project received ethical approval from the ethics research committee at the School of Veterinary Medicine and Science, University of Nottingham.

2.2 Larynx selection

Twenty-three larynges were collected from Texel ram carcases and 20 larynges were collected from Bluefaced Leicester ram carcases between August 2017 and October 2018. Bluefaced Leicester (BFL) rams were chosen as a control for the study based on carcase availability and having a similar body weight to the Texel. The larynges were labelled TX1 – TX23 and BL1 – BL20 for the Texel and BFL breeds, respectively. Adult entire males of each breed were selected from fallen stock (animals that have died or been killed on farm for reasons other than human consumption) brought to a Fallen Stock Collection Centre (a centre for carcase disposal) in Northern England. The characteristic appearances of each breed were used to select carcases for the study, which were collected when time allowed alongside the daily post mortem room workload. Age was estimated by examining the incisor teeth; two teeth (2T) ≈ 12-18 months old, four teeth (4T) ≈ 2 years-old, six teeth (6T) ≈ 3 years-old, full mouth (FM)

≈ 4 years-old and over, and broken mouthed (BM) ≈ older than FM (Cocquyt and others 2005). Farm of origin, clinical history, pedigree and cause of death were not known and none of the animals were weighed. Carcases or larynges showing advanced signs of autolysis were not chosen for the study.

2.3 Carcase measurements

The length of the head, neck circumference, length of the neck, height, and girth of each ram were measured to the nearest half centimeter with the carcase in lateral recumbency using a tape measure (Table 1). The girth measurement was used as a proxy for weight (Olatunji-akioye and Adeyemoa 2009).

Table 1 Description of carcase measurements

Carcase measurement	Points of measurement
Head length	Caudal mandibular edge to rostral mandibular point of lower jaw
Neck circumference	Circumference of cranial neck, measured immediately caudal to ear base
Neck length	Cranial point of sternum to caudal mandible, measured along ventral neck
Height	Caudal plantar heel to withers
Girth	Circumference of girth

2.4 Larynx collection, measuring and photography

The tongue, larynx and proximal trachea were removed from each carcase using a ventral approach. The tongue and loose soft tissue were removed and the larynx was placed whole in 10% neutral buffered formalin for at least one week.

At the University of Nottingham School of Veterinary Medicine and Science, the fixed larynges were dissected further to leave the intact larynx with two tracheal rings. Each larynx was photographed using a Canon EOS 1000D digital camera from the dorsal and ventral aspects (Figure 5 and Figure 6), from each side (Figure 7). The internal medial surfaces were also photographed (Figure 8). A Canon PowerShot SX50 HS digital camera was used to take photographs from the cranial and caudal ends (Figure 9) and an iPhone SE with flash was used to photograph the laryngeal lumen from the caudal aspect. Larynges were measured and photographed whole, before being split longitudinally with a scalpel blade. Larynges with foci of mineralisation were placed in decalcification solution for 12-24 hours before splitting.

Measurements of the fixed larynges, based on Zrunek and others (1988), were taken using a pair of compasses, a ruler and a goniometer:

1. Anterior thyroid length (distance from upper to lower thyroid incisure (mm)) (Figure 5; green line)
2. Dorsal thyroid length (distance between tips of upper and lower horns (mm)) (Figure 7; green line)
3. Maximum thyroid breadth (length of thyroid tubercula (mm)) (Figure 5; red line)
4. Upper thyroid breadth (length of thyroid tubercula (mm)) (Figure 6; purple line)
5. Lower thyroid breath (distance of inferior horns (mm)) (Figure 6; yellow line)

6. Length of thyroid lamina (distance of notches prior to horns (mm)) (Figure 7; light blue line)
7. Anteroposterior dimension (distance between laryngeal prominence and plane thought posterior margins of laminae (mm)) (Figure 7; red line)
8. Main length of larynx (extension of distance 6 to lower margin of cricoid cartilage (mm)) (Figure 7; dark blue line)
9. Length of cricoid lamina (mm) (Figure 6; green line)
10. Anterior length of cricoid arch (mm) (Figure 5; brown line)
11. Angle between thyroid laminae (˚) (Figure 10; brown line)
12. Width of epiglottis at attachment of soft tissue (mm) (Figure 6; pink line)
13. Width of trachea at second tracheal ring (as felt by palpation) (mm) (Figure 9; green line)
14. Height of trachea at second tracheal ring (as felt by palpation) (mm) (Figure 9; blue line)
15. Distance between midpoint cranial corniculate projections (mm) (Figure 6; pale line)
16. Split cricoid length (mm) (Figure 8; red line)
17. Cricothyroid distance measuring to outer edges (mm) (Figure 8; green line)
18. Split thyroid length (mm) (Figure 8; blue line)
19. Depth of the arytenoid projections including corniculate process (mm) (Figure 8; dark purple line)
20. Flat length of epiglottis (mm) (Figure 8; pink line)
21. Height of cricoarytenoid cartilage (mm) (Figure 8; orange line)

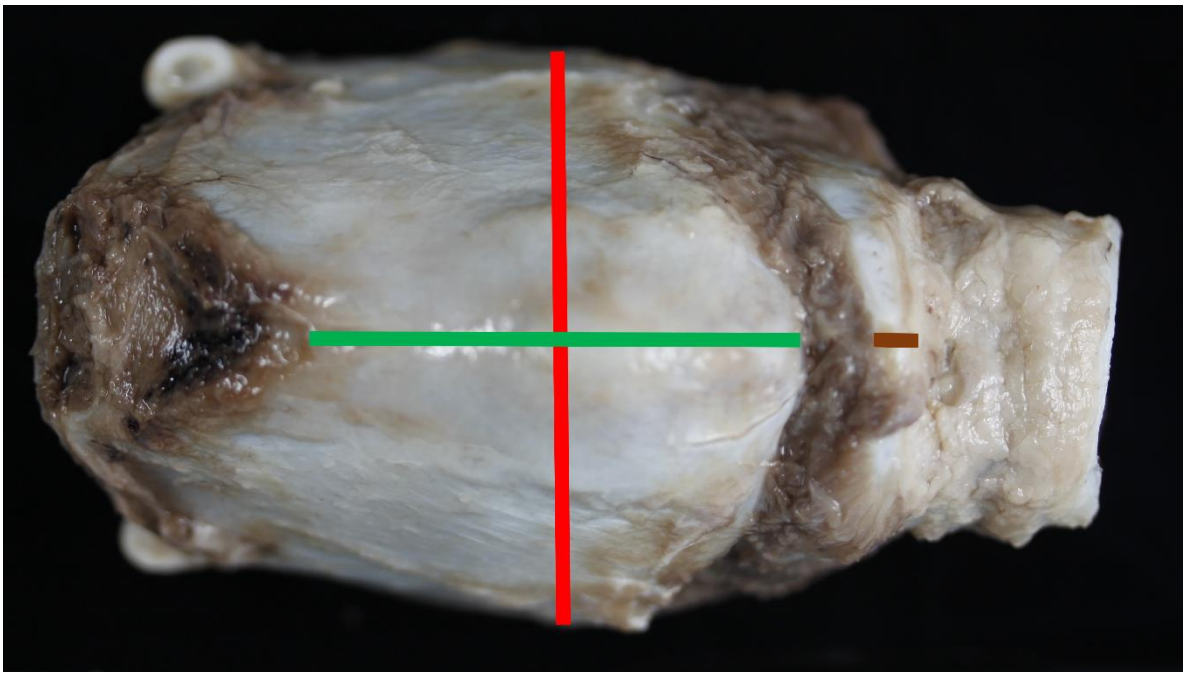


Figure 5 The ventral aspect of the larynx and measurements taken [Green line = measurement #1, red line = measurement #3, brown line = measurement #10].

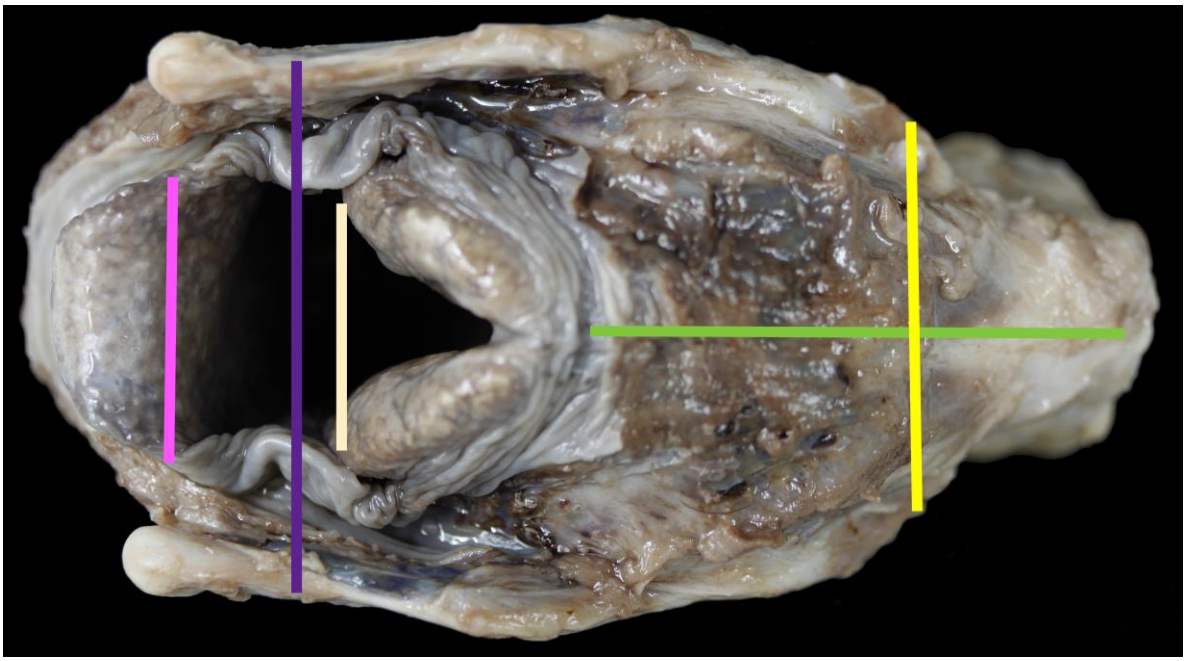


Figure 6 The dorsal aspect of the larynx and measurements taken [Pink line = measurement #12; purple line = measurement #4; pale line = measurement #15; yellow line = measurement #5; green line = measurement #9].

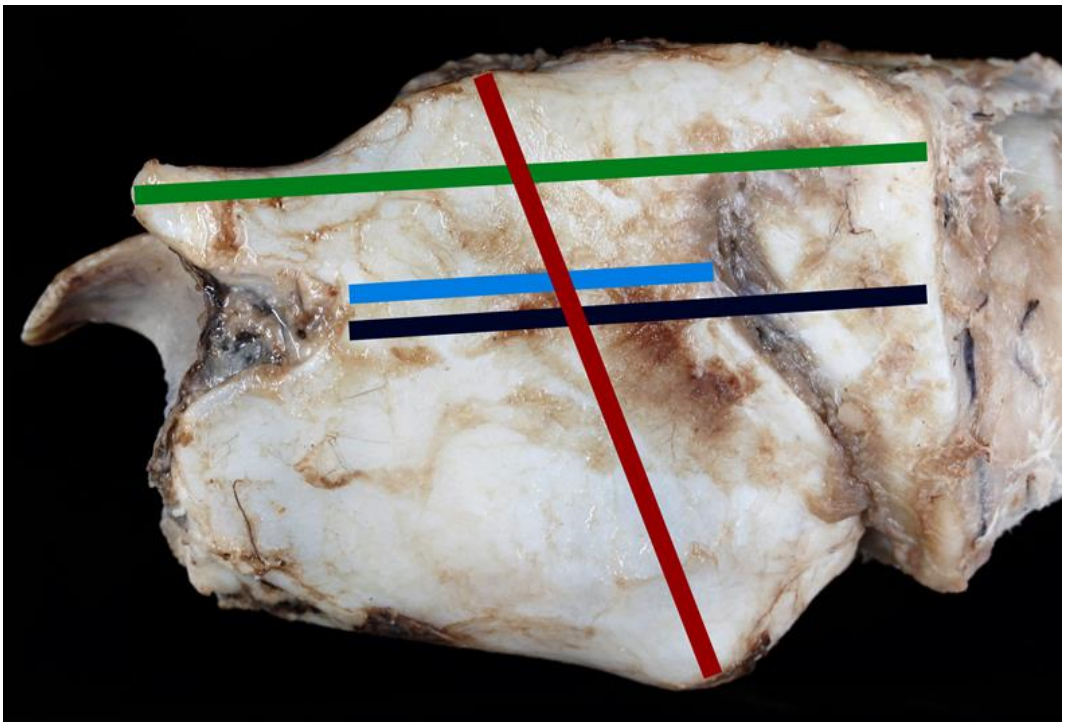


Figure 7 The lateral aspect of the larynx with measurements taken [Green line = measurement #2; light blue line = measurement #6; red line = measurement #7, dark blue line = measurement #8].

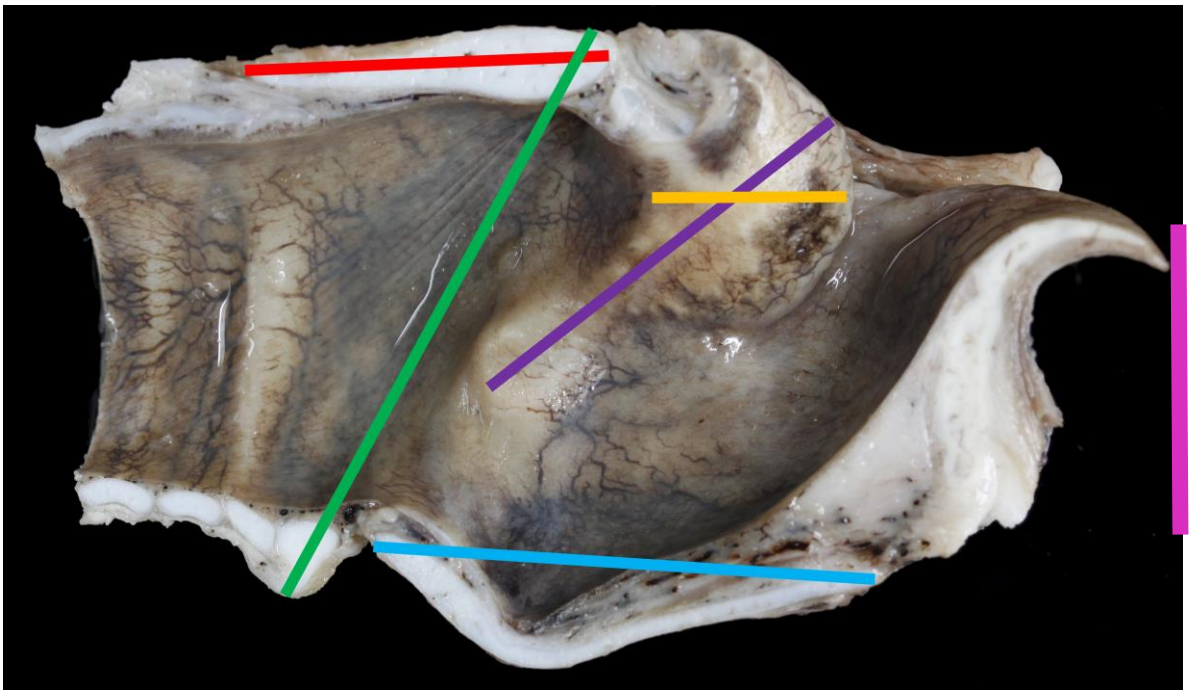


Figure 8 Medial view of the laryngeal lumen with measurements taken [red line = measurement #16; green line = measurement #17; blue line = measurement #18; dark purple line = measurement #19; pink line = measurement #20 (with epiglottis flattened); orange line = measurement #21].

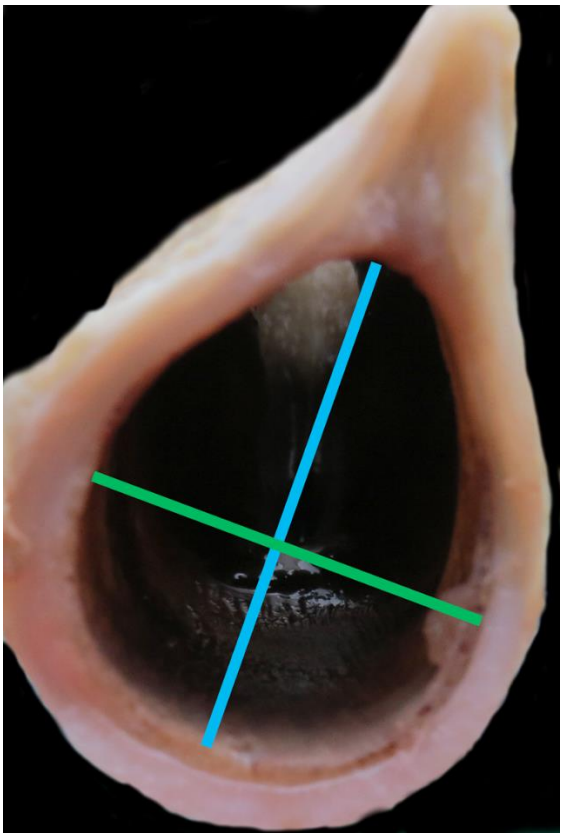


Figure 9 View of the caudal larynx looking cranially with measuring points for the tracheal rings [green line = measurement #13; blue line = measurement #14].



Figure 10 Transverse cross-section of the larynx to show measurement #11, the acute angle between the two brown lines. [NB In the study this measurement was taken with the larynx whole, the transverse section shown here is to demonstrate the angle only].

The tracheal area was estimated based on the area of an ellipse:

$$\text{Area of trachea} \approx \pi \times 0.5 \text{ tracheal width} \times 0.5 \text{ tracheal height}$$

Each larynx was subjectively assessed for its overall appearance with respect to the shape and the soft tissue surrounding the cartilage at each stage of the study.

2.5 Diagnostic imaging

Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) were carried out to determine if these modalities could be useful for assessing anatomical and

pathological features of the fixed sheep larynx. Larynges were sent for imaging before measurements had been taken and while each larynx was still intact. Selection was based on the best example of the anatomical features for each breed from the larynges available at the time (the most intact, with no external lesions and the most cleanly dissected that had not already been incised). One formalin-fixed Texel larynx and one formalin-fixed Bluefaced Leicester larynx were submitted to Scotland's Rural College (SRUC) CT Scanner Unit, Edinburgh for CT scanning. The larynges were scanned using a 16 Slice Siemens Somatom Scope CT scanner at 0.75mm slice thickness, 100mAs, 130kV, 450mm Field of View and Pitch 1. CT images were viewed using syngo Fast View imaging software (Siemens Healthcare, Erlangen). One larynx from each sheep breed was sent to Bearl Equine Clinic, Northumberland, for MRI. A Hallmarq standing equine distal limb MRI scanner (EQ2 System; Hallmarq Veterinary Imaging Ltd, Guildford, UK) with a low field strength open configuration permanent magnet (0.3 tesla) was used. Three scanning sequences were carried out to ascertain if MRI could produce suitable images to assess laryngeal anatomy and pathology; T1 gradient-echo (GRE), T2 (GRE and fast spin echo (FSE)) and Short-TI Inversion Recovery (STIR). The slice thickness varied from 1.5 mm for the T1 GRE HR (high resolution) images, to 3.5 mm for the T2 FSE and STIR sequences. All MRI images were processed and viewed using eFilm Lite 2.1.0 software (Merge Healthcare, IBM Watson Health, Chicago).

2.6 Statistical analysis

Data from the two breeds of sheep were compared using Pearson's T-test for continuous variables and Chi-squared or Fischer's exact test for categorical variables. Basic descriptive statistics were conducted using Microsoft Excel 2016 and the statistical tests were carried out using R V.3.4.0 statistical software (R Core Team 2016). Graphs and tables were made in Excel or R. Statistical significance was set at a stringent $p<0.01$.

3 Results

The age range of the carcases that the larynges were collected from is shown in Figure 11 using the estimated descriptors; there was no significant difference in age category between the breeds of the animals collected.

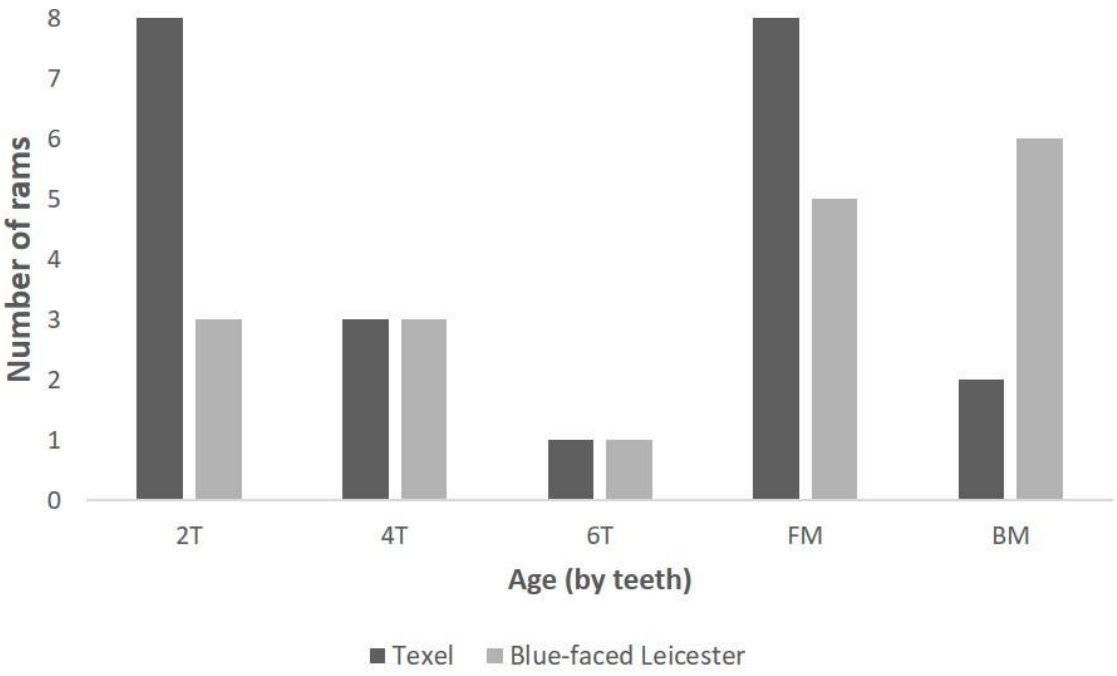


Figure 11 The age of the rams from which the larynges were collected [2T = two-toothed; 4T = four-toothed; 6T = six-toothed; FM = full mouth; BM = broken mouthed].

3.1 Anatomy of the larynx

3.1.1 General observations

Nine Texel larynges and eight BFL larynges had points of mineralisation at the caudal upper cricoid and/or the caudal thyroid cartilage that required decalcification (Figure 12).

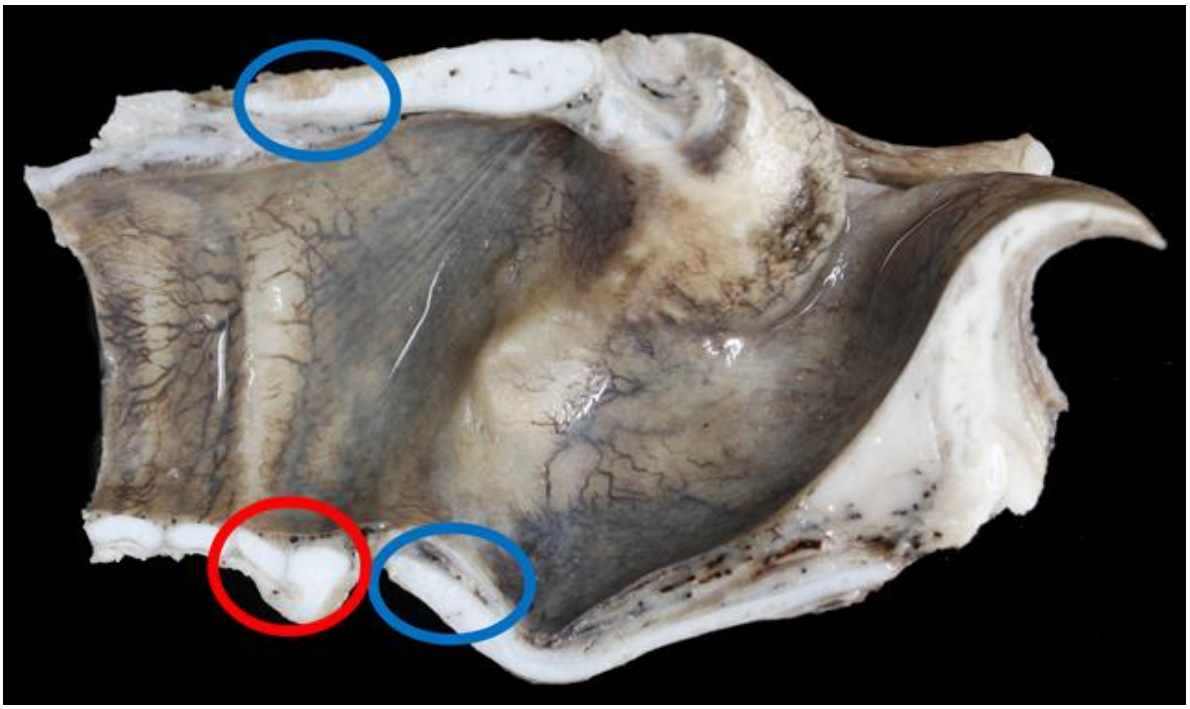


Figure 12 The blue rings show the common location of ossification found in the larynges examined. The red ring shows the cricoid cartilage (right) and the first tracheal ring (left) – in this specimen the tracheal ring is not overriding the cricoid cartilage [BL3].

The ventral cricoid ring and the first tracheal ring varied in shape and size, Figure 13 shows a very long and flat tracheal ring in a BFL larynx.

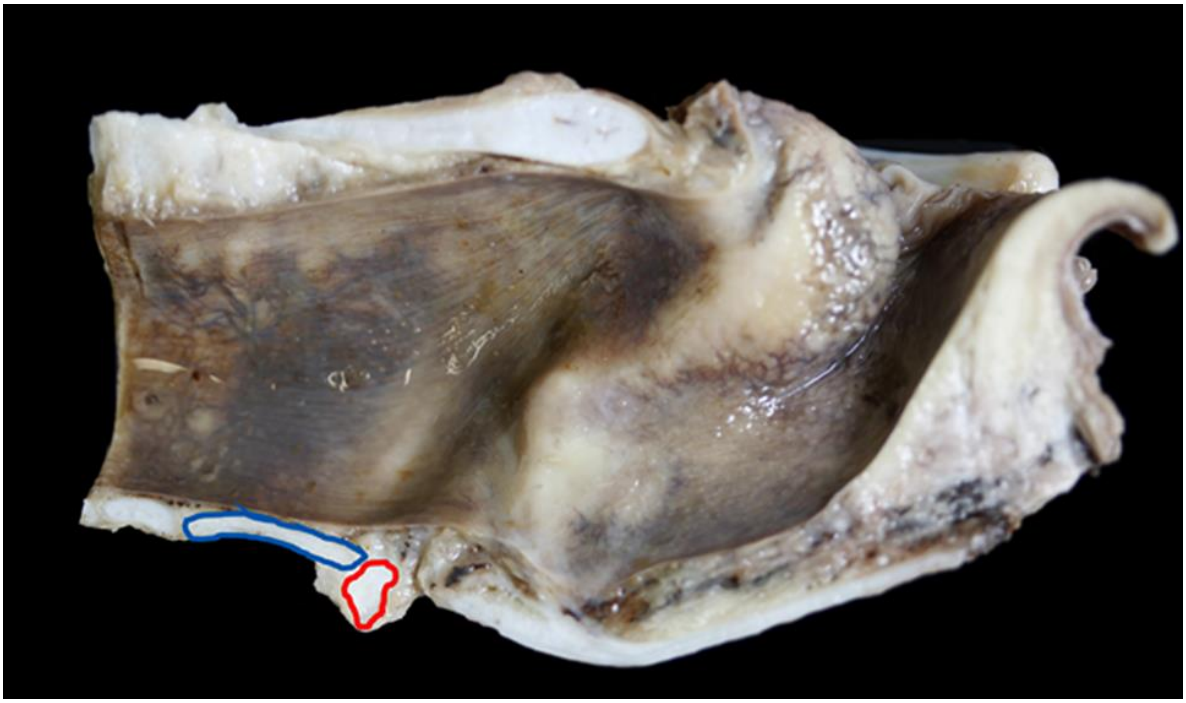


Figure 13 Mild overlap of the cricoid cartilage (red ring) by the first tracheal ring (blue ring) [BL6].

In nine of 19 (47%) BFL larynges the first tracheal ring overlapped the cricoid to some degree (an overlap was defined as any part of the first tracheal ring extending cranially beyond the level of the most caudal edge of the cricoid cartilage), in Texel larynges 15 out of 23 (65%) overlapped (Figure 12- 14).

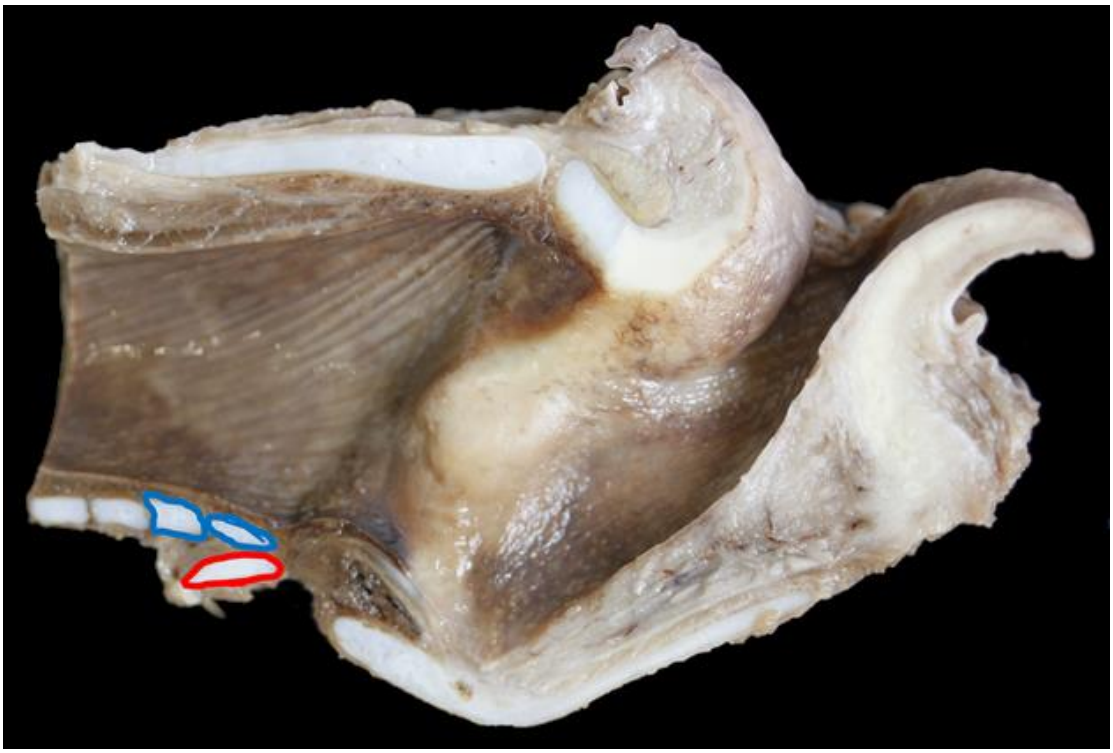


Figure 14 Extreme overlap of the cricoid cartilage (red ring) by the first, and in this case, second tracheal rings (blue rings) [TX5].

Overlap of the cricoid by the tracheal rings and varying lengths of the first tracheal ring retrospectively resulted in the tracheal measurements being taken at the level of the 2nd – 4th tracheal ring. The amount of soft tissue around the larynx, especially in the space between the epiglottis and corniculate processes, and between the corniculate processes and the thyroid cartilages, varied between individual larynges. A semi-quantitative scoring system (mild, moderate or severe) was used to assess this; Figure 15 shows a mild amout of soft tissue, Figure 16 a moderate amount and Figure 18 a severe amount. Generally the BFL had very little excess soft tissue (Figure 15) but occasional BFL larynges showed a moderate excess (Figure 16).

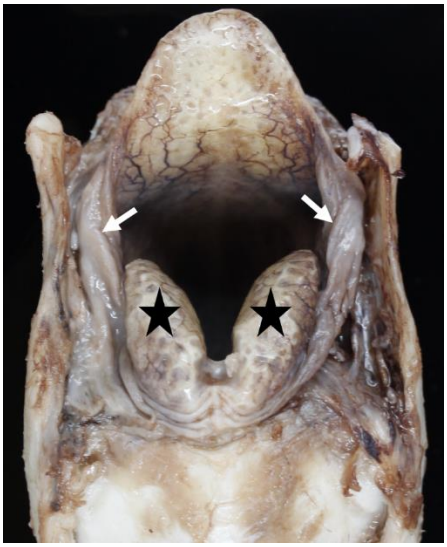


Figure 15 Little excess of soft tissue (arrows) seen around the corniculate processes (black stars) [BL3]

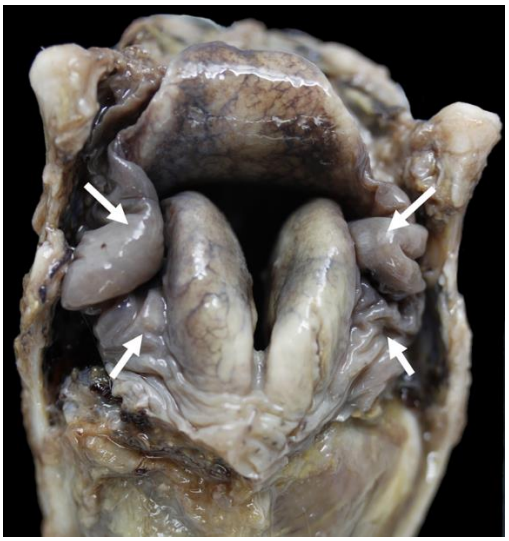


Figure 16 Moderate excess of soft tissue (arrows) around the corniculate processes [BL18]

Mild to severe amounts of excess soft tissue were observed in these spaces in Texels (Figure 17 and 18).

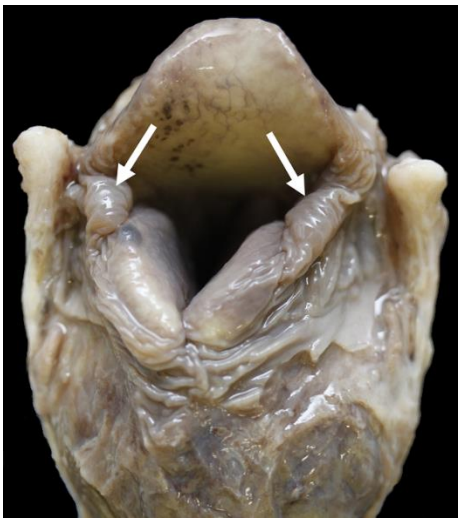


Figure 17 Little excess of soft tissue (arrows) around the corniculate processes [TX9]

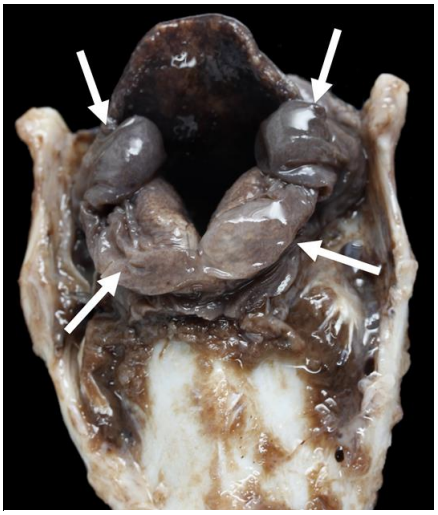


Figure 18 Severe excess of soft tissue (arrows) around the corniculate processes [TX2]

A summary of the measurements are shown in Table 2.

Table 2 A summary of the carcase and laryngeal measurements

Anatomical structure	Measurement	Texel		Blue-faced Leicester		p value
		n =	Mean (mm)	n =	Mean (mm)	
Head and neck	Head length	17	240	14	238	0.7
	Neck circumference	17	495	14	404	<0.001
	Neck length	14	402	14	486	<0.001
	Height	17	742	14	843	<0.001
	Girth	16	1037	13	1034	0.95
Larynx length	Anterior thyroid length	23	39.5	20	45.1	<0.001
	Dorsal thyroid length	23	55.8	20	65.1	<0.001
	Length of thyroid laminae	23	26.8	20	30.9	<0.001
	Main length of larynx	23	47.8	20	51.4	<0.001
	Split thyroid length	22	38.6	18	43.9	<0.001
	Length of cricoid cartilage	23	40.7	19	44.8	0.02
	Cricoid split length	22	34.4	18	38.8	0.02
	Anterior cricoid length	22	7.8	20	8.3	0.4
Larynx width	Maximum thyroid breadth	21	52.3	20	50.2	0.06
	Lower thyroid breadth	22	38.4	20	38.9	0.7
	Upper thyroid breadth	21	48.2	20	43.1	<0.001
Larynx height	Anteroposterior dimension	23	50.6	20	58	0.004
	Cricothyroid distance	20	43.3	18	51.5	<0.001
Larynx angle	Angle of thyroid cartilage	22	58.1°	20	50.4°	<0.001
Airway	Tracheal width	23	15.6	20	19	<0.001
	Tracheal height	23	19.2	19	23.9	<0.001
	Tracheal area	23	239mm^2	19	372mm^2	<0.01
Arytenoid cartilage	Corniculate process distance	21	15.7	19	16.8	0.23
	Depth of corniculate process	21	18.6	19	19.3	0.5
	Height of arytenoid cartilage	18	39.7	18	42.2	0.02
Epiglottis	Length of epiglottis	22	32.1	19	35.8	0.04

3.1.2 Carcase measurements

The neck circumference of the Texel rams was significantly larger than that of the Bluefaced Leicester rams, while the neck length was significantly shorter in the Texel. The Texel sheep were significantly shorter in height than the Bluefaced Leicester sheep but there was no significant difference in girth measurements between breeds suggesting they had a similar weight range. The luminal surface area of the trachea at the level of the 2nd – 4th tracheal ring of the Texel was significantly reduced in size compared to that of the Blue-faced Leicester (Figure 19).

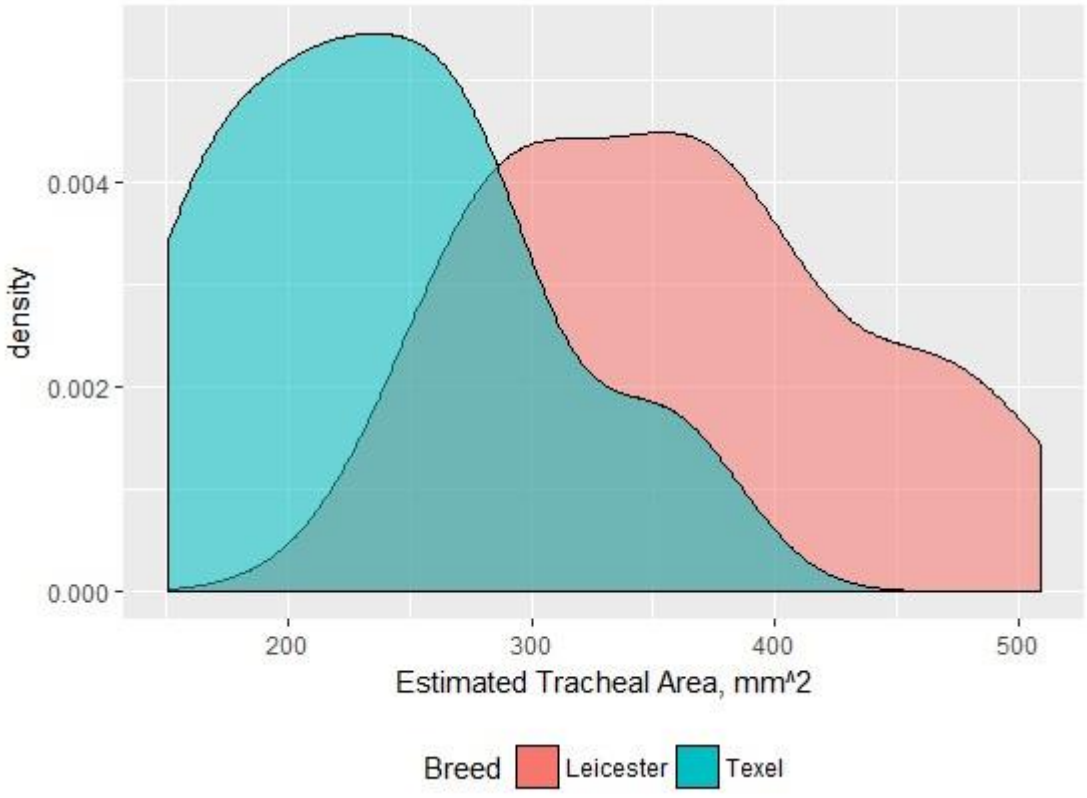


Figure 19 A density distribution of the tracheal lumen-surface areas for each breed measured at the 2nd – 4th tracheal ring (mm^2).

3.1.3 Larynx measurements

The Texel larynx was significantly shorter in length and height when compared to the BFL. It was significantly wider at the cranial and mid points and had similar sized arytenoid and epiglottal cartilages. The tracheal width, height and luminal area were significantly smaller in the Texel. There was no relationship between the girth length and the tracheal luminal surface area in either breed. With a significantly wider cranial end both in distance and angle, the Texel larynx narrows more substantially than that of the BFL, caudally creating more of a 'funnel' shape (Figure 20 and 21).

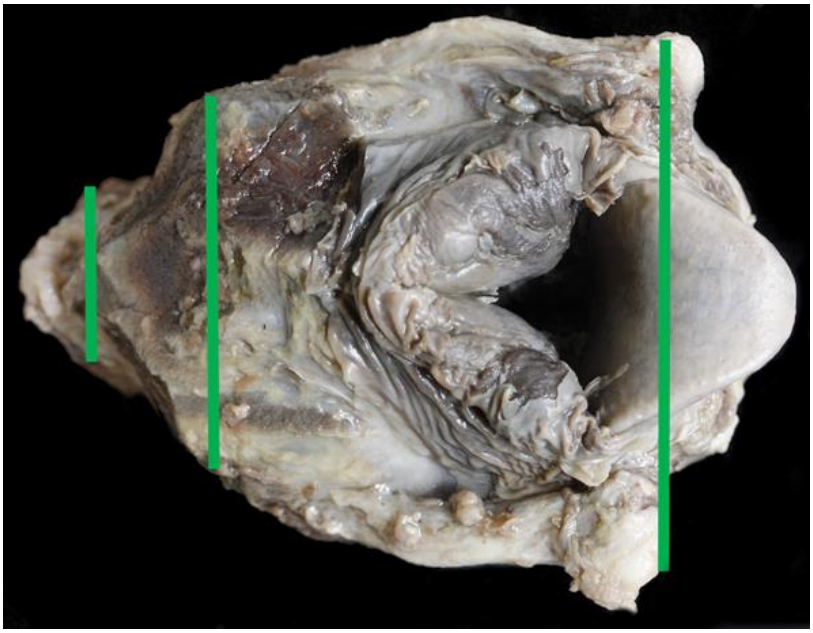


Figure 20 TX11 with a funnel shape to the airway.

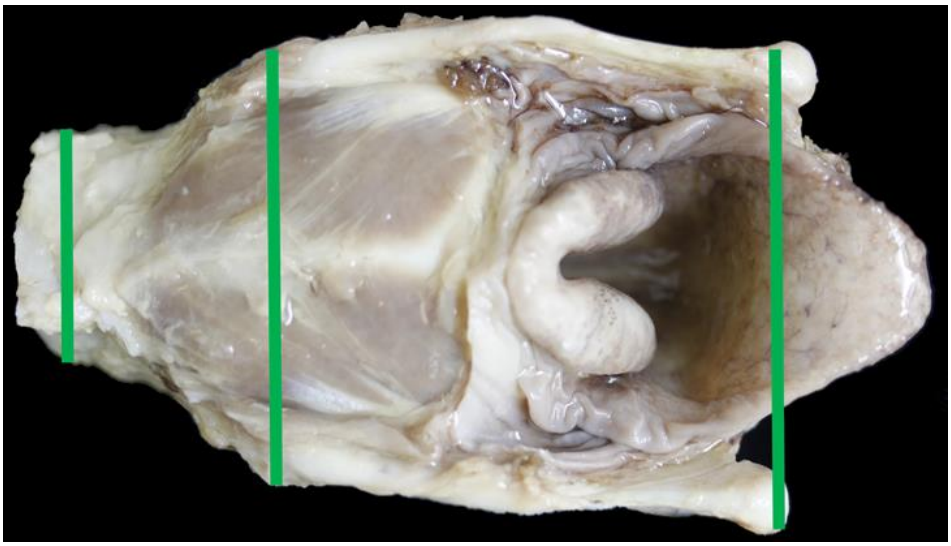


Figure 21 BL9 showing a more elongated larynx.

3.1.4 The glottis

In 10 of 22 (45.5%) Texel larynges the vocal folds were touching in the airway, in 20 out of 20 (100%) BFLs there was no contact between these structures (Figure 22).

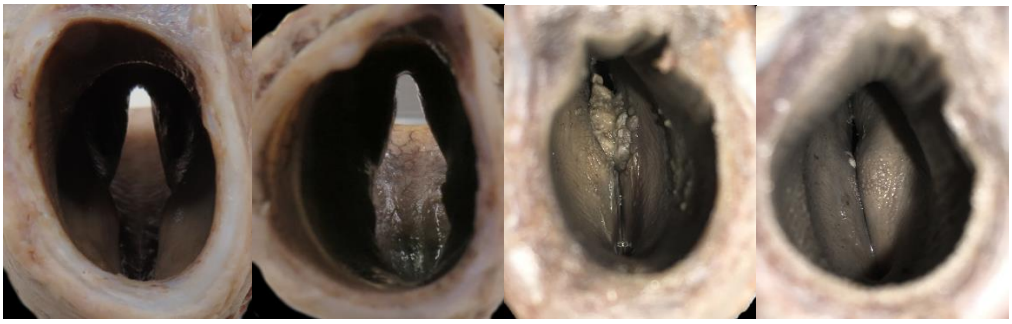


Figure 22 The vocal folds of the BFLs were not found to touch in any of the larynges examined (BL1 and BL3, left two photographs). In the Texel sheep (T11 and T12, right two photographs), 45% of the vocal folds had some contact when examined. These photographs were taken from the caudal (tracheal) end of the larynx looking cranially. Note also the shape of the trachea; the BFL shows an elliptical shape, while the Texel trachea appears subjectively more rounded.

In the Texel larynges the vocal folds were more likely to contact in larynges with a wider angle of thyroid laminae.

3.2 Diagnostic imaging

The CT images gave a clear view of the airway in the fixed larynges (Figure 23) but the MRI images provided a clear view of the airway and a clearer distinction between the laryngeal structures (Figure 24).

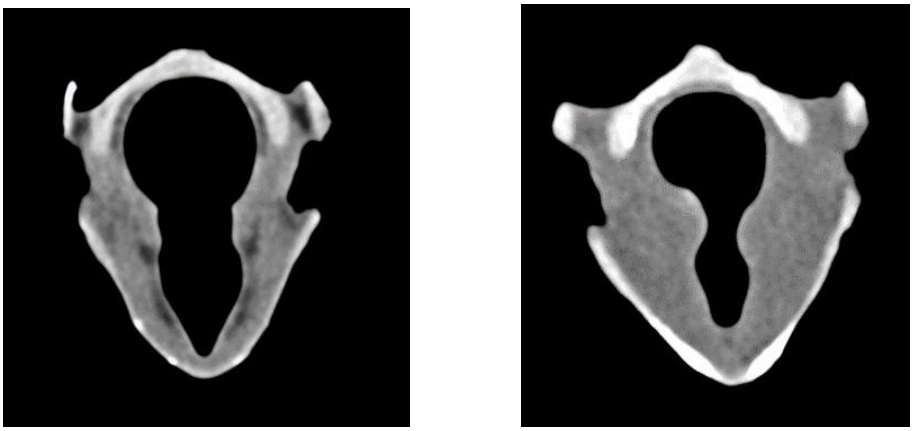
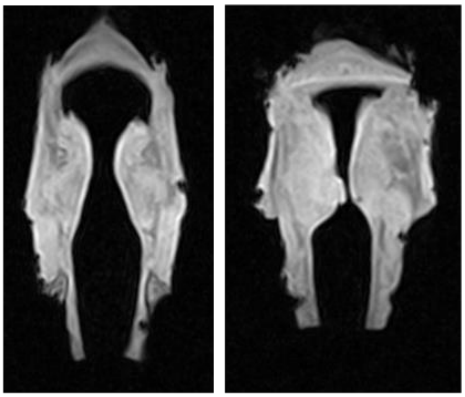
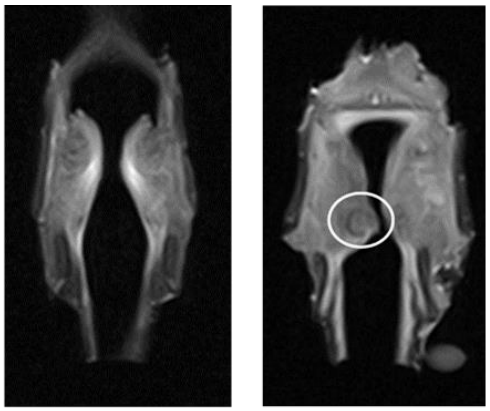


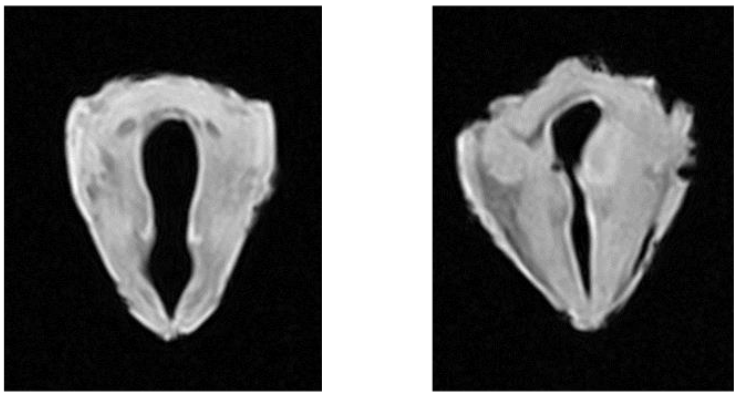
Figure 23 CT images at the narrowest point of the glottis: BL3 (left) and TX2 (right). The central black area in the middle of the greyish structure (laryngeal cartilages and soft tissue) is the airway. The bright white structures represent the laryngeal cartilages and the grey areas the soft tissue.



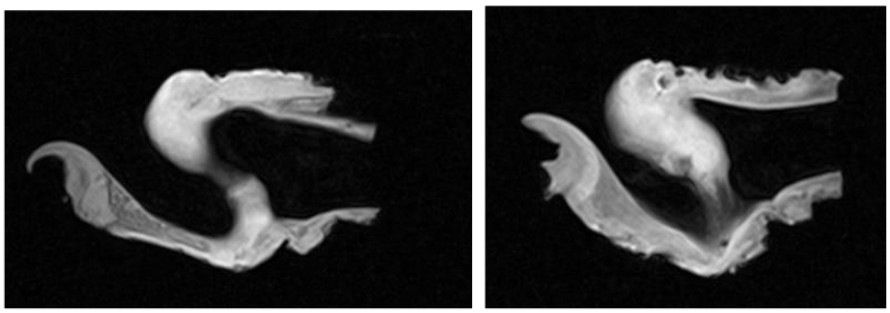
T1W 3D HR Frontal slices (BL8 left, TX1 right)



T2W FSE HR Frontal slices (BL8 left, TX1 right) showing focally extensive abscess formation in TX1 (white circle)



T1W 3D HR Transverse slices (BL8 left, TX1 right)



T1W 3D HR Sagittal plane (BL8 left, TX1 right)

Figure 24 MRI images of larynges BL8 and TX1

.

T2 FSE and STIR sequences gave better differentiation between tissues due to bigger differences in signal intensity, while T1 GRE HR appears to show better resolution for anatomical detail. MRI also proved more useful for identifying pathology; imaging of TX1 found a small focal area of abscessation that was visualised on MRI and confirmed at gross dissection.

3.2.1.1 Pathology

Gross lesions were found in 52% (12/23) of the Texel rams compared to 10% (2/20) of the Bluefaced Leicesters. A description of the lesions observed are summarised in Table 3 Gross lesions observed in the laryngesand Figures 25 - 28.

Table 3 Gross lesions observed in the larynges

Larynx	Gross lesion	Vocal fold contact
TX1	Moderate unilateral (right side) vocal fold mucosal hyperplasia	Yes
TX4	Moderate haemorrhage in right dorsal cricoarytenoid muscle, mild bilateral vocal fold mucosal erosion and hyperplasia	Yes
TX6	Mild bilateral vocal fold mucosal hyperplasia	No
TX7	Mild unilateral vocal fold mucosal hyperplasia	No
TX8	Mild vocal fold mucosal erosion	No
TX9	Unilateral (left side) mild vocal fold mucosal hyperplasia, right-sided mild vocal fold mucosa flattening, bilateral severe suppurative cricoarytenoid osteoarthritis	Yes
TX11	Bilateral, moderate vocal fold mucosal hyperplasia	No
TX12	Bilateral, mild, vocal fold mucosal ulceration	Yes
TX13	Massive bilateral necrosis of the corniculate process of the arytenoid cartilages with haemorrhage	No
TX16	Bilateral moderate vocal fold mucosal hyperplasia	Yes
TX17	Bilateral moderate vocal fold mucosal hyperplasia	Yes
TX21	Severe bilateral vocal fold mucosal hyperplasia	Yes
BL5	Mild unilateral vocal fold mucosal hyperplasia	No
BL20	Mild unilateral vocal fold mucosal hyperplasia	No

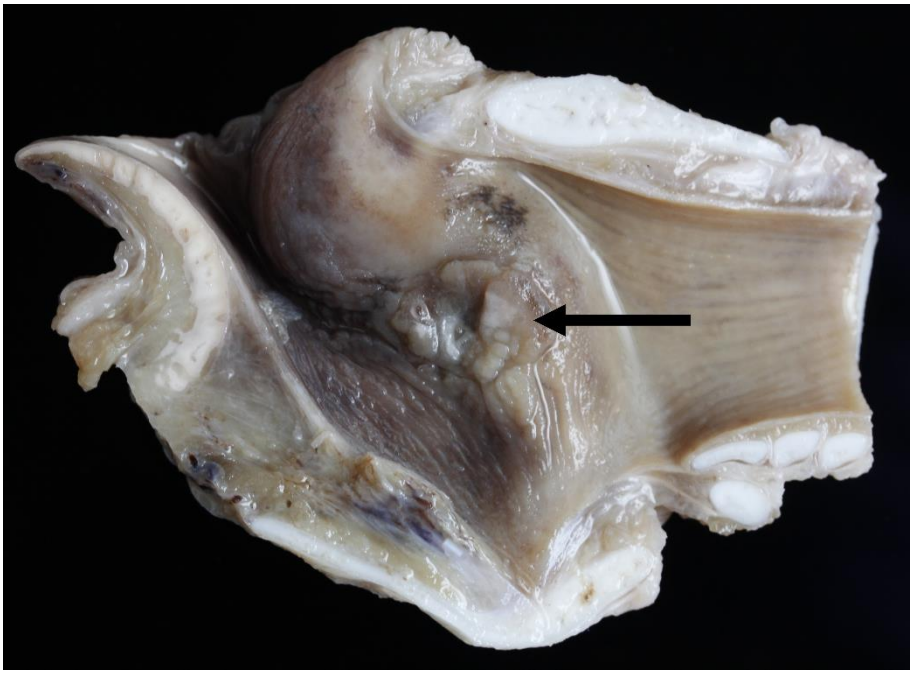


Figure 25 Right vocal fold moderate mucosal hyperplasia (arrow) [TX1].

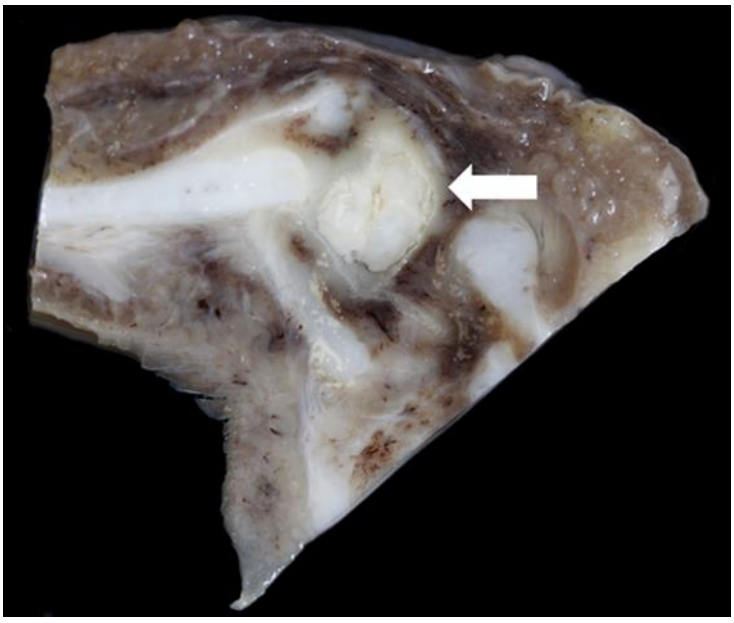


Figure 26 Medio-lateral slice through the left crico-arytenoid joint showing focally extensive abscessation (arrow) [TX9].

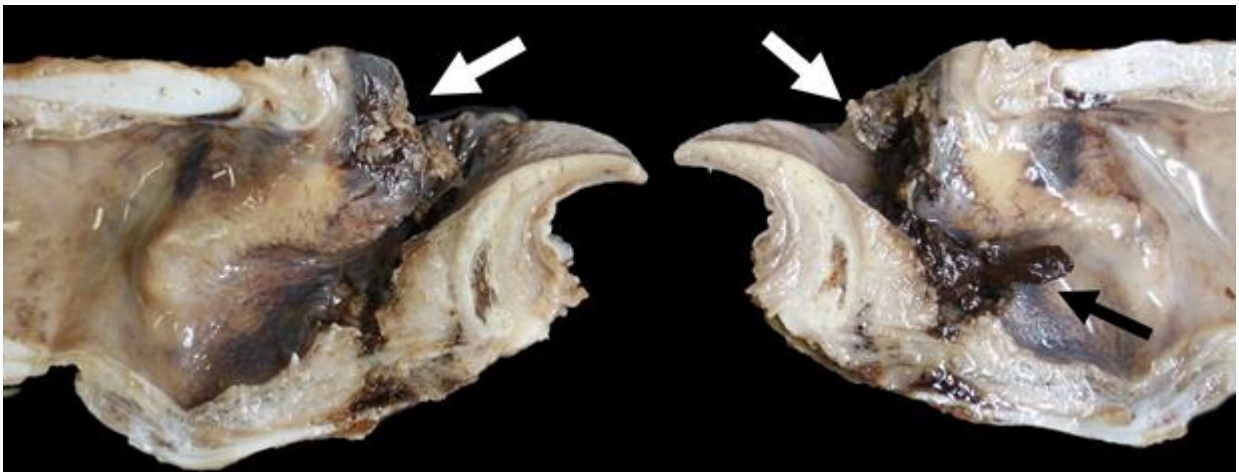


Figure 27 Massive bilateral necrosis of the corniculate process of the arytenoid cartilage (white arrows) with associated haemorrhage (black arrow) [TX13].

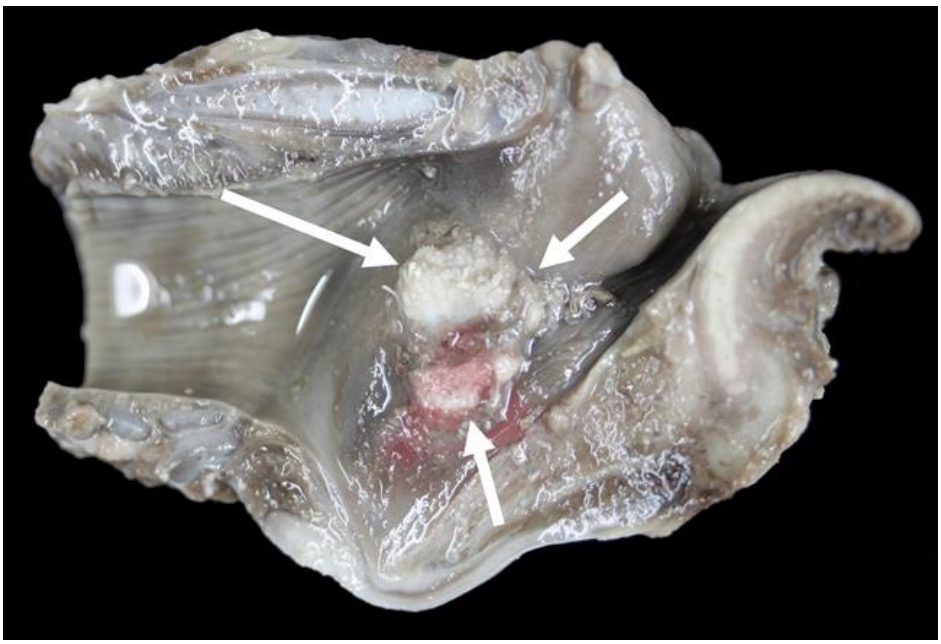


Figure 28 Severe unilateral vocal fold mucosal hyperplasia (arrows) (the red colouring is an artefact) [TX21].

Compared to the BFL, Texel sheep were significantly more likely to have laryngeal lesions ($p=0.01$) and more likely to have contact between vocal folds ($p<0.001$). It was not possible to associate lesions with animal age.

4 Discussion

This study provides an initial insight into the anatomy of the Texel sheep larynx and indicates how it differs from a breed less prone to laryngeal chondritis. The research

has established a protocol for measuring and examining the larynx and highlighted the potential value of diagnostic imaging for use in future projects. The authors are not aware of previous work investigating the normal anatomy of the ovine larynx. Zrunek and others (1988) studied the difference between the human and the ovine larynx, but the current study is the first to examine the sheep larynx in detail. This study has found that the overall shape, size and appearance of the larynx differs between individual sheep, and between breeds.

The Bluefaced Leicester was chosen as a control in this study due to the ease of availability of carcases in the region of the UK where the larynges were collected. The two breeds however serve two different purposes in the UK sheep stratification system: BFL rams are used to produce North Country Mules, a ewe used for breeding, whereas the Texel ram is used to produce lambs for meat. The Texel is therefore bred for its pronounced muscling and solid stance, while part of the breed description for the BFL is a good length of neck (Bluefaced Leicester Sheep Breeder's Association 2019; Texel Breed Society 2019). The average weight of the two breeds of ram are similar; the Texel averages 120kg (Texel Breed Society 2018, *personal communication*, 20 November) and the BFL ranges from 90-150kg (Bluefaced Leicester Sheep Breeder's Association 2018, *personal communication*, 16 November). Despite the Texel being a smaller animal in height and neck length (See Table 2), the larynx was not proportionately smaller in size compared to the BFL. Despite being of similar weight, the larynx of the Texel was not a similar size to that of the Bluefaced

Leicester. Although the larynx of the Texel is smaller in height and length, it has a funnel shape to the airway and the epiglottis and arytenoid cartilages are disproportionately large for the supporting framework. This study did not find a significant difference in head length between breeds of sheep, which is the underlying cause of BOAS in brachycephalic dogs (Packer and others 2015), however a disproportion between supporting structures and soft tissue elements of cranial anatomy play a large role in BOAS pathogenesis (Harvey 1989). Given that this study confirms the Texel is more likely to have laryngeal lesions than the BFL, disproportion of the Texel laryngeal anatomy may play a part in predisposing the breed to laryngeal pathology. More specifically, a funnel-shaped airway leading to increased or continuous vocal fold contact, with subsequent mucosal trauma, followed by local invasion of commensal bacteria to deeper structures could be hypothesized as part of the pathogenesis of laryngeal chondritis.

The disproportionate larynx and significantly smaller airway found in this study may also be a hindrance to animals with a high muscle mass. Texel sheep carry a large amount of muscle, which makes their weight similar to that of the taller BFL, but muscle has a high oxygen demand. It is not known how the smaller larynx of the Texel affects flow of air, or the amount of air that is inspired and expired with each breath. The narrow airway of the Texel may however account for the increased respiratory rate often observed in these animals when compared to other breeds. The reduced airway luminal diameter found in this study should be taken into

consideration at times of stress, hot weather, movement or handling when animals present with an increased respiratory rate or effort.

In brachycephalic dogs conformational factors have been shown to have a relationship with BOAS status (Liu and others 2017). Similarities could be drawn between brachycephalic dogs and breeds like the Texel, where some breeding lines have short broad faces, short necks and narrower nostrils than other breeds. A hypoplastic trachea is a component of BOAS in dogs, and is defined as a trachea with a markedly reduced lumen that does not vary in size during respiration (Coyne and Fingland 1992; Stadler and others 2011; Ingman and others 2014). The small size of the tracheal lumen found in this study in the Texel breed supports a similarity to brachycephalic dogs, but how the tracheal diameter varies during respiration in the live animal was not assessed here. The conformation of the Texel also varies between different family lines. Some are bred for short necks and it may be this conformation that effectively compresses the larynx to be shorter and wider. There are also anecdotal reports of longer necked animals having fewer laryngeal chondritis lesions. The study was unable to demonstrate a correlation between the length of head or neck and the shape of the larynx, which may have been due to the relatively small sample size, but it would be an important investigation point for further studies as it could prove useful as a simple tool for predicting future laryngeal pathology.

A range of pathology was observed in the collected larynges in this study. In the Bluefaced Leicester the lesions were mild in nature and infrequently observed while in the Texel a wide range of lesions was observed, some of which were severe and may have caused the death of the animal. The duration of the lesions is unknown but the prevalence of lesions in the Texel larynges suggests that laryngeal pathology, whether clinical or subclinical, could occur more commonly than currently considered. Further longitudinal studies are required to correlate antemortem clinical findings with post mortem lesions.

4.1 Imaging

MRI and CT scanning appear to be useful tools for assessing the anatomy of the formalin fixed larynx and could be used for future research projects. Moving forwards, a method to assess the anatomy of the larynx in the live sheep could be useful to prevent or predict laryngeal problems. In this study a standing equine distal limb MRI scanner was used. More commonly used to scan the foot of the horse its use for live sheep would be practically impossible. Logistics and finances would likely exclude the use of a low field MRI scanner, as used in small animal and human hospitals, for routine examination of live sheep, although it would not be impossible.

CT scanning is a diagnostic test that is often carried out in young breeding rams to assess muscle and fat carcase coverage using a mobile scanner in different geographical locations. These animals are however sedated for examination and the CT scanner only accommodates animals up to a certain weight. The effect of

breathing in the live animal on laryngeal assessment, and the subsequent effect of sedation has also not been verified in sheep, but the larynx is routinely assessed in dogs by CT with 3D internal volume rendered images of the larynx providing the most valuable information (Stadler and others 2011). The value of CT scanning to assess laryngeal anatomy and/or predict future laryngeal problems in the live sheep would be valuable to investigate due to the current use of mobile CT Scanner Units in the industry making it a viable diagnostic test option. Although CT scanning could be a viable option for some groups of rams, it is not a viable diagnostic option when purchasing a ram at market, or for diagnosing an individual case of laryngeal chondritis on farm. The use of ultrasound as a tool to assess laryngeal anatomy, function and its use as a diagnostic tool for laryngeal lesions would also be a useful and realistic method to investigate, in future studies.

4.2 Study limitations

The protocol for examining and measuring the larynges evolved as the project progressed which resulted in some measurements not being collected on the early samples. All laryngeal measurements were taken on dead, fixed samples and it is unknown how this translates to the live animal, especially as the larynx is a functional structure.

Although an increased incidence of laryngeal chondritis is seen in male Texel sheep (Edmunds and others 2017), the lesions can be found in all ages and in both sexes. This study focused on adult rams only because fallen stock of each breed could be

reliably identified by appearance alone. Younger animals and ewes may have been more difficult to accurately select, with no accompanying data or information about the animals. The effect of age on laryngeal anatomy or pathology was not possible to predict in this study, due the sample size.

As the clinical history of each animal sampled was unknown (as they were collected at a fallen stock centre), it was not possible to select 'clinically normal' animals and sheep that may have died as a result of laryngeal lesions. It was not possible for the larynges to be blindly assessed as the same author collected and measured them, and individual larynges could be recognised throughout the process.

4.3 Conclusions

This study confirms that there are anatomical differences in the Texel larynx relative to the BFL and these could be having a detrimental effect on the health and function of the airway. For the incidence of laryngeal chondritis to be reduced, further understanding about the pathogenesis is required. More practically, a diagnostic test that allows susceptible animals to be recognised early, either before purchase or before breeding, could prevent losses occurring at crucial stages of the sheep production system.

5 References

BACHA, W. and BACHA, L. (2012) Respiratory system. In Colour Atlas of Veterinary Histology. p 196.

BLUEFACED LEICESTER SHEEP BREEDER'S ASSOCIATION (2019). Breed description [Online] Available at: http://www.blueleicester.co.uk/breed/descriptionnew.html. [Accessed January 8, 2019].

BRITTON, J.W. (1945) Further observations on chronic laryngeal chondritis. *Cornell Veterinarian* **35**, p210–213.

CAMERON, H. and BRITTON, J. (1943) Chronic ovine laryngitis. *Cornell Veterinarian* **33**, p265–268.

CARSON, A. (2017) GB Emerging threats quarterly report; Small ruminant diseases. Animal and Plant Health Agency, UK.

COCQUYT, G., DRIESSEN, B. and SIMOENS, P. (2005) Variability in the eruption of the permanent incisor teeth in sheep. *Veterinary Record* **157**, p619–23.

CONSTABLE, P., HINCHCLIFF, K., DONE, S. and GRUNBERG, W. (2017) Veterinary Medicine: A textbook of the diseases of cattle, horses, sheep, pigs and goats. Eleventh edition. Elsevier. p534–536.

COYNE, B. and FINGLAND, R. (1992) Hypoplasia of the trachea in dogs: 103 cases (1974–1990). *Journal of the American Veterinary Medicine Association* **201**, p768–772.

DAVIS, E., FREEMAN, D. and HARDY, J. (2014) Respiratory infections. In Equine infectious diseases.

DYCE, K., SACK, W. and WENSING, C.J. (2002) The Larynx. In Textbook of Veterinary Anatomy. p152–156.

EDMUNDS, J., RODEN, J., FINCH, J. and MCEWAN, N. (2017) Factors affecting the development of laryngeal chondritis in sheep. *Large Animal Review* **23**, p219–222.

FAULL, W.B. and SCHOLES, S.F. (1987) Laryngeal chondritis in texel sheep. *Veterinary Record* **121**, p155.

FRANCE, M.P., ROTHWELL, T.L. and KANNEGIETER, N.J. (1995) Unexpected death in a horse with arytenoid chondritis and perilaryngeal lesions. *Australian veterinary journal* **72**, p351–2.

GARRETT, K., EMBERSTSON, R., WOODIE, J. and CHEETHAM, J. (2013) Ultrasound features of arytenoid chondritis in Thoroughbred horses. *Equine Veterinary Journal* **45**, p598–603.

HARVEY, C.. (1989) Inherited and congenital airway conditions. *Journal of Small Animal Practice* **30**, p184–187.

HAYNES, P., SNIDER, T., MCCLURE, J. and MCCLURE, J. (1980) Chronic chondritis of the equine arytenoid cartilage. *Journal of the American Veterinary Medical Association* **177**, p1135.

INGMAN, J., NASLUND, V. and HANSSON, K. (2014) Comparison between tracheal ratio methods used by three observers at three occasions in English Bulldogs. *Acta Veterinaria Scandinavica* **56** (79).

JENSEN, R., LAUERMAN, L.H., BRADDY, P.M., HORTON, D.P., FLACK, D.E., COX, M.F., EINERTSON, N., MILLER, G.K. and REHFELD, C.E. (1980) Laryngeal contact ulcers in feedlot cattle. *Veterinary pathology* **17**, p667–671.

KIM, M.J., HUNTER, E.J. and TITZE, I.R. (2004) Comparison of Human, Canine, and Ovine Laryngeal Dimensions. *Annals of Otology, Rhinology & Laryngology* **113**, p60–68.

LANE, J.G., BROWN, P.J., LANCASTER, M.L. and TODD, J.N. (1987) Laryngeal chondritis in Texel sheep. *Veterinary Record* **121**, p81–4.

LAWRENCE, J.A. (1967) Laryngeal abscesses in calves. *Veterinary Record*, p540–541.

LEKEUX, P. and ART, T. (1987) Functional changes induced by necrotic laryngitis in double muscled calves. *Veterinary Record* **121**, p353–5.

LIU, N.-C., TROCONIS, E.L., KALMAR, L., PRICE, D.J., WRIGHT, H.E., ADAMS, V.J., SARGAN, D.R. and LADLOW, J.F. (2017) Conformational risk factors of brachycephalic obstructive airway syndrome (BOAS) in pugs, French bulldogs, and bulldogs. *PLOS ONE* **12**, e0181928.

LOPEZ, A. and MATINSON, S. (2017) Respiratory system, mediastinum and pleurae. In Pathologic basis of veterinary disease. Ed J.F. Zackary. Sixth edition. Elesvier. p502.

LOVATT, F., STEVENSON, H. and DAVIES, I. (2014) Sudden death in sheep. *In Practice* **36**, p409–417.

MARCHANT, T.W., DIETSCHI, E., RYTZ, U., SCHAWALDER, P., JAGANNATHAN, V., HADJI RASOULIHA, S., GURTNER, C., WALDVOGEL, A.S., HARRINGTON, R.S., DRÖGEMÜLLER, M., KIDD, J., OSTRANDER, E.A., WARR, A., WATSON, M., ARGYLE, D., TER HAAR, G., CLEMENTS, D.N., LEEB, T. and SCHOENEBECK, J.J. (2019) An ADAMTS3 missense variant is associated with Norwich Terrier upper airway syndrome. *PLOS Genetics* **15**, e1008102.

NATIONAL SHEEP ASSOCIATION (2019) Understand why sheep farming in the UK is different to other parts of the world [Online]. Available from: https://www.nationalsheep.org.uk/know-your-sheep/uk-sheep-farming/ [Accessed 27th August 2019].

NICHOLS, S. and ANDERSON, D.E. (2009) Subtotal or partial unilateral arytenoidectomy for treatment of arytenoid chondritis in five calves. *Journal of the American Veterinary Medical Association* **235**, p420–425.

OKLAHOMA STATE UNIVERSITY. (2015) Breeds of liverstock - Texel sheep [Online]. Available at: http://www.ansi.okstate.edu/breeds/sheep/texel/. [Accessed 27th August 2019].

OLATUNJI-AKIOYE, O.K. and ADEYEMOA, O.. (2009) Liveweight and Chest Girth Correlation in Commercial Sheep and Goat Herds in Southwestern Nigeria. *International Journal of Morphology* **27**.

PACKER, R.M.A., HENDRICKS, A., TIVERS, M.S. and BURN, C.C. (2015) Impact of Facial Conformation on Canine Health: Brachycephalic Obstructive Airway Syndrome. *PLoS ONE* **10**, 137496.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

RIDEOUT, H. (2019) A Qualitative Analysis on the Impact of Laryngeal Chondritis on UK Sheep Farms. *Unpublished dissertation*, Harper Adams University.

SALISBURY, R. (1956) Chronic ovine laryngitis. *New Zealand Veterinary Journal* **4**, p144–146.

SAVALLI, U.. (2014) Sheep larynx [Online] Available from: http://www.savalli.us/BIO202/Labs/07-Respiratory/LarynxLabel.html. [Accessed 27th August 2019].

SIGURÐARDÓTTIR, Ó.G., JÖRUNDSSON, E. and FRIÐRIKSDÓTTIR, V. (2016) Laryngeal Chondritis in Sheep in Iceland. *Journal of Comparative Pathology* **155**, p310–313.

TEXEL BREED SOCIETY. (2019) Texel - background [Online] Available at:

https://texel.uk/texel-the-breed-that-has-something-for-everybody/ [Accessed 27th August 2019].

SCOTLAND'S RURAL COLLEGE (SRUC) (2014) SAC Conculting Veterinary Surgeons Monthly Report for October 2014. p1–6.

STADLER, K., HARTMAN, S., MATHESON, J. and O'BRIEN, R. (2011) Computed tomographic imaging of dogs with primary laryngeal or tracheal airway obstruction. *Veterinary Radiology & Ultrasound* **52**, p377–384.

WINTER, A. and CLARKSON, M. (2012) A handbook for the sheep clinician. Seventh edition. CABI International. p125.

ZRUNEK, M., HAPPAK, W., HERMANN, M. and STREINZER, W. (1988) Comparative Anatomy of Human and Sheep Laryngeal Skeleton. *Acta Oto-Laryngologica* **105**, p155–162.