Sonoanatomic study of carpal region
in 12 healthy sheep

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1. INTRODUCTION

Sheep are more efficient than cattle for converting forage to animal products. This is a result of multiple births, faster growth rates, and the ability of lambs to fatten on range forages without grain. Sheep have distinct economic advantages when compared with other livestock. They do not require the expensive housing used in the intensive farming of chickens or pigs (SMITH et al., 1997). Some farmers who keep sheep also make a profit from live sheep, providing lambs for youth at many programs such as 4-H (youth organization of United States Department of Agriculture) and competition at agricultural shows is often a dependable avenue for the sale of sheep. Farmers may also choose to focus on a particular breed of sheep in order to sell registered purebred animals, as well as provide a Ram Rental Service for Breeding. A new option for deriving profit from live sheep is the rental of flocks for grazing; these "mowing services" are hired in order to reduce unwanted vegetation in public spaces and to lessen fire hazard (SIMMONS and EKARIUS, 2001). Sheep may suffer from varying soft tissue injuries, swelling and infections of the carpal area. There are many infectious, non-infectious and metabolic disorders which affect muscles, tendons, bones and joints of the carpal area in sheep and cause morbidity, mortality and debility in this profitable animal. Causes of infection include miscellaneous isolated bacteria like \textit{Streptococcus dysgalactiae} (BLAKEMORE et al., 1941; WATKINS and SHARP, 1998), \textit{Erysipelothrix rhusiopathiae}, \textit{Arcanobacterium pyogenes}, \textit{Staphylococcus aureus} and \textit{Fusobacterium necrophorum} (ANGUS, 1991a, b). Viral causes include the Maedi-visna virus (MVV) also called Ovine Progressive Pneumonia (OLIVER et al., 1981; CUTLIP et al., 1985; BULGIN, 1990). Others are the \textit{Chlamydia psittaci} (ADAMS, 1983) and \textit{Mycoplasma agalactiae}, \textit{M. capriculum} and \textit{M. mycoides} (EGWU et al., 2000) and osteomyelitis. The non-infectious and mechanical causes which affect the carpal area in sheep include fractures, degenerative joint diseases and carpal hygroma. The carpal joint is a compound synovial joint. The carpal joint includes the antebrachiocarpal (ABC), mediocarpal (MC), carpometacarpal (CMC) levels and also a distal radioulnar joint. Since the rectangular accessory carpal bone articulates only with the ulnar carpal its upper and lower margins provide rough guides to the levels of the antebrachiocarpal and mediocarpal joints (DYCE et al., 2002). The carpal area comprises various tendons and their corresponding tendon sheaths as well as ligaments, which surround the joint.
pouches, and bone structures that form the 3 joint levels. In the past ten years, diagnostic imaging procedures such as Ultrasonography, Computed and Thermal Tomography (CT), Magnetic Resonance Imaging (MRI), Survey and Contrast Radiography and Endoscopy have got widespread use to characterize soft tissue injuries in veterinary medicine. Computed Tomography and Magnetic Resonance Imaging are still in limited use because of the high costs and necessity to use anaesthesia (KOFLER and HITTMAIR, 2006). Ultrasonography has sustained as a multipurpose diagnostic tool for visualizing soft tissue changes in humans and animals musculoskeletal disorders (GENOVESE et al., 1986; DIK, 1990; TNIBAR et al., 1993; CHHEM et al., 1994; MUNROE and CAUVIN, 1994; KOFLER, 1996a, b, 1997). Ultrasonography has sustained as a multipurpose diagnostic tool for visualizing soft tissue changes in humans and animals musculoskeletal disorders (GENOVESE et al., 1986; DIK, 1990; TNIBAR et al., 1993; CHHEM et al., 1994; MUNROE and CAUVIN, 1994; KOFLER, 1996a, b, 1997). Ultrasonography has sustained as a multipurpose diagnostic tool for visualizing soft tissue changes in humans and animals musculoskeletal disorders (GENOVESE et al., 1986; DIK, 1990; TNIBAR et al., 1993; CHHEM et al., 1994; MUNROE and CAUVIN, 1994; KOFLER, 1996a, b, 1997). Ultrasonography has sustained as a multipurpose diagnostic tool for visualizing soft tissue changes in humans and animals musculoskeletal disorders (GENOVESE et al., 1986; DIK, 1990; TNIBAR et al., 1993; CHHEM et al., 1994; MUNROE and CAUVIN, 1994; KOFLER, 1996a, b, 1997). Ultrasonography has sustained as a multipurpose diagnostic tool for visualizing soft tissue changes in humans and animals musculoskeletal disorders (GENOVESE et al., 1986; DIK, 1990; TNIBAR et al., 1993; CHHEM et al., 1994; MUNROE and CAUVIN, 1994; KOFLER, 1996a, b, 1997).
frequently performed as essential part of clinical examination. In this regards, ultrasonography enables accurate needle placement following the ultrasonographic examination of the desired structure. Ultrasonography also assists measuring the distance from the skin surface to the structure when free hand biopsy technique has to be performed. The benefits of ultrasound-guided needle placement are well described by KING (2006). Like human medicine, most veterinary teaching hospitals are now equipped with ultrasound machines as ultrasonographic examinations have become an integral part of diagnostics in specialities such as orthopaedics, internal medicine, cardiology and gynaecology. Similarly it has facilitated to examine the patient immediately and without delay. The advantage of this union of clinician and sonographer is that the individual is well informed about the anatomical sites in question and therefore in a better position to relate them to clinical findings. Other diagnostic imaging modalities must not however be forgotten and the radiography skill remains the method of choice for bony structures and to gain an overview of mass lesions and their location. Ultrasonography can complete the imaging procedure by adding valuable information so the radiologist can combine the findings and make a more precise diagnosis. The technique has become routine in many veterinary practices, particularly for gynaecological examinations in mares, cows and ewes, for pregnancy diagnosis in cattle, sheep, goats, pigs and small animals, tendon ultrasonography in equines and abdominal ultrasonography in small animals. However, one of the drawbacks of diagnostic ultrasonography is that it requires a great deal of skill and experience to make a diagnosis. When employed correctly, ultrasonography is of great benefit to every veterinary clinician and practitioner in continuing the clinical examination.
Objectives of study

Many scientists have investigated the sonoanatomy of joints and carpal region in different animals such as cattle, horses, camel and dogs. Yet none of them has explored the normal ultrasonographic appearance of the carpal joint region in sheep. It will be a new research in ovine arthrosonography. The following objectives could be achieved through study.

- Ultrasonographic views of the carpal joint area in healthy sheep without any signs of pathological changes would be taken in this study and serve as reference data for further investigation in clinical practices.
- This study will be significant for the sheep which are kept for breeding and exhibition purposes. As most farm owners provide Ram Rental Services for breeding and also present sheep in Exhibitions and Shows. The owner is much more interested for routine orthopaedic examination in such expensive and valuable sheep. Normal ultrasonography will prove as model in depicting any pathological change to this area at earlier stage.
- This study will open new horizon in the field of joints study of sheep through ultrasonography as it has got little attention in previous researches. It will also strengthen the application of ultrasonography in the field of sheep joint studies.
1.1. Sheep carpal region anatomy

1.1.1. Bony structures at carpal

Distal extremity of radius and ulna

The articular surface of the radius is irregular and oblique with the medial side being more prominent. The distal surface comprises of three articular areas: (a) medially for the radial carpal bone, (b) centrally for the intermediate carpal bone, (c) laterally for the ulnar carpal bone. On the caudo-lateral surface there is an articular facet for the distal end of the ulna, while on the lateral surface there is a pronounced groove for the tendon of the common digital extensor muscle. The distal extremity of the ulna bears two articular facets-cranial the facet for the ulnar carpal bone and the medial facet for the accessory carpal bone (Fig. 1). A facet on the cranial surface is the articular area for the radius but these surfaces may fuse in some specimen (MAY, 1970).

Carpus

It consists of six bones. The proximal row of the carpal skeleton comprises of radial, intermediate and ulnar carpal bones extended caudolaterally by an accessory carpal bone. Radial carpal, intermediate carpal, ulnar and accessory carpal bones are arranged in proximal row from medial to lateral. Since the rectangular accessory carpal bone articulates only with the ulnar carpal its upper and lower margins provide rough guides to the levels of the antebrachiocarpal and midcarpal joints. The distal row consists of only two bones, fused 2nd and 3rd, and 4th carpal bone. Proximally, the radial and intermediate carpal bones articulate with the radius bone and distally they articulate with the fused 2nd and 3rd carpal bone. Proximally ulnar carpal bone articulates both with radius and ulna and distally with the 4th carpal bone. The distal row consists of the fused 2nd and 3rd carpal bone and the 4th carpal bone. Proximally, the fused 2nd and 3rd carpal bone articulate with the radial carpal bone and to a smaller extend with the intermediate carpal bone and distally it articulates with the 3rd metacarpal bone. The 4th carpal bone is present in the distal row (Fig. 1). Proximally, the 4th carpal bone articulates with the intermediate and ulnar carpal bones and distally with the 4th metacarpal bone (SCHALLER, 1992; DYCE et al., 2002).
Metacarpus

It consists of a large bone formed by union of the 3rd and 4th metacarpal bones. The bones unite during foetal life. The proximal extremity is irregularly semicircle, large on the medial aspect for articulation with the fused 2nd and 3rd carpal bones and smaller on the lateral surface for the articulation with the 4th carpal bone. The metacarpal tuberosity can be found on the medial dorsal surface with smaller tubercles on the medial and lateral palmar surfaces (MAY, 1970).

1.1.2. Carpal joints

The carpal joints are a complex joint system. They allow flexion, extension and lateral movements (Fig. 1). They include, the antebrachial carpal, mid carpal, carpometacarpal levels of articulation and the distal radioulnar joint (CONSTANTINESCU, 2001). The carpus as whole acts as a hinge joint; the single joint surface allows different ranges of movement. Most movements take place at the proximal articulation, considerable movement is possible at the middle articulation but virtually no movement takes place at the distal articulation (DYCE et al., 2002; LIEBICH et al., 2007).

Antebrachiocarpal joint

It is formed between the distal extremities of the radius bone/ulna bone, and the proximal row of the carpal bones (Fig. 1). The antebrachiocarpal and the radioulnar joint share a common joint cavity. It has a voluminous synovial sac which includes the joints formed by the accessory carpal bone and extends as far as the interosseous ligaments of the proximal carpal bones. This joint can be regarded as cochlear joint in ruminants (DYCE et al., 2002; LIEBICH et al., 2007).

Mediocarpal joint

It is formed between the two rows of the carpal bones and has an extensive pouch which communicates with the carpometacarpal pouch between the 3rd and the 4th carpal bone (Fig. 2). The mediocarpal and carpometacarpal joint cavities are
interconnected. Less movement takes place in the mediocarpal joint, which is also a complex hinge joint (DYCE et al., 2002; LIEBICH et al., 2007).

**Carpometacarpal joint**

This joint is formed between the distal row of the carpal bones and the metacarpal bones (Fig. 2). They are plane joints which do not allow any significant movement (DYCE et al., 2002; LIEBICH et al., 2007).

### 1.1.3. Ligaments of carpus

The ligaments are fibrous tissue bands connecting bones or cartilages to support and strengthen joints. Many distinct ligaments and several fibrous bands of the joint capsule support the carpus. The ligaments of the carpus can be divided in two groups.

**Long lateral and medial collateral ligaments**

They extend between the forearm and the metacarpus and consist of following ligaments.

**Lateral collateral ligament**

Proximally it attaches to the lateral styloid process of the radius and divides into a superficial branch, which inserts at the proximal extremity of the lateral metacarpal bone and two deep branches, which insert at the ulnar carpal and the 4th carpal bone (LIEBICH et al., 2007).

**Medial collateral ligament**

It extends between the medial styloid process of the radius and the proximal extremity of the medial metacarpal bone. The deep branch is detached to the 2nd carpal bone (LIEBICH et al., 2007).

**Short ligament**

They connect the accessory carpal bone to the ulna, the ulnar carpal bone, the 4th carpal bone and the 4th and 5th metacarpal bone (LIEBICH et al., 2007).
**Extensor retinaculum or dorsal annular ligament**

The tensor fascia antebrachii is the proper antebrachial fascia which surrounds the entire forearm, it continues on the dorsal aspect of the carpus as extensor retinaculum or dorsal annular ligament (Fig. 1, 2). The fibrous layer of the joint capsule is strengthened by the dorsal annular ligament which surrounds the extensor tendons. The joint capsule and the dorsal annular ligament are interconnected by septa. Those septa separate the several tunnels from each other for gliding. The dorsal annular ligament disappears on the dorsal aspect of the metacarpus (CONSTANTINESCU, 2001).

**Flexor retinaculum or palmar annular ligament**

The tensor fascia antebrachii continues on the palmar aspect of the carpus as flexor retinaculum or palmar annular ligament (Fig. 1, 2). The flexor retinaculum closes the carpal canal protecting the tendons of the digits. The flexor retinaculum continues on the palmar aspect of the metacarpus as palmar fascia and on the palmar aspects of the digit and the digital fascia (CONSTANTINESCU, 2001).

**Carpal canal**

It is the space outlined by the palmar carpal joint (deep), the accessory carpal bone (lateral), and the flexor retinaculum (on the medio palmar aspect). In ruminants, the carpal canal is divided in two spaces, one superficial and one deep due to the two laminae of the flexor retinaculum. There are superficial and deep carpal canals. Within the superficial carpal canal, the superficial tendons of the superficial digital flexor, the tendon of the flexor carpi radialis muscle (on the medial side) pass together. Lateral to it, is the palmar branch of the ulnar nerve and the radial artery and the radial vein can be exposed. Inside the deep carpal canal, the deep flexor tendon, the deep tendon of the superficial digital flexor and the median artery, vein and nerve are located (CONSTANTINESCU, 2001).
Fig. 1: Medial section of left forelimb in cadaver sheep and associated structures (bones, carpal joints, muscles, tendons and ligaments) at the carpal region. The bony structures are distal radius, 3rd & 4th metacarpal bone. Carpal bones consists of radial, intermediate, ulnar, accessory, 2nd and 3rd fused carpal and 4th carpal bones. Carpal joints-antebrachiocarpal (abc), mediocarpal (mc) and carpometacarpal joints (cmc). Caudo-medial muscles are flexor carpi ulnaris muscle (fcu), extensor carpi ulnaris muscle (ecu), superficial digital flexor (sdf) and deep digital flexor muscle (ddf). Tendons are superficial digital flexor tendon (sdf), deep digital flexor tendon (ddf). Ligaments consisted of extensor retinaculum (dorsal annular ligament) and flexor retinaculum (palmar annular ligament).
**Fig. 2:** Medial section of right forelimb in cadaver sheep showing bones, muscles of cranio-lateral and caudo-medial carpus, carpal bones, carpal joints and ligaments. The following muscles are prominent extensor carpi ulnaris (ecu), flexor carpi ulnaris (fcu), superficial digital flexor (sdf) and deep digital flexor (ddf) muscles. Extensor carpi radialis (ecr) tendon is passing over the dorsal carpus. Dorsal and palmar annular ligaments are highlighted. The proximal row of carpal bones consists of radial carpal articulates with distal extremity of radius medially, intermediate carpal also articulates with radius centrally and accessory carpal bone articulates with ulna laterally. The distal row of carpal bones consist of fused 2nd and 3rd and 4th carpal bones articulates proximally with the radius and ulna and distally with the fused 3rd and 4th metacarpal bone respectively.
1.1.4. Vessels and nerves across the carpus

**Median artery**

The median artery follows the medial border of the radius deep to the flexor carpi radialis before accompanying the deep digital flexor tendon through carpal canal. It runs with the satellite vein and the median nerve within the metacarpus where it lies on the medial surface of the flexor tendons under cover of thick deep fascia (DYCE et al., 2002).

**Radial Artery**

It is located on the medial side of the carpus. It pierces the fascia dorsal to the flexor carpi radialis muscle and becomes superficial as it passes across the tendon of this muscle. It is associated with the cephalic vein in the distal third of the forearm and passes with this vessel along the groove on the medial side of the carpus to the metacarpal region (MAY, 1970).

**Median vein**

The median vein passes proximally with the median artery and is joined by the interosseous vein and muscular branches from the flexor group of muscles in the proximal part of forearm (MAY, 1970).

**Radial vein**

It is associated with the radial artery and arises in the distal third of the forearm mainly from the cephalic vein. It is associated with the radial artery and unites with the deeper ulnar vein to form the median vein in the proximal third of the forearm (MAY, 1970).
Accessory cephalic vein

It arises at the carpus as a continuation of the dorsal metacarpal vein and joins the cephalic vein at the middle of the dorsal surface of the forearm. The accessory cephalic vein ascends the forearm on the medial border of the tendon of the extensor carpi radialis muscle to join the cephalic vein in the middle third of the forearm (MAY, 1970).

Median nerve

The large median nerve runs down the medial aspect of the arm, crosses elbow joint and dips under the flexor muscles to which it sends branches. The much reduced trunk then follows the median artery under cover of the flexor carpi radialis into the carpal canal before dividing in the midmetacarpus into several branches that supply most of the palmar aspect of foot (DYCE et al., 2002).

Ulnar nerve

The ulnar nerve arises with the median nerve but diverges from this in mid-arm. After releasing a branch to the skin, it passes towards the olecranon where it dips between the origins of the flexor muscles. It detaches branches to these before continuing among the muscles in the caudal part of the forearm as a mainly sensory nerve, which divides as short distance above the accessory carpal bone. The palmar branch runs through the carpal canal lateral to the flexor tendons, the dorsal branch becomes superficial and may be palpated where it descends over the lateral aspect of the accessory carpal bone (DYCE et al., 2002).

Superficial radial nerve

The radial nerve lies more caudally in the arm. It dives between the heads of triceps before following the brachialis to reach cranial surface of elbow. The radial nerve is exclusive supply to the extensors of all joints distal to the shoulder (DYCE et al., 2002).
1.1.5. Muscles and tendons at the dorso-lateral carpus

Extensor carpi radialis muscle

The origin of the muscle is from the lateral condyloid crest of the humerus, the coronoid fossa and the deep fascia of the arm and forearm. It inserts at the metacarpal III tuberosity on the dorsal-lateral surface (Fig. 2). Over the capsule of the carpal joint it is bound by the dorsal annular ligament and is invested with a synovial sheath. This muscle extends the carpus and flexes the elbow joint. Interosseous and collateral radial arteries supply blood and the nerve supply is from the radial nerve (MAY, 1970; DYCE et al., 2002).

Extensor carpi obliquus muscle (abductor pollicis longus muscle)

This is a small muscle and unipennates and arises from the lateral border of the radius and from the interosseous ligament between the ulna and the radius. It inserts at the medial border of the base of the large metacarpal bone. The muscle has a flat muscular belly, and the tendon, which begins as it crosses the extensor carpi radialis muscle, occupies an oblique groove at the distal end of the radius. It extends and possibly rotates the carpus. The blood supply is from the interosseous artery and the nerve supply from the radial nerve (MAY, 1970; DYCE et al., 2002).

Common digital extensor muscle

It lies lateral to radial extensor muscle of carpus. The origin of this muscle is by two heads from the lateral epicondyle of the humerus (the larger head) and lateral collateral ligament of elbow joint, radius and ulna. The insertions are to the extensor processes of the 3rd phalanges. The two heads fuse about the middle of the forearm, terminating soon afterwards in a tendon passing over the lateral aspect of the carpus in a synovial sheath with preceding muscle. At the metacarpal region it gradually inclines dorsally. The blood supply is from the radial and the interosseous arteries, and the nerve supply is by the radial nerve. Its action is to extend the carpus and the 3rd and 4th digits and to flex the elbow joint (DYCE et al., 2002).
**Lateral digital extensor muscle**

It is located lateral to the common digital extensor muscle. It originates from the lateral epicondyle of the humerus, from the lateral ligament of the elbow and from the lateral tuberosity of the radius. Its insertion is at the second phalanx of the lateral digit. It extends the carpus and 4th digit and flexes the elbow joint. The blood supply is from the common interosseous artery and the nerve supply is by the radial nerve (MAY, 1970; DYCE et al., 2002).

**Extensor carpi ulnaris/Ulnaris lateralis muscle**

This muscle lies on the lateral surface of the forearm behind the extensor group. It arises on the lateral epicondyle of the humerus and is inserted on to the lateral surface and the proximal border of the accessory carpal bone and the lateral side of the proximal end of the large metacarpal bone. This muscle is flattened and has two tendons of insertion (Fig. 1, 2). The longer is small and rounded, passing distally and dorsally through the groove on the accessory carpal bone with a synovial bursa beneath it. It flexes the carpus and extends the elbow joint. The blood supply is from the common interosseous artery and the nerve supply from the radial nerve (MAY, 1970; DYCE et al., 2002).

**1.1.6. Muscles, tendons and structures at the caudo-medial carpus**

**Flexor carpi ulnaris muscle**

It has two heads of origin from the medial epicondyle of the humerus behind the origin of the flexor carpi radialis muscle (Fig. 1, 2). The other head originates from the caudal border of the olecranon. The muscle ends in a strong flat tendon on the proximal edge of the accessory carpal bone and fused with the tendon of the extensor carpi ulnaris. It flexes the carpus (MAY, 1970; DYCE et al., 2002).
**Superficial digital flexor muscle**

The superficial flexor of the digit is blended with the flexor carpi ulnaris muscle to a certain extent at its origin, and it divides into superficial and deep portions near the middle of the radius (Fig. 1, 2). It arises on the medial epicondyle of the humerus and is inserted to the palmar surface of the second phalanx (MAY, 1970; DYCE et al., 2002).

**Superficial part of superficial digital flexor muscle**

It originates from the medial epicondyle of the humerus and has two heads. The superficial head runs over the flexor retinaculum to join the deep head in the middle of the metacarpus. It is inserted to the palmar surface of the 2nd phalanx.

**Deep part of superficial digital flexor muscle**

It arises about the middle of the forearm, and in the distal 3rd it detaches the fibrous band to the tendon of the deep flexor muscle of the digits. Muscle fibres are present connecting it to the deep flexor tendon as far as its reunion with the superficial part and these may represent the lumbricales muscles.

**Deep digital flexor muscle**

It is the largest muscle of the flexor group. It has three heads and arises from the medial epicondyle of the humerus, from lateral, palmar, and the medial surfaces of the olecranon, from the palmar surface of the radius and a small adjacent area of the ulna. It inserts at the palmar surface of the 3rd phalanges. It flexes the carpus as well as the 3rd and 4th digits and extends the elbow. The blood supply is from the median and common interosseous arteries and the nerve supply is from the median nerve (MAY, 1970; DYCE et al., 2002).

**Flexor carpi radialis muscle**

This muscle arises from the medial epicondyle of the humerus and is inserted into the proximal end of the metacarpal bone. In the distal 3rd of the radius it crosses the ulnar artery and median nerve. The tendon begins near the distal 3rd of forearm. Along the
medial surface of this tendon lies the radial artery and vein from the distal 3rd of the radius and middle of the carpus. It flexes the carpus. The blood supply is from the interosseous artery and nerve supply is from the median nerve (MAY, 1970; DYCE et al., 2002).

**Lumbricales muscles**

These muscles are absent as definite structures in sheep, but may represented as bundles of muscle arising on the deep flexor tendon distal to the carpus and attached to the superficial flexor tendon (MAY, 1970; DYCE et al., 2002).

**1.1.7. Tendon sheaths and synovial structures of the carpus**

**Tendon sheath of the extensor carpi radialis muscle**

In sheep, the sheath begins about 2.5 to 3.75 cm proximal to the carpus and extends to the distal end of the proximal row of the carpal bones. The joint capsule of the mediocarpal joint pouches is located beneath the tendon as it crosses the joint (MAY, 1970).

**Tendon sheath of the extensor carpi obliquus muscle (abductor pollicis longus muscle)**

This muscle is invested by a synovial sheath as it crosses the medial face of the carpus in sheep (MAY, 1970).

**Tendon sheath of the medial and common digital extensor muscle**

In sheep, at the carpus, the medial and common digital extensor muscles are invested with a common synovial sheath which extends from 2.0 cm proximal of the carpus to the proximal end of the metacarpus, passing over the dorsal surface of the ulnar and the 4th carpal bones (MAY, 1970).
**Tendon sheath of the lateral digital extensor muscle**

This muscle is invested at the carpus by a synovial sheath as it crosses the surface of the ulnar and 4th carpal bones behind the other extensor tendons. In sheep, the synovial sheath extends from 2.5 cm proximal of the carpus to the proximal end of the metacarpus (MAY, 1970).

**Tendon sheath of the extensor carpi ulnaris muscle**

There is a synovial pouch under the origin of the muscle (MAY, 1970).

**Tendon sheath of the superficial and the deep digital flexor muscle**

In sheep the synovial sheath for the superficial and deep flexor tendon extends from 1 cm proximal of the carpus to 3.5 cm below the carpus (MAY, 1970).

**Tendon sheath of the flexor carpi radialis muscle**

This muscle is covered by a synovial sheath from about 3.5 cm proximal to the carpus to almost its insertion. In sheep, the tendon sheath lies on the medio-palmar side of the carpus at the same level as the deep flexor tendon. The sheath is continuous with the fibrous part of the carpal capsule (MAY, 1970).

**Precarpal subcutaneous bursa**

The fibrous layer of joint capsule blends dorsally with the thick deep fascia (extensor retinaculum) which holds the extensor tendons in place. An inconstant bursa between the retinaculum and skin is the precarpal subcutaneous bursa exits in all ruminants. It is located deep under the skin on the dorsal surface of the carpus (CONSTANTINESCU, 2001; DYCE et al., 2002).
1.2. Routine Diagnostic methods for musculoskeletal disorders

Sheep are also prone to most of the bone diseases seen in other domestic animals (fractures, local abscesses, osteomyelitis and tumours for example) but most are seen only sporadically or rarely. Physical orthopaedic examination and the use of special techniques and procedures lead to an exact diagnosis and prognosis (DALE, 1983). These include:

Routine clinical orthopaedic examination
Arthrocentesis
Radiology
Ultrasonography

1.2.1. Ultrasonography

Physical principles of ultrasound

Ultrasounds are sound waves having the frequency beyond the audible range of human ears. Human ears can hear at frequencies between 20 to 20,000 Hz and ultrasound is a sound wave above 20 kHz. In diagnostic examinations, sound frequencies in range of 2 to 10 MHz are normally employed. Each ultrasound transducer emits sound waves of one frequency. The frequency is defined as a wave repeated every second. Wavelength is the distance wave travels in one second. Since sound velocity is independent of frequency and nearly constant in body soft tissues, so with selection of higher frequency transducer, sound waves of decreased wavelength are produced and provide better resolution (WELLS, 1969; CARTEE, 1995). The basic principle of ultrasound is that sound waves pass through the tissues and are either reflected, refracted or absorbed. Reflection is responsible for producing the image, the reflected ultrasound waves are transformed into the image when they reach the transducer. The reflection depends upon the size of the reflecting structure and the frequency of sound wave in use. Higher frequency sound waves are reflected from smaller structures and are attenuated more quickly so higher frequency sound waves
are used for skin or more superficial structures. Waves also travel from one tissue to other so reflection or acoustic impedance takes place. It explains need for good coupling between the probe and the skin surface. When ultrasound beams are perpendicular to the skin surface, the reflection is straightforward (CURRY et al., 1990; MANNION, 2006). Ultrasound anticipates a constant velocity of sound within soft tissues when the beam encounters gas or bone. Marked velocity differences are resulted in high reflection and improper echo interpretation. This strong reflection is due to the abrupt change in sound velocity or media density (acoustic impedance) at a soft tissue-bone or soft tissue-air interface. The depth of penetration of the sound is directly proportional to the employed frequency. The velocity of sound is different in different body tissues. The average speed of sound in soft tissue is 1540 m/s, through bone it is 4000 m/s and through gas it is only 300 m/s (HERRING, et al., 1985; MANNION, 2006). Ultrasonography is based on the pulse-echo principle. Ultrasound waves are produced by the transducer and the frequency emitted by a specific transducer is dependent on the characteristics of special piezoelectric crystals contained in a transducer. These crystals convert electric energy into ultrasound. Ultrasound waves are produced in short pulses, some are penetrated into soft tissues and other reflected back to the transducer. The echoes that are reflected to the probe (sound source) vibrate the crystals again and produce some voltage signals that amplify to form the final image on the ultrasound unit screen of the anatomical pattern. When voltage or potential difference is applied across the crystal it is deformed and in response sound waves are produced. This is the piezoelectric effect. These crystals have the ability to transfer electrical energy into mechanical ultrasound waves and to reconvert ultrasound waves into electrical energy. When the echoes are returned the crystal is deformed again and this time an electrical signal is produced which is displayed on the screen. Ultrasound waves emitted from crystals have three basic properties. The sound waves of certain frequencies measured in megahertz are produced depending upon the thickness and damping of the crystal. The frequency is analogous to pitch or tone of the audible sound and has great bearing on resolution and penetration capabilities of the ultrasound. Second is the intensity of ultrasound, the intensity is determined by a signal that is stimulating the crystal but it is altered by the medium through which the ultrasound passes. The third property of ultrasound is that it passes through a medium at a certain speed of velocity. Although this velocity may vary within soft tissues and varies greatly between hard and soft tissues, it is
generally accepted to be constant 1540 m/s in mammalian body. This assumption of prime speed is one of the prime determinants of the operation of all ultrasound equipment. After production, a portion of intensity is reflected back from body to crystal while other portions may travel deeper into the body to be reflected back at some later time or greater depth. The relative brightness of the images represents the relative intensity or loudness of the returning echoes (POWIS, 1986; KREMKAU, 1989; CARTEE, 1995; MANNION, 2006).

**Instrumentations**

An ultrasound machine always contains of the basic set of controls. These control panels include

**Power (intensity, output) control**

It modifies voltage to activate the crystals, so it regulates the intensity of the sound output from the transducer. Increasing power results in an increase in the amplitude of the returning echoes. The power is set low to get refine resolution and prevent artifacts (NYLAND et al., 1995; MANNION, 2006).

**Gain/Reject**

Gain and reject controls affect the amplification of returning echoes. Some scanners have an overall gain control that cause uniform amplification of all returning echoes regardless of their depth of origin. The reject control eliminates weaker echoes from all depths that do not contribute in image formation. If the reject control is set too high, the echoes that are significant for image formation will also be lost. The amount or degree of gain applied is the ratio of the output signal to the input signal and it should not be confused with power (NYLAND et al., 1995; MANNION, 2006).

**Time-gain compensation controls**

This control may be in form of twist knobs or a sliding scale. Its function is to dampen down the higher intensity echoes which return from the more superficial structures and to amplify the echoes that return from deeper regions, resulting in uniform image. The echo return time is direct proportional to the depth of the reflecting surface. Increasing the gain also increases the echo return time and it selectively compensates for weaker echoes arriving at the transducer from deeper structures. It is very
important for producing a high quality diagnostic image (NYLAND et al., 1995; MANNION, 2006).

**Image recording**

The returning echoes produce electric energy at the transducer, the information is then passed to a scan convertor which stores information and allows it to be displayed on TV or a computer monitor (NYLAND et al., 1995; MANNION, 2006).

**B mode (brightness mode)**

The mode used most commonly is the B mode. It uses the principle that each returning echo is displayed on a screen as a bright spot. The loudness of the echo is displayed by correspondingly bright spots on a screen. The B mode stands for brightness. The display of different level of brightness is called a gray scale display. Real time ultrasound, where the image displayed on the screen has just acquired and which is constantly updated, uses B-mode ultrasound. Before the real-time imaging, the entire field of view was frozen on the screen until erased and replaced by another, the static B mode display (PARK et al, 1981; GINTHER, 1986; POWIS, 1986; KREMKAU, 1989; MANNION, 2006).

**Transducer types and selection**

The ultrasound transducer is key part of ultrasound system. They are classified as mechanical or electronic and according to the shape of field of view they produce. Most transducer use an array of crystals rather than a single crystal element. There are four main types of array in existence and use: linear array, curvilinear array and phased array are electrical and annular array is a mechanical probe. Electric probes have an array of crystals which are electronically fired to produce the image. The sequence in which this happens determines the shape of field of view (CARTEE, 1995; MANNION, 2006). Linear array transducers have a large number of rectangular crystal elements arranged in a line; sequential groups of these are fired intermittently to produce a rectangle image. There may be up to 250 elements with groups of up to 20 fired off each time. When the signal has returned to the transducer
the next beam is fired off and it is from parallel and adjacent groups of crystals. This type of transducer has a wide field of view with good definition of structures in the near field. Curvilinear and phased array transducers produce a sector shaped image, which is the shape of a section of a pie chart. Curvilinear arrays are so similar in construction with linear array except that the crystal elements are laid out on a convex surface and beam lines are not parallel but emerge like spokes on a wheel. These have much bigger footprint then the phased arrays but they do have the advantage that the beam is perpendicular to the surface of the probe (CARTEE, 1995; MANNION, 2006). Real time ultrasonography is used to evaluate soft tissues, allowing an accurate visualization of structures to be examined. Generally, a 7.5 MHz transducer is used in evaluation of the structures up to 4 cm in depth. Tendon and ligaments fall within this range. A lower frequency transducer is required for adequate penetration and a 5.0 MHz transducer penetrates adequately to a depth of 10-15 cm in most cases. For the depth of 25 cm, a 2.5 to 3.5 MHz transducer is used normally (CRAYCHEE, 1995). For areas such as the thorax, a sector, phased array or microconvex transducer is preferred. In deep chested breeds, to assess the most cranial part of the abdomen and the ribcage, a sector scanner should be used (CRAYCHEE, 1995; LANG, 2006).

**Preparation of patients**

Body hairs affect the image quality so shaving of the site of scanning is recommended. Clipping of hair and shaving afterwards provide a good contact of the transducer with the skin surface. Occasionally, in the case where we scan without clipping then wetting of the hair coat is performed. Application of coupling gel is essential for a good image quality and frequent replication may be necessary. Some commercial preparation especially viscous gives more satisfactory results. The standoff pad is another prerequisite for a good contact between the transducer and the skin. The standoff pad is usually made of a solid silicone gel material and can be shaped in or cut in convenient sizes and thickness (WOOD et al., 1991).
1.3. Normal ultrastructural anatomy of musculoskeletal components

Ultrasound can distinguish between most components of the musculoskeletal system, the images obtained are often confusing and accurate interpretation depends on the skill and knowledge of the examiner and familiarity with the anatomy of the region under examination (DICKIE, 2006).

1.3.1. Skin, subcutaneous tissue or fat

The use of sonography in evaluating the animal skin has not been well reported. Sonographic techniques have been used successfully to measure subcutaneous fat thickness in man and sheep (HAYES et al., 1988; FUKUNAGA, 1989). The subcutaneous fat thickness and longissimus muscle was also estimated by ultrasound in beef cattle (PERKINS et al., 1992a, b). Frequencies of 7 and 10 MHz have been used to study subcutaneous fat tissue (FORNAGE, 1987; CARTEE, 1995). The epidermis is characteristically hyperechoic whereas dermis and subcutaneous structures are hypoechoic.

1.3.2. Tendons and ligaments

The tendon is a highly organized tissue and composed of type I collagen fibrils embedded in a proteoglycan water matrix (SCOTT, 1980; AMIEL et al., 1984). Tendons have a large fibrous component and therefore contain a large number of tissue interfaces which produce a hyperechoic appearance. If the transducer is placed parallel to the long axis of a tendon, it appears rectangular in shape and the linear arrangement of the tendon fibres can be visualized surrounded by the hyperechoic peritendon. The tendon appears most echogenic and pattern fibres can best be appreciated when the beam is at 90 angles to the tendon. If the transducer is then rotated through 90, the tendon appears round or oval shaped in outline, with regular stippled pattern throughout the body of the tendon. In some areas, a tendon sheath surrounds a tendon which appears as a thin hyperechoic line separated from the
tendon by an anechoic region representing fluid within the sheath (CRASS and HARKAVY, 1988; DICKIE, 2006). Ligaments are more metabolically active than tendons, having more plump cellular nuclei, higher DNA content, larger amounts of reducible cross-links, and the presence of more type III collagen, as compared with tendons. They also contain slightly less total collagen than tendons and more glycosaminoglycans. Ligaments are structurally similar to tendons except their elements are less arranged. Ligaments consist of almost dense, closely packed, collagenous fibers oriented along their longitudinal axis (AMIEL, et al., 1984). Most ligaments are equally or slightly more echogenic than tendon, and can have more solid appearance. Ligaments tend to have coarser fiber patterns on the longitudinal scan. The tendons and ligaments have an almost similar structure in composition but can be differentiated on their function, localization, position and size.

1.3.3. Muscles

Muscles appear hypoechoic on the ultrasound image. However the fibrous tissue surrounding each muscle bundles produces a series of hyperechoic lines throughout the muscle belly. When a muscle is imaged longitudinally it creates a coarse, striated appearance and reticular pattern in the transverse scan. The sonographic imaging of muscles also depends upon the angle at which they are imaged. In addition, each muscle is surrounded by connective tissue fascia which produces a well defined smooth, hyperechoic margin. In both transverse and longitudinal scans, a muscle is hypoechoic. During contractions, the thickness of the muscular body increases and therefore the dimensions of each muscle are not constant (CRAYCHEE, 1995; DICKIE, 2006). Muscles are more hypoechoic than tendons as well as in longitudinal and transverse views but subcutaneous tissues appear more echogenic than muscles (KAPLAN et al., 1990).

1.3.4. Synovial structures (synovial sheaths and bursae)

Normally there is a small amount of fluid within a synovial sheath, which can be identified ultrasonographically as small amount of hypoechoic fluid. Without fluid distention or hypertrophy of synovial tissues, the synovial sheath cannot be
visualized. Excessive synovial fluid accumulation can be visualized within the sheath (JEFFREY et al., 1987; CARTEE, 1995). Bursae are hypoechoic to sonolucent, flattened and are usually adjacent to the tendon or bone. Normal bursae are not visualized similar to synovial sheaths. With bursitis it appears relatively hypoechoic (FORNAGE, 1987).

1.3.5. Bony structures and joints

Bone is highly reflective to the ultrasound beam and returns 50 % of the ultrasound waves back to the transducer with the remaining 50 % of the beam being absorbed within the dense material. This results in the production of a hyperechoic line on the image with a strong distal acoustic shadow. The shape of the line reflects the shape of bone-joint interface and should be smooth. The joint spaces are themselves narrow and are located between the adjacent bone surfaces which appear as smooth, curved, hyperechoic lines producing distal acoustic shadowing (DICKIE, 2006).

1.4. Artifacts

Artifacts are produced by physical interaction between the ultrasound beam and matter and are not due to an improper scan technique. Some of these artifacts are easy to recognize and are even helpful in diagnostic procedures (PENNINCK, 1995; LANG, 2006).

Acoustic shadowing

Acoustic shadowing produced by structures with high attenuation, lead to complete reflection and absorption of sound energy. The result is that the distant area is anechoic. This artifact can be produced by gas or bone or a soft-tissue-bone interface so that reflection is different in acoustic impedance (ROBINSON et at., 1981; SOMMER et al., 1989; LANG, 2006).
**Acoustic enhancement**

It represents a localized increase of echo amplitude occurring distal to a structure of low attenuation (KREMKAU, 1989; LANG, 2006). This artifact is helpful in differentiating cystic structures from solid hypoechoic masses. Cysts often have smooth, discrete borders while abscesses, granulomas have usually irregular, ill-defined borders (KIRBERGER, 1995; PENNINCK, 1995).

**Reverberation**

It involves the reflection of the ultrasound beam backwards and forwards between the transducer and a highly reflective surface. This occurs commonly at the interface of a body wall (external reverberation) but can occur at the interface of any highly reflective surface in path of the ultrasound beam such as small intestine or between the body wall and lung (internal reverberation). The number of reverberation images depends on the penetrating power of the beam and sensitivity of the probe (CURRY et al., 1990; PENNINCK, 1995).

**Mirror image artifact**

An ultrasound image is generated by transforming the time taken by the ultrasound beam to be reflected back from the tissues to the transducer into a location or depth, assuming that the ultrasound beam travels in a straight line to and from the reflector. This error in interpreting the location of an organ or structure can occur when a large reflector such as diaphragm-lung interface is encountered (GARDNER et al., 1982; KREMKAU, 1989; PENNINCK, 1995).

**Side lobe artifact**

Lateral displacement of structures not aligned with the sound beam is called side-lobe artifact (LAIN and KURTZ, 1982; LAING, 1983). The ultrasound beam is composed of a main lobe and weaker secondary lobes, or side lobes. Normally the image results from reflective objects in the path of the primary beam. These interfaces in the path of a side lobe can result in an echo returning to the transducer. The returning echo will
be misplaced into the path of the main lobe. This artifact is generated if curved surfaces and strong reflectors such as air are present.

1.5. Review of different studies for research

Ultrasonography of the carpal joint area has been performed in cattle, horses, the camel and dogs. The following studies were reviewed for brief knowledge of the technique and the procedure.

1.5.1. Ultrasonographic examination of the carpal region of cattle

KOFLER in 2000 performed the ultrasonographic examination of 14 non pregnant cows. In his study, a 7.5 MHz linear transducer with a standoff pad was used to improve the contact with the skin. For the ultrasonographic examination of the carpal tendons and tendon sheaths, transverse and longitudinal planes were recommended. Soft tissues structures, bone surfaces of the dorsal, lateral, medial and palmar aspect of the carpal and distal antebrachial region were scanned beginning proximally and moving the transducer distally. The carpal extensor and flexor tendons with their muscle-tendon transition, tendon sheaths, collateral ligaments, antebrachiocarpal, mediocarpal, carpometacarpal joints and the radial and the median arteries were studied. The position, echogenicity, degree of demarcation of tendons, ligaments and appearance of the boundaries of joint pouches were visualized. During this study, 10 cadaver limbs from five killed adult cows showing no superficial lesions were studied for anatomical description as well as ultrasonographically. In four cadavers, the tendon sheaths of the extensor carpi radialis, lateral digital extensor, common digital extensor, superficial and deep digital flexor tendons were filled with water to imitate the distend and to get clear demarcation of the structures.

1.5.2. Arthrosonography of ovine joints

MACRAE and SCOTT in 1999 studied the superficial ultrasonographic anatomy of the elbow, the carpal, the fetlock and the stifle joints of six clinically normal sheep using a 7.5 MHz linear transducer with a stand-off pad. The arthrosonography of five
sheep infected with chronic arthritis and synovitis of one or more joints was performed and gross pathological changes were examined at necropsy. A total of one elbow, three stifle and three carpal joints were examined and sheep were euthanized and joints examined at routine necropsy and joint dissection. A sample of joint fluid was taken from at least one affected joint of each sheep for bacteriology. Ultrasonographic findings of normal joints were then compared with clinical, radiographic and necropsy findings to determine the ultrasonographic anatomy of the joint. Distension of the joint capsule with up to 10 ml isotonic saline was also executed and visualized ultrasonographically before and after distension. It was a comparative study between normal and diseased joints like the elbow, carpal, fetlock and the stifle. All these joints were studied at the surface level and no detailed examinations were made for surrounding structures like tendons, muscles, ligaments, arteries, veins and nerves. The carpus and fetlock joints were investigated only in dorsal and longitudinal planes. The study was restricted to take views of joints to visualize optimally the synovial membrane and the joint capsule. The appearances of the carpal extensor and flexor tendons, tendon sheaths and muscle orientation were not considered during this study. The appearances of bones forming the antebrachio-carpal, mediocarpal and carpometacarpal joints were absent in this research. The cross sections were not prepared. The contours of vessels and nerves were not depicted during this study. It was a very superficial and surface study of different joints in one of two planes, which did not give comprehensive facts and figures regarding any joint structure. It was direly needed to explore the complete joint area and its related structures through ultrasonographically.

1.5.3. Sonoanatomy of the carpal region of one-humped camel

KASSAB (2007) described the ultrasonographic anatomy of the carpal region of eight normal camels using a 7.5 MHz linear transducer. He was able to visualize the extensor carpi radialis tendon, extensor digitorum communis tendon and extensor digitorum lateralis tendon at the dorsal aspect of carpus easily. Laterally, the ulnaris lateralis tendon was identified but the extensor carpi obliquus tendon was imaged with difficulty. Soft tissue structures like the lateral and medial collateral ligaments were observed. Ultrasonographic anatomy correlated with the gross anatomy in the dissected limbs. The results of the study will serve as reference data for the
ultrasonographic investigation of disorders of the camel carpus.

1.5.4. Dorsal and lateral aspects of the equine carpus: technique and normal appearance

TNIBAR et al. (1993) depicted the normal ultrasonographic picture of the dorsal and lateral soft tissue structures and anatomic landmarks of the equine carpus area. Both limbs of 5 cadavers and 5 clinically sound adult horses were imaged using a 7.5 MHz sector transducer. At the dorsal aspect of the carpus, the extensor carpi radialis and the common digital extensor tendon and their tendon sheaths were easily visualized. Smaller and more difficult to identify were the tendon and tendon sheath of the extensor carpi obliquus, lateral digital extensor and the ulnaris lateralis muscles. Other soft tissue structures examined included the lateral collateral ligament, the carpal joint capsule and the distal articular cartilage of the radius. Ultrasonographic findings correlated well with the gross anatomy in the cadavers limbs.

1.5.5. Ultrasonographic study of the carpal canal in dogs

TURAN et al. (2009) studied the course of the median nerve and its adjacent structures in the carpal canals of 8 healthy dogs by using high-frequency transducers. On the transverse sonogram, the deep digital flexor tendon was seen in almost the centre of the carpal canal like a comma shape and it also had small concavity on the caudal side. The superficial digital flexor was seen as an ovoid structure of the transverse sonogram and it was nearly located at the posterior side of the carpal canal. Both tendons were seen as intermediate grade echogenic structures. The median artery was located inside the concavity of the deep digital flexor tendon. Also the median artery was imaged. The cross section areas of the median nerve were also measured.
2. **ANIMALS, MATERIAL AND METHODS**

2.1. Dissection of cadaver limbs

Ten cadaver forelimbs were selected for ultrasonographic examination. Out of ten, six cadaver forelimbs were dissected to study the normal anatomy of the dorsal, lateral, medial and palmar carpal region. Only sheep that had been euthanized for non-orthopaedic reasons were used in the cadaver study. The front limb was disarticulated at the shoulder to maintain the soft tissue tautness around the carpus. The limbs were examined in horizontal position on a table. The area of interest was explored and investigated. The landmark and structures were studied as described in anatomical books and atlas (MAY, 1970; DYCE et al., 2002; POPESKO, 2007).

2.2. Transverse slices of frozen limbs

Two cadaver limbs were frozen and sliced at the carpal area, one transversely, the other longitudinally. One centimeter thick slices were obtained, photographed and compared with the sonographic findings.

2.3. Experimental filling of joints

On two additional cadaver limbs, the antebrachiocarpal joint, mediocarpal joint and carpometacarpal joint were injected with tap water using a hypodermic needle. A 0.65 x 30 mm hypodermic needle was selected for the injection of water to prevent leakage after removal of the needle. The needle was inserted into the palpable joint spaces. All joints were filled starting 3 ml up to 8 ml of water after external palpation of the joint spaces. The joints were filled with water to determine the boundaries of the structures ultrasonographically. The experimental filling of joint was performed similarly to arthrocentesis in goats. The antebrachiocarpal joint is distinct while mediocarpal and carpometacarpal are communicative. Access to these joints was improved by flexing carpus to a 90 degree angle. The extensor carpi radialis tendon was identified as landmark running centrally over the anterior aspect of carpus. The antebrachiocarpal joint was entered lateral to lateral edge of extensor carpi radialis tendon while the
more distal mediocarpal joint was approached medial to medial edge of extensor carpi radialis tendon (SMITH and SHERMAN, 2007). The carpometacarpal joint is not accessed directly (SACK and COTTRELL, 1984).

2.4. Restraining and position of sheep

Then 12 live sheep (10 rams and 2 non-pregnant ewes) with a mean age of five years (ranges 4-6), a mean weight of 80 kg (range 70-90) were selected. All sheep were clinically sound and healthy. The left and right carpal regions of these 12 sheep were studied ultrasonographically. The sheep were examined in lateral recumbency and restrained on a surgical bed with ropes (Fig. 4). Sedation was not necessary in any sheep. Long lateral recumbency was avoided due to any respiratory stress but sheep could be restrained up to 40 minutes without any symptoms of stress.

2.5. Operating ultrasound unit, transducer and stand-off pad

The sheep were examined with a SonoAce PICO unit (Deutschland GmbH) (Fig. 3). The machine was equipped with 7.5 MHz linear transducer. The selected area was shaved and cleaned (Fig. 5, 6). The standoff pad was used in most of the animals to improve contact with the skin surface, after application of ample quantity of coupling gel (Fig. 7, 8). The soft tissue structures and joint surfaces of the dorsal (Fig. 9), lateral (Fig. 10), palmar (Fig. 11a, 11b) and medial aspects of the carpus were scanned in longitudinal and transverse planes (Fig. 12, 13) beginning proximally and moving the transducer step by step distally. The position, echogenicity and degree of demarcation of the tendons and ligaments, appearance of the muscles, boundaries of the joints, joint pouches, tendon sheath lumina and vessels at the carpal region were examined. The examination started 6 cm proximal to the accessory carpal bone which was used as anatomical landmark ending distally 6 cm distal to the accessory carpal bone. These landmarks provided comprehensive detail and orientation of all structures including muscles, tendons, joints and bones. The observations were recorded and saved digitally.
Fig. 3: The ultrasound unit consists of 1) portable ultrasound machine, 2) standoff pad, 3) 7.5 MHz transducer. Also necessary are 4) Shave machine, 5) liquid soap, 6) coupling gel and 7) gloves

Fig. 4: Lateral recumbence and restraining of sheep on surgical bed and forelimb fastened with rope and to be prepared for ultrasonography
Fig. 5: Shaving of the dorsal, lateral, medial and palmar carpal region with a shaving machine

Fig. 6: Shaving for clear skin without hair
Fig. 7: Application of coupling gel on the shaved forelimb through all the areas around the carpus

Fig. 8: Vigorous coupling of gel throughout the carpal area
Fig. 9: Longitudinal scan of the dorsal antebrachiocarpal, mediocarpal and carpometacarpal joint at the carpus showing the position and placement of a 7.5 MHz transducer with a stand-off pad
Fig. 10: Longitudinal scan of the lateral aspect of the carpus using a 7.5 MHz transducer with a stand-off pad
Fig. 11a: Longitudinal scan at the palmar aspect of the carpus for joints orientation with a stand off pad

Fig. 11b: Longitudinal scan of the palmar aspect of carpus for antebrachiocarpal, mediocarpal and carpometacarpal joint without a stand-off pad
Fig.12: Transverse scan just above the carpus showing the postion and placement of the 7.5 MHz transducer without using a stand-off pad
Fig. 13: Transverse scan 6 cm above the carpus for orientation of the caudal flexor muscles
3. RESULTS

3.1. Ultrasonographic appearance after experimental filling of carpal joints

3.1.1. Longitudinal sonograms of the antebrachiocarpal joint from dorsal

The experimental filling of dorsal antebrachiocarpal joint was performed in order to imitate effusion. The hypodermic needle between the joint surfaces was inserted by following the anatomical landmarks described in material and method (SMITH and SHERMAN, 2007). The needle was inserted and 3 ml and 8 ml water injected respectively. The ultrasonographic image was recorded during and after filling (Fig. 14, 15).

Fig. 14: Longitudinal scan of the antebrachiocarpal (abc) joint dorsal with 7.5 MHz linear probe in a cadaver limb for experimental filling a hypodermic needle was inserted in the joint space, acoustic shadowing of the needle can be noted. The surface of the radius, radial carpal and 2nd and 3rd carpal bones appeared as hyperechoic lines. An echogenic fat pad is also prominent at antebrachiocarpal (abc) joint level. The mediocarpal joint (mc) can be identified as interruption of hyperechoic bone surfaces of radial carpal and fused 2nd and 3rd carpal bones.
Fig. 15: Longitudinal sonogram in a right cadaver limb dorsal at the antebrachiocarpal (abc) joint. The joint was filled with 3 ml water; marked distension of antebrachiocarpal (abc) joint is noted. The joint pouch appears as large anechoic area. The bone surfaces of the radius and radial carpal bone can be identified as hyperechoic lines. The mediocarpal joint (mc) can be identified as interruption of hyperechoic bone surfaces of radial carpal and fused 2nd and 3rd carpal bones. The carpometacarpal (cmc) joint is visible as narrow gap between the fused 2nd and 3rd carpal bones and the metacarpal bone surfaces.
3.1.2. Longitudinal scan of the mediocarpal joint from dorsal

Experimental filling of the mediocarpal joint was done in a cadaver limb from dorsal carpus by inserting a hypodermic needle medial to the medial edge of extensor carpi radialis tendon. The ultrasonographic image during and after experimental filling was captured (Fig. 16a, b).
Fig. 16 a, b: Longitudinal scan dorsal of the mediocarpal (mc) joint area in a right cadaver forelimb during and after experimental filling of water with a hypodermic needle. In figure a, acoustic shadowing of the needle can be seen and a small anechoic pouch appeared during filling. In figure b, the large anechoic area represents the joint pouch of the mediocarpal (mc) joint. The heterogeneous capsule of the joint is separated from the echogenic surfaces of the radial and 2\textsuperscript{nd} and 3\textsuperscript{rd} carpal bone. The tendon of the extensor carpi radialis muscle can be identified as a flat oval shaped structure under the skin. The slight filling of the tendon sheath of extensor carpi radialis tendon was noted in this limb.
3.1.3. **Longitudinal scan of the antebrachiocarpal joint, lateral view**

The experimental filling was performed lateral to common digital extensor tendon in antebrachiocarpal joint between distal radius, ulna and ulnar carpal bone. The scan of joint recess after filling was captured (Fig. 17).

**Fig. 17:** Experimental filling of the lateral antebrachiocarpal (abc) joint in a right cadaver limb after injecting 3 respectively 8 ml water. The small anechoic zones represent the fluid filled joint pouches covering the articular bone surfaces. An edema of the lateral digital extensor (lde) tendon and separation of the capsular from the echogenic surfaces of the radius, ulnar and 4th carpal bone can be noted. The injection of fluid produced insufficient distension to allow a clear visualization of the pouch and pressure of the transducer also pushed the fluid into other parts of the synovial cavity.
3.1.4. Longitudinal scan of the antebrachiocarpal joint, medial view

The medial antebrachiocarpal joint was filled between distal radius and radial carpal bone medially. The area was visualized ultrasonographically after imitation filling with water (Fig. 18).

Fig. 18: Experimental filling of the antebrachiocarpal (abc) joint from medial in a right cadaver limb after injecting 8 ml water. The anechoic zone represents the fluid filled joint pouch of the antebrachiocarpal joint. The medial collateral ligament (mcl) has detached from the distal radius and cannot clearly be seen. The joint space of the mediocarpal joint (mc) can be noted as small gap between the hyperechoic surfaces of the radial carpal bone and the fused 2\textsuperscript{nd} and 3\textsuperscript{rd} carpal bones.
3.1.5. **Longitudinal sonogram of the mediocarpal and carpometacarpal joints, medial view**

The medial mediocarpal and carpometacarpal joints were also approached. The needle was injected between the spaces of radial carpal bone and fused 2\textsuperscript{nd} and 3\textsuperscript{rd} carpal bone for mediocarpal joint. The carpometacarpal joint was accessed by injecting needle between distal carpal bones and metacarpal. The ultrasonographic image was taken (Fig. 19).

![Figure 19](image)

**Fig. 19:** Longitudinal scan from the medial side after experimental filling of the mediocarpal (mc) joint and the carpometacarpal (cmc) joint in a cadaver on the left limb with a 7.5 MHz linear probe. The distension of the joint spaces appeared as anechoic zones. The bone surfaces of the radial carpal, fused 2\textsuperscript{nd} and 3\textsuperscript{rd} carpal and metacarpal bones can be identified as hyperechoic lines. The medial collateral ligament (mcl) is now separated from the distal radial bone surface and can be seen over the metacarpal bone surface.
3.1.6. Transverse scan of the antebrachiocarpal joint, caudal view

The needle was inserted lateral to accessory carpal bone caudally to access antebrachiocarpal joint caudally. The joint pouch after filling was noticed by ultrasonography (Fig. 20).

![Transverse scan of the antebrachiocarpal joint](image)

**Fig. 20:** Transverse scan of the caudal antebrachiocarpal (abc) joint of the right cadaver forelimb after experimental filling with 3 ml water. Acoustic shadow of the accessory carpal bone, a large anechoic zone representing the joint pouch area of the antebrachiocarpal joint caudally can be seen.
3.2. Ultrasonographic findings of carpal joints, muscles, tendons, ligaments, vessels and comparison of the transverse images with the anatomical slices

3.2.1. Ultrasonographic findings of carpal joints

Longitudinal scan of the carpal joints, dorsal view

The bone surfaces of the radius, carpal and metacarpal bones were represented as smooth, linear hyperechoic structures with acoustic shadowing distally. The joint spaces of the antebrachiocarpal, mediocarpal and carpometacarpal joints on the dorsal aspects of the carpus appeared as clear interruptions of the bones surfaces with a triangular or funnel-shaped contour when scanned in longitudinal direction. The antebrachiocarpal joint appeared as funnel-shaped interruption of the hyperechoic surfaces of the distal radius and the radial carpal bone in all sheep. Covering the bone surface dorsally, a homogeneous echogenic fat pad could be seen, which was more prominent at the antebrachiocarpal level. A thin capsular could also be seen along the fat pad but it was not clearly separated from the fat pad. The joint spaces of the mediocarpal and carpometacarpal joints could be seen clearly with very small joint spaces covered with an echogenic fat pad and connective tissue. The echogenic fat pads at these two joints were not so outstanding. During examination of the joints, the tendon of the extensor carpi radialis muscle crossing the dorsal aspects of the carpal area at the joint spaces of the antebrachiocarpal, mediocarpal and carpometacarpal joints could be envisioned simultaneously (Fig. 21). The boundaries of the joint pouches of the antebrachiocarpal, mediocarpal and carpometacarpal joints could not clearly be identified under normal conditions. Dorsally, the midcarpal joint space was formed by the surface of the radial carpal and fused 2nd and 3rd carpal bones, the carpometacarpal joint was formed between the fused 2nd and 3rd carpal and metacarpal bone surfaces. The joint spaces were quite small and narrow and the joint pouches were not visible. The joint spaces appeared as triangular, anechoic zones. The longitudinal sonograms presented a better overview of the joints dorsally. The tendon of the extensor carpi radialis muscle at this level was clearly seen crossing the carpus.
dorsally; the extensor carpi radialis tendon appeared as echogenic structure having prominent linear pattern of parallel fibre bundles crossing over the antebrachiocarpal, mediocarpal and carpometacarpal joints at the dorsal aspect of the carpal area in the longitudinal planes (Fig. 21). The dorsal annular ligament or extensor retinaculum that covers most of the tendons in the carpal area was poorly demarcated during the observations.

**Fig. 21:** Longitudinal scan of the dorsal aspect of the carpal area of the left limb in a 4-year-old male sheep. The image shows the antebrachiocarpal (abc), mediocarpal (mc), carpometacarpal joint (cmc) spaces bounded by the radius proximally, the radial carpal and the, 2nd and 3rd carpal centrally and metacarpal bone distally. Note the echogenic fat pad and connective tissue of capsule which is more prominent at the antebrachiocarpal (abc) joint. The echogenic tendon of extensor carpi radialis (ecr) passes over the joints.
Longitudinal scan of carpal joints, lateral view

The antebrachiocarpal, mediocarpal and carpometacarpal joints were also visualised laterally. All three joints were observable. The antebrachiocarpal joint formed between the distal part of the radius and the ulnar carpal bone was viewed as narrow triangular area bounded by the hyperechoic bone surfaces. The midcarpal joint formed between the ulnar and 4th carpal bone appeared as smooth interruption of bone surfaces. The carpometacarpal joint formed between the 4th carpal and metacarpal bone. The joint spaces could be imaged simultaneously during the examination of echogenic lateral digital extensor tendon. The differentiation between the tendons of common digital and lateral digital extensor tendon was not possible at the longitudinal direction (Fig. 22).

Fig. 22: Longitudinal scan in a 5-year-old male sheep at the left limb for the lateral digital extensor (lde) tendon on its course over the antebrachiocarpal (abc) joint, mediocarpal (mc) joint, carpometacarpal (cmc) joints laterally. The echogenic lateral digital extensor (lde) tendon passes over the ulnar and 4th carpal bone. The joint spaces of the antebrachiocarpal (abc), mediocarpal (mc) and carpometacarpal (cmc) are also depicted as interruptions of the linear hyperechoic bones.
**Longitudinal scan of antebrachiocarpal joint, palmar view**

All three joints were studied at the palmar aspect of the carpal area first in longitudinal direction. The antebrachiocarpal joint is formed between the radius and the intermediate carpal bone. At level of the accessory carpal bone caudally, it was not possible due to overlapping of the bone over the joint but slightly lateral to the accessory carpal bone, the caudal antebrachiocarpal joint could be imaged. In the longitudinally plane, at the antebrachiocarpal joint level, the surface of the accessory carpal bone was seen as hyperechoic contour with the acoustic shadowing distally. At this level, the tendons of the superficial and deep digital flexor muscles were also observed running distally towards the surface of the accessory carpal bone. The superficial digital flexor muscle appeared more hypoechoic due to the muscle fibers. The deep digital flexor muscle had echogenic patterns of fibrous bundles (Fig. 23).

**Fig. 23:** Longitudinal scan of the palmar aspect of the carpus in a 4-year-old male sheep at the left limb showing the antebrachiocarpal (abc) joint. The radius and radial carpal bone appeared as hyperechoic bone lines. At this level, an anechoic trapezoid area of the joint pouch could be visualized. The muscle bundle fibers of the superficial (sdf) and deep digital flexor (ddf) muscles are also visible. The deep digital flexor muscle appeared more hyperechoic covering the distal echogenic radial bone surface than the superficial digital flexor muscle. The image was captured lateral to the accessory carpal bone at the palmar antebrachiocarpal (abc) joint level.
Longitudinal scan of the mediocarpal and carpometacarpal joints, palmar view

The palmar mediocarpal and carpometacarpal joints were also visualized. The palmar mediocarpal joint formed between the radial carpal and the fused 2\textsuperscript{nd} and 3\textsuperscript{rd} carpal bones appeared as small interruption of the hyperechoic bone surfaces as anechoic joint space. The carpometacarpal joint formed between the fused 2\textsuperscript{nd}, 3\textsuperscript{rd} carpal and the metacarpal bones was visualized as interruption of the hyperechoic bones. During the sonographic observations at the level of these joint spaces, triangular anechoic areas representing the visible parts of the joint pouches were noted. The anechoic structure with an echogenic valve was depicted as median vein. The median artery and vein were more deeply located side by side, closer to the accessory carpal bone and adjacent to the deep part of the superficial digital flexor tendon. These deep vessels were difficult to define at this level. The deep digital flexor tendon appeared echogenic running over the mediocarpal and carpometacarpal joint distally. The superficial digital flexor tendon appeared less echogenic or hypoechoic due to the more muscular component. The palmar annular ligament or flexor retinaculum could also be visualized at this level but it was not distinguished (Fig. 24).
**Fig. 24:** Longitudinal scan of the left limb in a 4-year-old male sheep of the palmar aspect of the carpus showing the mediocarpal (mc) and carpometacarpal (cmc) joint spaces. The bone surfaces of the intermediate and radial carpal bones, fused 2nd and 3rd carpal bones and metacarpal appeared as hyperechoic lines. The triangular funnel shaped anechoic areas represented the joint pouches of the (mc) and (cmc) joints. The deep digital flexor (ddf) tendon appeared more echogenic than the superficial digital flexor (sdf) tendon. An anechoic more or less round structure adjacent to the superficial digital flexor (sdf) tendon represented the median vein (mv).
Longitudinal scan of the carpal joints, medial view

At the medial side of the carpal area, the joint spaces of the antebrachiocarpal, mediocarpal and carpometacarpal joints could be detected ultrasonographically. Medially all joints could be visualised. The joints appeared as regular interruption of the bone surfaces. The appearance of the joints was similar to the lateral and dorsal aspects of the carpus. The joint spaces were also visualized poorly. The antebrachiocarpal joint was formed between the distal radius and the radial carpal bone, the mediocarpal joint was formed between the radial and the fused 2nd and 3rd carpal bone and the carpometacarpal joint was formed between the fused 2nd, 3rd carpal and metacarpal bone. At the antebrachiocarpal joint level, the medial collateral ligament could be noted in the longitudinal direction on its course over the distal radius, the radial carpal bone and the proximal extremity of the metacarpal bone. It appeared as echogenic structure, characterized by parallel fibre bundles (Fig. 25). In the transverse direction the collateral ligament could be identified because of its oval shaped and echogenic configuration.
**Fig. 25:** Longitudinal scan of the medial collateral ligament (mcl) in a 4-year male sheep at the right limb was captured. The medial collateral ligament (mcl) appeared as echogenic structure. The medial collateral ligament was clearly visible over the surface of the distal radius and the proximal antebrachiorcarpal (abc) joint medially. The surfaces of the radius and radial carpal bone appeared hyperechoic. The small antebrachiorcarpal (abc) joint space between the radius and the radial carpal bone could also be visualized.
3.2.2. Extensor carpi radialis muscle and tendon scans

Longitudinal scan

The longitudinal view of the extensor carpi radialis muscle was possible. At this level, the large muscle belly of the extensor carpi radialis appeared hypoechoic lying over the surface of the hyperechoic radial bone. At this level, the muscle belly was more hypoechoic and intercepted by echogenic septa (Fig. 26). The extensor carpi radialis tendon was visualized in longitudinal direction at its course over the carpal joints dorsally. The extensor carpi radialis tendon was depicted as strong echogenic structure having a clear cut pattern of parallel fibre bundles in longitudinal planes. The course of the tendon was clearly seen at the dorsal carpal area. The echogenic tendon was passing above the antebrachio-carpal, mediocarpal and carpometacarpal joints. The diameter of the tendon got reduced distally. The insertion at the lateral tuberosity of the metacarpus could be visualised in all sheep. The point of insertion could be viewed best with the transducer moving in a little oblique direction at the metacarpal tuberosity. The insertion of the extensor carpi radialis tendon was best visualized following the path of the tendon and moving the transducer within the direction of the tendon. It appeared wider at the antebrachio-carpal joint and became smaller as it descends over the carpal bones until its insertion at the metacarpal tuberosity (Fig. 21).
Fig. 26: Longitudinal scan of the extensor carpi radialis (ecr) muscle in 4.5-year-old female sheep of the right limb, 6 cm proximal to the dorsal antebrachiocarpal (abc) joint. The muscular part of the extensor carpi radialis (ecr) appeared hypoechoic with interception of the echogenic septae. Proximally the extensor carpi radialis (ecr) muscle belly appeared wider and became smaller distally.
Transverse sonogram
The transverse scans gave comprehensive details of the muscular structures. Transverse ultrasonogram 2cm proximal to the level of antebrachio-carpal joint captured the tendon of the extensor carpi radialis muscle as it crossed over the distal radius and the carpal bones. At this level, it was visualized as an oval to round hypoechoic structure surrounded by echogenic margins reflecting the structure of the muscle fibers. The larger muscle belly also continued with its tendon above the carpus. It represented the anatomical situation as muscular components continue with the tendon at this level (Fig. 27).

Fig. 27: Transverse dorsal sonogram proximal to the level of the antebrachio-carpal (abc) joint of the left forelimb in a 4-year old male sheep with 7.5 MHz linear transducer. The tendon of the extensor carpi radialis (ecr) tendon appeared as oval shaped echogenic structure. The muscular hypoechoic part of the extensor carpi radialis (ecr) muscle is also prominent over the echogenic surface of radial bone.
**Transverse muscle scan and anatomical slice**

In all sheep, the topography of muscles was scanned in transverse planes starting 6 cm proximal the carpus. The ultrasonographic transverse scan of the extensor carpi radialis muscle was captured 6 cm proximal the carpus and compared with the anatomical cross section area of the same region. The muscle appeared as large hypoechoic structure with echogenic septae covering the radial bone. The findings of the sonogram were equal to the corresponding anatomic slices (Fig. 28).
Fig. 28: Transverse scan and the cross section of the extensor carpi radialis muscle 6 cm proximal to the carpus. (1) The surface of the radial bone appeared hyperechoic and circular. (2) Cranial to the hyperechoic radial bone a hypoechoic small portion of flexor carpi radialis (fcr) muscle can be seen. (3) Large hypoechoic muscular portion of the extensor carpi radialis (ecr) muscle can be visualized. (4) Caudal to the radial bone the hypoechoic portion of the common digital extensor (cde) muscle can be visualized. (5) Small hypoechoic lateral digital extensor (lde) muscle can be seen. (6) The cross section image is showing extensor carpi ulnaris (ecri) muscle. (7) The superficial digital flexor (sdf) muscle, (8) the deep digital flexor (ddf) muscle, (9) the ulna bone.
3.2.3. **Extensor carpi obliquus muscle (abductor pollicis longus muscle) and tendon scan**

The extensor carpi obliquus muscle crosses the extensor carpi radialis muscle from lateral to distal-medial proximal to the antebrachial carpal joint. Its belly is lying between the common digital extensor tendon and the radial bone anatomically but could not be visualized due to its small structure.

3.2.4. **Lateral digital extensor muscle and tendon scans**

**Transverse and longitudinal scan**

During the transverse scan 6 cm proximal to the carpus laterally, the differentiation between the muscle bellies of the lateral digital extensor muscle from the bellies of the common digital extensor muscle was nearly impossible but the differentiation of the tendons was possible at the carpus level in the transverse direction (Fig. 29). However it could be well visualized after the change of its course more dorsally, distal to the proximal row of the carpal bones where it passes over the ulnar carpal bone. The echogenic tendon had a typical appearance when visualized in longitudinal direction running through all the joints at the lateral side. The detailed description has been included in the examination of joints laterally (Fig. 22). In the transverse scan, the lateral digital extensor tendon appeared echogenic oval at the dorsal surface of the hyperechoic ulnar carpal bone. Palmar to it, the extensor carpi ulnaris tendon was poorly demarcated from the surrounding tissues. The lateral collateral ligament could not be imaged ultrasonographically at this level also (Fig. 29).
Fig. 29: Transverse scan of the right limb in a 4.5-year old male sheep. The image of lateral digital extensor (Ide) tendon was recorded. The lateral digital extensor (Ide) tendon appeared as oval structure covering the hyperechoic bone surface of the ulnar carpal bone dorsally. The extensor carpi ulnaris (ecu) tendon could also be visualized palmar to the lateral digital extensor (Ide) tendon but it was poorly demarcated from the surrounding tissues due to the similar echogenicity. The image was taken just proximal to the lateral antebrachio-carpal (abc) joint.
3.2.5. Transverse scan of the common digital extensor muscle and tendon

During the transverse scan 6 cm proximal to the carpus laterally, the differentiation between the muscle bellies of the common digital extensor muscle and the bellies of the lateral digital extensor muscle was nearly impossible. The transverse scans 2 cm proximal to the antebrachiocarpal joint laterally were also taken. At this level, the surface of the radial bone appeared as hyperechoic line covered by two oval hyperechoic structures representing the cranial and caudal branches of the common digital extensor tendon. The cranial branch of the tendon was a bit larger than the caudal one. The lumen of the tendon sheath could be partly visualized in three sheep as a very narrow anechoic rim surrounding the tendon but it could not clearly be outlined in all the animals (Fig. 30).
Fig. 30: Transverse scan of the common digital extensor (cde) tendon in a 3-year old male sheep at the left limb. The hyperechoic cranial and caudal branches of the common digital extensor (cde) tendon are lying superficial to the hyperechoic bone surface of the radius. The cranial branch is a bit larger than the caudal one. The image was captured 2 cm proximal to the antebrachio-carpal (abc) joint laterally.
**3.2.6. Extensor carpi ulnaris muscle and tendon scan**

**Transverse muscular scan and anatomical slice comparison**

The muscle belly of the extensor carpi ulnaris muscle could be identified at the caudolateral aspects of the radius 6 cm proximal to the carpus. In the transverse direction it had an oval to round shape and a hypoechoic appearance with wave-like echogenic septa seen inside the muscle. The muscles belly of the extensor carpi ulnaris muscle was clearly seen 6 cm proximal the lateral carpal joint level in the transverse direction by placing the probe caudo-lateral. At this level a deep part of the deep digital flexor muscle was also observed below the hypoechoic muscle belly of the extensor carpi ulnaris muscle, a muscle with prominent hyperechoic fascia, covered by the hypoechoic muscle belly of the extensor carpi ulnaris muscle separated by echogenic septa. On the transverse image, the large hypoechoic muscle belly of the extensor carpi ulnaris muscle was clearly visualised with wave-like echogenic septae between the muscle bellies. The anatomical cross section depicted the same picture of the extensor carpi ulnaris muscle (Fig. 31).
Fig. 31: Transverse scan and anatomical section of the extensor carpi ulnaris muscle in a 5-year-old male sheep at the left limb, 6 cm proximal to the carpus in caudo-lateral direction. (1) and (2) are echogenic radius and ulna, (3) hypoechoic extensor carpi radialis (ecr) muscle appeared cranial to the radius, (4) hypoechoic cranial and caudal muscle bellies of the common digital extensor (cde) muscle with echogenic tendon is visible, (5) small hypoechoic lateral digital extensor (lde) muscle can be seen, (6) hypoechoic extensor carpi ulnaris (ecu) muscle belly intercepted with typical S-shaped echogenic fascia is prominent, (7) below the extensor carpi ulnaris muscle, the hypoechoic deep digital flexor muscle appeared in bundle with echogenic fascia, (8) hyperechoic superficial and deep heads of the superficial digital flexor muscle can be palpated, (9) flexor carpi ulnaris muscle in a 5-year-old male sheep at the left limb.
Transverse tendon scan

The tendinous cranial branch of the extensor carpi ulnaris muscle runs palmar to the lateral digital extensor tendon up to its insertion at the rudimentary 5th metacarpal bone, but it was poorly differentiated due to its similar echogenicity. The main branch of the extensor carpi ulnaris tendon inserts together with the flexor carpi ulnaris muscle, as flat, wide echogenic tendon at the accessory carpal bone. In the transverse direction, at the level of the accessory carpal bone at its insertion, the extensor carpi ulnaris tendon appeared as round hypoechoic structure at the proximal side of the image separated by the superficial digital flexor and deep digital flexor tendons by hyperechoic fascia (Fig. 32).

3.2.7. Flexor carpi ulnaris muscle and tendon scan

Transverse muscular scan

The flexor carpi ulnaris muscle was seen exactly caudally in the transverse plane 6 cm proximal to the carpus as small triangular shaped muscle surrounded by echogenic septa separating it from the superficial digital flexor muscle (Fig. 33). The superficial digital flexor muscle appeared as large muscle below the flexor carpi ulnaris muscle with multiple septa separating the superficial and deep heads of the superficial digital flexor muscle. Both flexor carpi ulnaris and superficial digital flexor muscle bellies appeared hypoechoic, the only difference was that the superficial digital flexor muscle appeared with more hyperechoic fascia. The anatomical position was an important landmark for differentiation. Muscles at the caudal aspect appeared in layers and these layers could be differentiated by the anatomic position. In the transverse direction at the level of the accessory carpal bone, the flexor carpi ulnaris tendon appeared as a very small hypoechoic body lying over the superficial digital flexor tendon. The site of insertion of the muscle over the surface of the accessory carpal bone was also imaged (Fig. 34).
Transverse tendon scan and anatomical slice, caudal view

Transverse scans 2 cm proximal to the antebrachioacarpal joint were also taken and compared with the anatomical slices. The ultrasonographic picture presented few hypoechoic round to oval bodies with echogenic bundle of fibres below them. These hypoechoic bodies were identified according to the anatomical situation of the area. The cranial located round body was representing the extensor carpi ulnaris tendon, caudally two hypoechoic structures were visible separated by echogenic fascia. These were the superficial and the deep head of the superficial digital flexor muscles. An anechoic, small part of the flexor carpi ulnaris tendon was visualized at this level covering the superficial digital flexor muscle. The deep digital flexor muscle was seen as round large bundle of muscle fibres with many echogenic septae covering the radius bone. The anatomical section was taken at the same level. This anatomic slice corresponded perfectly with the picture taken by sonography (Fig. 32).
Fig. 32: Transverse scan of the left limb in a 4.5-year-old male sheep of the palmar aspect of the carpus and comparison with the anatomical section of the corresponding site. 2 cm proximal of the palmar aspect of the carpus, the echogenic surface of the radius can be seen, (7) ulna is visible, (3) hypoechoic extensor carpi ulnaris (ecu) tendon viewed, (4) hypoechoic superficial digital flexor (sdf) muscle, (5) echogenic deep digital flexor (ddf) muscle is visualized. In cross section image (7) echogenic superficial digital flexor (sdf) muscle and radial artery, (8) extensor carpi radialis (ecr) muscle and radial artery, (9) echogenic deep digital flexor (ddf) muscle is visualized.
3.2.8. Superficial and deep digital flexor muscles and tendons scan

Transverse muscles and tendons scan and anatomic slice comparison

The superficial digital flexor muscle consists of a superficial and deep part running through the carpal canal. The transverse scan 6 cm proximal to the carpus caudally gave a typical image for caudal carpal muscles. The superficial and deep part of the superficial digital flexor muscle appeared hypoechoic with echogenic septa. The deep digital flexor muscle appeared as large hypoechoic bundle of muscle fibers but the differentiation of the three heads of the muscle was not possible at this level and comparison with the corresponding anatomical section also justified the ultrasonographic findings (Fig. 33). The transverse scan at the accessory carpal bone at the antebrachiocarpal joint showed a typical picture of some hypoechoic structures separated by echogenic septa. The tendons of the superficial digital flexor and deep digital flexor could be identified at this site with the tendons of the extensor carpi ulnaris and flexor carpi ulnaris. The tendons appeared as small round hypoechoic bodies. The comparison of the anatomical section of the relevant side also verified the findings of the ultrasonographic investigation (Fig. 32). The flexor retinaculum or dorsal annular ligament had the same echogenicity as surrounding soft tissues and therefore difficult to visualize in sheep.
Fig. 33: Transverse scan and anatomical section of the palmar aspect of the carpus in a 5-year-old male sheep at the left limb, 6 cm proximal to the carpus. (1) The echogenic radius is visible, (2) hypoechoic extensor carpi ulnaris (ecu) muscle, (3a) hypoechoic superficial head of the superficial digital flexor muscle, (3b) hypoechoic deep head of the superficial digital flexor muscle, (4) hypoechoic deep digital flexor muscle can be imaged, (5) flexor carpi ulnaris (fcu) muscle, (6) ulna, (7) extensor carpi radialis (ecr) muscle, (8) common digital extensor (cde) muscle, and (9) lateral digital extensor muscle.
**Longitudinal muscular and tendon scan**

Muscular components of the superficial digital flexor muscles were visualized at the level of the carpometacarpal joint space or further distally, so the tendon appeared heterogeneous. The muscular component of the superficial digital flexor muscle appeared as hypoechoic area patterned by echogenic septa resulting in a feather like appearance in longitudinal planes. In contrary to this, the deep digital flexor muscle was seen as mainly tendinous, echogenic structure within the carpal canal. The differentiation between the parts of the deep digital flexor muscle was not possible at this level. The longitudinal scan of the muscles was best imaged by ultrasonography from caudal side (Fig. 23, 28). The longitudinal scan lateral to the accessory carpal bone represented the heterogeneous appearance of the superficial digital flexor tendon. The tendon of the deep digital flexor muscle appeared more echogenic than the superficial digital flexor tendon (Fig. 34). The tendons of the superficial and deep digital flexor muscles were differentiated lateral to the accessory carpal bone at the level of antebrachiocarpal joint from caudally. The shadow of the accessory carpal bone was also imaged. The tendons pass across the accessory carpal bone (Fig. 34).
Fig. 34: Longitudinal scan of the palmar aspect of the carpus in a 5-year-old male sheep at the right limb using a 7.5 MHz linear transducer with stand-off pad at the level of the palmar antebrachiocarpal (abc) joint. The shadow of the accessory carpal bone can be seen clearly. The echogenic tendon of the deep digital flexor and the hypoechoic tendon of the superficial digital flexor appeared across the accessory carpal bone. The insertion of the tendon of the extensor carpi ulnaris muscle and flexor carpi ulnaris muscle could be visualized at the accessory carpal bone but it was not possible to differentiate between both tendons.
3.2.9. **Flexor carpi radialis muscle and tendon scan**

The small muscle belly could be explored in the transverse plane 6 cm proximal to the carpal joint caudomedially. The flexor carpi radialis muscle was bordered cranially by the radius bone, caudal by the flexor carpi ulnaris muscle separated by the small septa. It was small round to oval structure presented between the radial bones cranially and the flexor carpi ulnaris muscle caudally in the transverse plane. Its muscle belly was more prominent than the tendon. The radial artery and vein could also be imaged (Fig. 35).
Fig. 35: Transverse scan at the medial side and cross section of the flexor carpi radialis muscle and the radial artery and vein are visible. (1) echogenic radius is visible, (2) hypoechoic flexor carpi radialis (fcr) muscle is bounded cranially by radius and caudally by superficial digital flexor and deep digital flexor muscle (3) hypoechoic flexor carpi ulnaris (fcu) muscle, (4a) (4b) hypoechoic superficial and deep heads of the superficial digital flexor muscle (4c) muscle is bounded cranially by radius and caudally by superficial digital flexor muscle and deep digital flexor muscle (5) hypoechoic flexor carpi radialis and radial vein in a 4.5-year-old male sheep in the right limb. (6) anechoic radial artery and vein are visible.
3.2.10. Tendon sheaths scan

The lumina of the tendon sheaths of the common digital extensor tendon, the lateral digital extensor tendon, the extensor carpi radialis tendon, the superficial digital flexor tendon, the deep digital flexor tendon and the flexor carpi radialis tendon could not be visualised, neither the tendon sheath wall be differentiated from the tendon by sonographic examination. In three animals, a very narrow anechoic rim was depicted surrounding the common digital extensor tendon. The lumina of the other tendon sheaths could not be imaged in live animals. The precarpal subcutaneous bursa could not be seen in any sheep.

3.2.11. Ligaments of carpal area scan

Medial collateral ligament

The medial collateral ligament was depicted as a large, highly echogenic band longitudinally. The echogenic medial collateral ligament was seen with its course over the distal radius and the radial carpal bone and the antebrachiocarpal joint space medially (Fig. 25).

Lateral collateral ligament

It appeared normally as band located caudo-medial to the lateral digital extensor tendon. Its contour was impossible to differentiate from the adjoining structures such as the lateral digital extensor and the surrounding connective tissues.

Dorsal annular ligament or extensor retinaculum

During the ultrasonography examination, it was not visualized due to its similar echogenicity with surrounding fat and subcutaneous tissues (Fig. 1, 2).

Palmar annular ligament or flexor retinaculum

It was not clearly visualized or demarcated during ultrasonography (Fig. 1, 2).
3.2.12. Vessels scan

The larger vessels passing within the carpal tunnel like the radial artery and vein and the median artery and vein were depicted as anechoic tubular structures surrounded by an echogenic wall in transverse planes and as anechoic band-like structures in longitudinal planes. The larger vessel was the radial vein running subcutaneously on the palmero-medial aspect, accompanied laterally by the smaller radial artery. The median artery and vein were located more deeply side by side closer to the accessory carpal bone and adjacent to the median margin of the deep part of the superficial digital flexor. The arteries were thicker walled and could not be compressed in comparison to the veins and pulsation could felt in arteries. Due to the more superficial course of the radial vein, the transducer had to be positioned with minimal pressure, sufficient to obtain good skin contact, while avoiding the compression of the vein.

3.2.13. Nerves scan

The nerves could not be visualized and differentiated through ultrasound.
4. DISCUSSION

This study was undertaken to evaluate the practical uses of ultrasound in examination of the ovine carpal joint. The normal ultrasonographic details of the carpal region would serve as reference data for disorders of the sheep carpus. The normal ultrasonographic appearance of the carpal region in sheep has not been explored in detail until now. Many authors have described ultrasonography of the carpal region in horses, cattle, camel and dogs respectively (TNIBAR et al., 1993; KOFLER, 2000; KASSAB, 2007; ERKUT et al., 2009). An arthrosonographic research in sheep has been performed by MACRAE and SCOTT (1999) but this study was limited to the surface level of the elbow, carpal, fetlock and stifle joints. The researchers imaged the dorsal carpus superficially only in longitudinal direction and did not identify bones and joints of the dorsal, lateral, medial and palmar sides. They scanned only dorsal views from various joints to visualize optimally few soft tissue structures like tendons, synovial membrane and joint capsule. The study gave no information about the contour of the bones and formation of the antebrachio-carpal, mediocarpal and carpometacarpal joints. The separate views of tendons, muscles and ligaments were not recorded during the study. Moreover, it did not describe the ultrasonographic appearance of all muscles, vessels and other structures around or passing over the carpal joint region. Our study provides comprehensive details of all the structures including bones, joints, tendons, muscles, ligaments and vessels which have not been explored yet using ultrasonography. Clinical examination and arthrocentesis are the diagnostic tools for infectious arthritis in animal practice. In contrast, fibrinous arthritis cannot always be diagnosed by arthrocentesis (NUSS, 2000). Centesis is painful as a needle is inserted in the centre of a joint and many animals require mild sedation as well during this procedure. Centesis is a tool for information of cells but it does not give any information about the involvement of the adjacent tissues by inflammation. KOFLER and MARTINEK (2004) found sonography as useful tool for evaluating the extent of inflammation, the consistency of the inflammatory content in synovial cavities, and the involvement of adjacent tissues by inflammation. Similarly, KOFLER and EDINGER (2002) described that sonography has the advantage of allowing the identification of the synovial content, particularly if centesis does not provide results because the content is no longer liquid but consists of high viscous
purulent exudates masses of clotted fibrin or necrotic tissue. INTAS et al. (2005) declared that sonography provided significant information for diagnosis of soft tissue inflammation in bovine limbs, capsule thickness and masses in inflamed bursae, which were important factors in deciding treatment but could not be detected clinically as well as by diagnostic centesis. The same findings were made when other cavities in cattle, like bursae, abscesses or haematomas were examined (NEUBERTH et al., 1990). KING (2006) pointed out, that ultrasonography is non invasive and well tolerated in unsedated animals. He also described ultrasound-guided needle placement or arthrocentesis of joints. Similarly many non-infectious or mechanical conditions affect the carpal region of sheep like fractures (NELSON, 1983) and sometime fractures lead to contamination of joints and bony structures as well which cause septic arthritis (LAURA et al., 2002). In such cases palpation and radiographs provide less information as radiographs provide bony changes in later stages but sonography is useful for early detection of arthritis and osteomyelitis. RUTTEN (2007) described an outstanding use of ultrasound that it was effective in healing of fresh fracture of radius and tibia as well as in human patients. Likewise REEF et al. (2004) declared that ultrasonographic examination is more sensitive than radiography for the detection of the early bony changes associated with degenerative joint disease. FIKRET et al. (2005) showed that radiography proved to be least modalities among other diagnostic techniques like magnetic resonant imaging (MRI) and ultrasound for osteomyelitis. Many authors pointed out that ultrasonography is useful for the extent and the character of fluid accumulation, soft tissue swellings, differentiation of edema, haemorrhage, synovial fluid, purulent exudates and coagulated fibrin masses like carpal hygroma (KOFLER and MARTINEK, 2004). Keeping in view all these circumstances, we selected ultrasonography in our research as its applications are widespread as diagnostic tool. Diagnostic ultrasound therefore enables serial examinations to monitor the progression of the condition, response to the treatment and to practice scanning techniques (KOFLER and EDINGER, 2002; NYLAND and MATTOON, 2002). The carpal region is unique where tendons can be imaged from a single position (GENOVESE et al., 1986; TNIBAR et al., 1993; KOFLER, 2000; KOFLER and EDINGER, 2002). In the present study, a 7.5 MHz transducer allowed better resolution of all the examined anatomical structures, similar to that in horses (TNIBAR et al., 1993), sheep (MACRAE and SCOTT, 1999), cattle (KOFLER, 2000) and the camel (KASSAB, 2007). The problems encountered in ovine
arthrosonography are the generation of intense echoes in the most superficial zone of the near field due to transducer reverberations. In order to avoid this problem, a stand-off pad was placed to the area of interest for complete contact to the superficial structures. The use of a stand-off pad is also recommended for the ultrasonography of the normal bovine carpus, as it permits adaptation of the rigid transducer to the contours of the carpus. However in the diseased joints with severely thickened joint capsules and synovial membranes, the stand-off pad can be discarded (KOFLER, 1996a, b, 1997). The bone surfaces of the radius, the carpal and metacarpal bones were imaged as smooth, linear hyperechoic contours showing acoustic shadowing distally. The carpal joint spaces were well distinguished from dorsal, lateral, medial and palmar. The joint spaces appeared as clearly defined interruptions of the bone surfaces with a funnel-shaped contour. The joint spaces of the antebrachiocarpal joint (abc), the mediocarpal joint (mc) and the carpometacarpal joint (cmc) could also be imaged simultaneously due to small size of the anatomical structures. The results are in agreement with (KOFLER, 2000). MACRAE and SCOTT (1999) only visualized the antebrachiocarpal joint dorsally and midcarpal and carpometacarpal joints were only visualized after distension. In the present study, the joints were examined from all four sides. The studies of KASSAB (2007) and TNIBAR et al. (1993) did not explain all carpal joints in camel and horses through ultrasonography. The longitudinal sonograms provided a better overview for the carpal joint spaces and pouches in dorsal, lateral, palmar and medial directions. It also enabled imaging of two joint spaces together on one sonogram. The joint spaces on the dorsal and palmar aspect of the carpus appeared as clearly defined funnel shaped interruptions of bone surfaces. The dorsal joint pouches were not depictable, only at the level of joint spaces were very small, triangular, anechoic areas seen. However, the palmer pouches could be partly imaged only at the level of the mediocarpal and carpometacarpal joint as small anechoic fluid filled areas but with difficulty as the area of contact between the skin and transducer is narrow in sheep. The trapezoid of caudal antebrachiocarpal joint pouch was not visualized due to overlapping of the accessory carpal bone in sheep. Our results are in agreement with KOFLER (2000) as we were able to image the small and narrow palmar joint pouches. The capsular fat pad had a heterogeneous echogenic appearance and was confluent with the articular bone surface dorsally. The capsule/connective tissue interface was difficult to identify. The study of KOFLER (2000) and TNIBAR et al. (1993) showed the same results. Similarly the joint spaces
were also more prominent at the level of the antebrachio-carpal joint. At the palmar side, longitudinal sonograms without the use of stand-off pad provided a better overview. Synovial fluid and the joint capsule were not consistently identified in living healthy sheep. Except after distension of the joint with 3-8 ml of water in cadaver specimen the joint pouches could be identified. This poor identification is due to the lack of fluid accumulation and the very thin joint capsule in most normal ovine joints. These findings are in agreement with previous ultrasonographic studies of the joints of the horse (Pennick et al., 1990; Dik, 1990), the dog (Reed et al., 1995), sheep (Macrae and Scott, 1999) and cattle (Kofler and Edinger, 2002). An important finding in this study was the fact that carpal joint pouches and tendon sheath lumina are not clearly defined in healthy sheep. Thus the ability to image these structures indicates the presence of synovial effusion. These findings were similar to those in ultrasonographic examination of carpal region in healthy cattle (Flury, 1996; Kofler, 2000; Kofler and Edinger, 2002), the stifle region (Kofler, 1999), the bovine shoulder Martinek et al. (2007) and the hip joint region and bony pelvis in cattle (Grubelnik et al., 2002). After experimental filling of the joint spaces in cadaver specimen, the carpal joint pouches were identified as well-defined anechoic areas. Other authors (Dik, 1990; TniBar et al., 1993; Mettenleiter, 1995) found similar results for digital, carpal and tarsal joints and adjoining tendon sheaths in healthy horses. Since the injection introduced small air bubbles with the water, a number of small echogenic foci showing artifacts were often visible within the anechoic fluid. Injection of water caused distension of the dorsal, lateral, palmar and medial pouches of the antebrachio-carpal joint and as well communicating mediocarpal and carpometacarpal joints and displacement of the joint capsule from the articular surface. An oedema of extensor carpi radialis tendon and medial collateral ligament was also noticed. Experimental filling of the carpal joint pouches in cadavers is intended to imitate the presence of effusion and allow the most clinically important synovial structures to be imaged and evaluated. These are similar findings to Kofler (2000). Distension and clear visualization of joint pouches and tendon sheaths have been described in clinical arthritis and tenosynovitis in animals and man (Chhem et al., 1994; Craychee, 1995; Mettenleiter, 1995; Kofler, 1996a, b, 1997). The carpal tendons and ligaments have a homogenous echogenic texture. Similar findings were reported in the camel by Kassab (2007), tendons in cattle by Flury (1996) and Kofler (2000), for tendons in horses by
TNIBAR et al. (1993) and METTENLEITER (1995) as well as in sheep by MACRAE and SCOTT (1999). The lumina of the tendon sheaths of the extensor carpi obliquis tendon, lateral digital extensor tendon, extensor carpi ulnaris tendon, superficial and deep digital flexor tendon, and the flexor carpi radialis tendons could not be visualized, neither the tendon sheath wall be differentiated ultrasonographically from the tendon. In only five cases was a very narrow anechoic rim depicted around the extensor carpi radialis and common digital extensor tendon. The lumina of other tendon sheaths could not be imaged. The carpal extensor and flexor tendons, comprising the extensor carpi radialis tendon, common digital extensor tendon, lateral digital extensor tendon and superficial and deep digital flexor tendon were imaged in all the sheep and specimen, from the muscle-tendon transition, across the carpus to their insertion in or distal to the carpal region. Most of the extensor and flexor tendons in sheep are clear and can be easily imaged over the distal radius, the carpus and proximal metacarpus. Neither the lumen of the precarpal subcutaneous bursa not the wall of the bursa could be differentiated from the surrounding structure in any case. The contact between the transducer and the skin was difficult in some areas due to the joint flexion and the small size of ovine joints relative to the transducer. The thickened subcutaneous tissue on the dorsal aspect of carpus in sheep that spent increased time in sternal recumbency could be mistaken for joint swelling on clinical examination, but was readily differentiated ultrasonographically due to its superficial position above the extensor tendons overlying the carpal joints. This superficial thickening did not affect ultrasound wave penetration and good quality imaging of underlying structures was obtained in sheep. The study of KOFLER (2000) was in contrast in which roughening and thickening of the skin over the dorsal aspect of the carpus hindered imaging of the underlying structures, such as the extensor carpi radialis tendon and the joint spaces. The largest and most medially located structure is the extensor carpi radialis tendon. The tendon was depicted as echogenic structure showing strong linear pattern of parallel fibre bundles in longitudinal planes. The extensor carpi radialis tendon, the echogenic tendinous part with central anechoic muscular parts extended further distally. The results were in agreement with KOFLER (2000) and TNIBAR et al. (1993). In both imaging planes, the extensor carpi obliquis muscle and tendon could not be distinguished as it crosses the extensor carpi radialis muscle proximal to the antebrachio-carpal joint due to its smaller size in sheep. Even KASSAB (2007) found it difficult because of its small size in camel as well but it was
possible to distinguish it in his study. The common digital extensor tendon is located lateral to the extensor carpi radialis tendon and was imaged 2 cm proximal to the antebrachio-carpal joint with cranial and caudal branches of the tendons. The transverse planes were more useful because these extensor tendons were side by side for much of their length and could not be readily distinguished by longitudinal images. The study of KOFLER (2000) in cattle and KASSAB (2007) also supported our results. Owing to the small size in sheep the cranial and caudal branches of common digital extensor tendon require some practice to be scanned, but their visualization was possible. The lateral digital extensor tendon and the lateral collateral ligaments were harder to differentiate due to their similar echogenicity and smaller size in sheep in the transverse plane. KASSAB (2007), KOFLER (2000) and TNIBAR et al. (1993) visualized the lateral digital extensor tendon as a low echogenic elliptical structure with poorly defined border distal to the carpus in the transverse direction. In our study, we visualized the tendon more clearly in the longitudinal direction at the lateral carpal joint where it passes over the ulnar and 4th carpal bone laterally as echogenic tendinous structure. In the transverse direction it was visualized at the level of the antebrachio-carpal joint laterally over the ulnar bone as small elliptical echogenic structure. The main branch of the extensor carpi ulnaris tendon inserts, together with the flexor carpi ulnaris tendon at the accessory carpal bone as a thick and flat echogenic tendon in longitudinal direction. The study of KASSAB (2007) supported our results. It was not possible to differentiate between the long and short tendons of the extensor carpi ulnaris muscle in our study due to smaller sizes in sheep. A thorough knowledge of anatomy and simultaneous palpation of these tendinous structures during scanning facilitates their identification on sonograms. On the transverse images, the tendons of the extensor carpi ulnaris and flexor carpi ulnaris muscles showed a typical ultrasonographic appearance with narrowing echogenic septae surrounding the anechoic muscle component. Our results were confirmed to the observations of KOFLER (2000). During our study we were also able to identify the typical muscular component of the extensor carpi ulnaris muscle by placing the transducer 6cm proximal to the carpus at a caudo-lateral position. The muscle belly of the extensor carpi ulnaris muscle was more prominent than the flexor carpi ulnaris muscle due to the position and overlapping of the flexor carpi ulnaris muscle with the superficial digital flexor muscle. It may help in localizing abnormalities of muscles during injuries. KASSAB (2007), KOFLER (2000),
MACRAE and SCOTT (1999) and TNIBAR et al. (1993) had not described typical muscle images in their study. The medial collateral ligament was depicted as a large, highly echogenic band in longitudinal plane. The findings were similar to KOFLER (2000) and KASSAB (2007). The contour of the lateral collateral ligament was difficult to differentiate from the adjoining structures such as the lateral digital extensor tendon and the surrounding connective tissues. Similar findings were noticed in cattle by KOFLER (2000) and KASSAB (2007). The muscular components of the superficial digital flexor and deep digital flexor were seen in longitudinal planes at the radius caudally. The muscular components of the superficial digital flexor and deep digital flexor muscles appeared as hypoechoic patterned by echogenic septa, resulting in a featherlike and tendinous appearance in longitudinal planes respectively. In transverse direction, superficial and deep heads of the hypoechoic superficial digital flexor muscles were separated by echogenic septae and the pictures of the transverse scan compared with anatomical slices gave the similar picture of the specific area. Similarly the muscular components were seen to reach the level of carpometacarpal joint and tendon appeared heterogeneous. In the longitudinal plane at the antebrachio-carpal joint lateral to the accessory carpal bone, the tendons of the superficial digital flexor and the deep digital flexor muscle were identified running across to the accessory carpal bone. The superficial and deep digital flexor tendons have a similar echogenicity although the deep digital flexor tendon is sometime more echogenic and it was the same in our results. This is in agreement with that observed in horses (CUESTA et al., 1995) and camel (KASSAB, 2007). The tendons of these muscles were also identified in the transverse direction. The transverse scan 2 cm proximal to the caudal antebrachio-carpal joint was also taken and few hypoechoic bodies with echogenic septae were identified. They were marked as tendons of flexor muscles according to anatomical situation. The flexor retinaculum which divides the superficial and deep part of the superficial digital flexor tendon could not be visualized in our study due to the similar echogenicity of the structures and the very smaller size in sheep. The results are in contrast to KOFLER (2000). In transverse medial section of the limb the extensor and flexor retinaculum were identified. The flexor carpi radialis tendon was not identified in our study in contrast to KASSAB (2007) where it was identified from the palmar aspect in the carpal region. KOFLER (2000) described it as difficult to distinguish from the adjacent echogenic masses representing connective tissue. In my opinion, the area of contact between the
transducer and caudal carpus is really small in sheep so it is not easy to capture many structures together and therefore the separate view of flexor carpi radialis tendon was not possible. The muscular part appeared medially 6 cm proximal to the carpus as triangular hypoechoic area. The muscular component was not defined in the studies of KOFLER (2000) and KASSAB (2007) as well. The median artery and vein were more deeply located side by side closer to the accessory carpal bone. The median artery was identified as anechoic tubular structure adjacent to the superficial digital flexor tendon in longitudinal plane and pulsation could be felt in artery. The adjoining parts of the superficial digital flexor tendon also composed of anechoic muscular tissue, the deep vessels were difficult to define in all sheep in our study. The largest vessel was the radial vein running subcutaneously on the palmaro-medial aspect, accompanied by the smaller radial artery. They appeared as oval to round anechoic small structures and veins could be identified by pulsation. The results were in accordance to KOFLER (2000). The nerves were impossible to visualize and results are in accordance to KOFLER (2000) and KASSAB (2007). In conclusion, the results of this study indicate that ultrasonography will be most useful as a complementary technique for examining the muscles, tendons and ligaments and to some extent bones of the carpal region in sheep. Differentiation of joints, muscles, tendons, ligaments and vessels is possible through ultrasonography. Easily identified anatomical landmarks provide a useful aid for the examination of these tendons. The gross anatomy and frozen anatomical slices correlated well with the ultrasonographic images. A similar ultrasonographic appearance was noted in cadaver specimen and live sheep. I recommend the longitudinal plane for joints and tendons examination. The transverse plane is suitable for orientation in order to examine muscles. Based on our findings in normal sheep, ultrasonography appears to be very helpful to characterize lesions in sheep with carpal soft tissue abnormalities. Fortunately, the most clinically significant structure of examined areas, the extensor carpi radialis and the common digital extensor tendon, were the most easily visualized structures. Further investigation should focus on the clinical usefulness of ultrasonography for the diagnosis and prognosis of specific carpal soft tissue injuries. This research will be of great significance for the sheep owner who has kept expensive sheep for exhibition and Ram Rental Services.
5. SUMMARY

Sheep are of great economic importance all over the world. Live sheep profit can be obtained by presenting them in shows and exhibition. Provision of Ram Rental Services is also significant and in practice by farm owners. Sheep may suffer from varying orthopaedic lesions affecting carpal structures. Soft tissues, tendons, muscles, ligaments and bony structures can be affected by traumatic injuries, infectious agents and degenerative diseases as well. The carpal area comprises various tendons and their corresponding tendon sheaths as well as ligaments, which surround the joint pouches and bony structures that form the three joint levels. The carpal joint is a compound synovial joint. The carpal joint includes the antebrachiocarpal (ABC), mediocarpal (MC), carpometacarpal (CMC) levels and also a distal radioulnar joint. Ultrasonography has become a multipurpose diagnostic tool for visualizing soft tissue changes in humans and also in veterinary musculoskeletal disorders. Many scientists have already described the sonoanatomic appearance of the carpal joints and the carpal region in different animals such as cattle, horses, camels and dogs. Yet none of them has investigated the ultrasonographic appearance under physiological conditions in sheep. The purpose of the thesis is to describe the normal ultrasonographic appearance of the anatomical structures of the carpal joint area in healthy sheep in order to establish reference data for the diagnosis of orthopedic disorders of this region. In this study ten cadaver forelimb specimens were used, six were dissected for the study of the carpal anatomy. In two experimental filling of the joints was performed to imitate effusion and the remaining were frozen and 1 cm anatomical slices were prepared and compared to ultrasonographic images to show correspondence. Afterwards twelve live sheep with a mean age of five years and a mean weight of 80 kg were selected. All sheep were clinically sound. The left and the right carpal regions of these sheep were studied ultrasonographically. The sheep were examined in lateral recumbency on a surgical table, none of the animals had to be sedated. For the examination a SonoAce PICO unit with a 7.5 MHz linear probe was used. In the present study the differentiation of the antebrachiocarpal, mediocarpal and carpometacarpal joints was possible in all animals. These joints appeared as funnel shaped interruptions of the hyperechoic bone surfaces, the joint spaces were anechoic. The tendons of the extensor carpi radialis muscle, lateral digital extensor muscle, superficial digital flexor and deep digital flexor muscle appeared as strong
linear pattern of fiber bundles. The lumina of the tendon sheaths could not be visualized except a very narrow anechoic rim, which was depicted surrounding the tendon of the extensor carpi radialis muscle in three animals. Also the lumen of precarpal subcutaneous bursa was not seen. The extensor carpi radialis, lateral digital extensor, common digital extensor, extensor carpi ulnaris, flexor carpi ulnaris, superficial and deep digital flexor and flexor carpi radialis muscles were also identified due to their typical sonoimage and differentiation between muscles was possible due to their anatomical position.

The medial collateral ligament could be differentiated as large highly echogenic band in the longitudinal direction. The lateral collateral ligament could not be detected. The radial artery and vein and the median artery and vein were depicted as anechoic tubular structures surrounded by an echogenic wall in transverse planes and as anechoic band like structures in longitudinal planes. The nerves could not be visualized and differentiated through the sonographic examination from the surrounding soft tissues. All tendons were best visualized in longitudinal direction while muscles in transverse direction.

The presented results indicate that ultrasonography will be most useful as technique for the detection of lesions of muscular structures, tendons, ligaments and also for the detection of superficial bony lesions. A very important finding of this thesis was that the lumina of the tendon sheaths cannot be seen under physiological conditions and therefore an increased filling is pathological.

Ultrasonography is a minimal invasive procedure and should be used together with other diagnostic modalities like radiography and laboratory diagnosis.

Key words: ultrasonography, 7.5 MHz linear probe, sheep carpal region, extensor carpi radialis muscle
6. Zusammenfassung


Die Darstellung des Lig. collaterale laterale war dagegen nicht möglich. Die V. und A. radialis und die Hauptmittelfußarterie waren als mehr oder weniger runde anechoische Strukturen, umgeben von einer echogenen Wand, in transversaler Richtung sichtbar. In longitudinaler Schallrichtung hatten sie ein bandförmiges Erscheinungsbild.

Ein wichtiges Ergebnis der vorliegenden Arbeit ist die Tatsache, dass Sehnenscheiden bei gesunden Tieren nicht darstellbar sind. Auch die Ausweitung der Gelenkrezessus kann als pathologisch interpretiert werden.


Schlagwörter: Sonographie, 7,5 MHz Linearschallkopf, Schaf, Karpalgelenksregion, M. extensor carpi radialis.
7. REFERENCES


