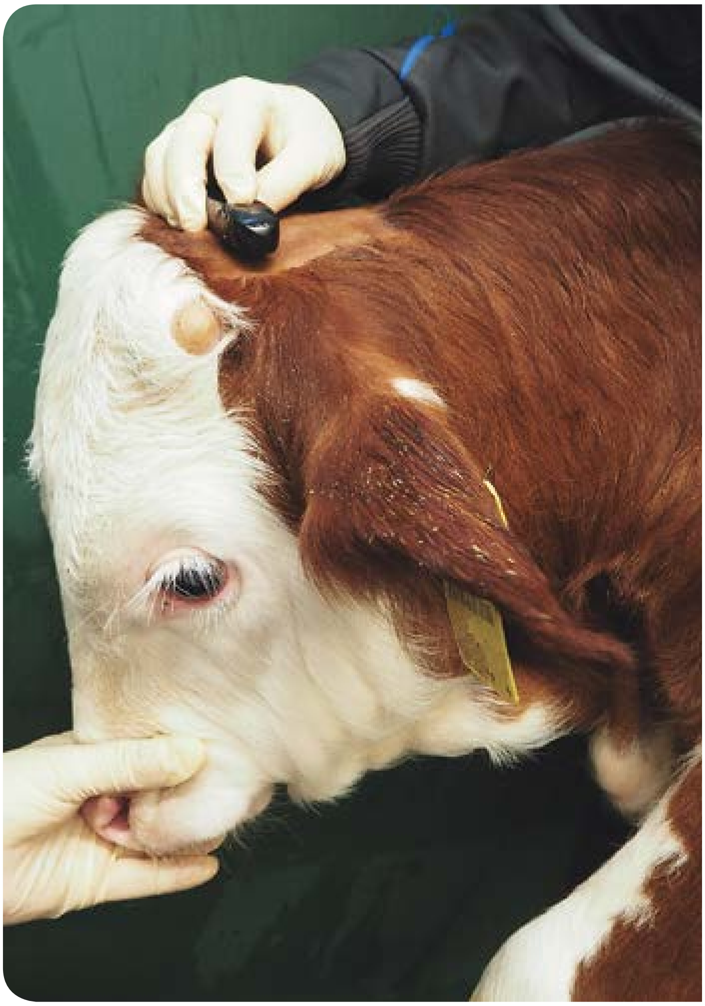
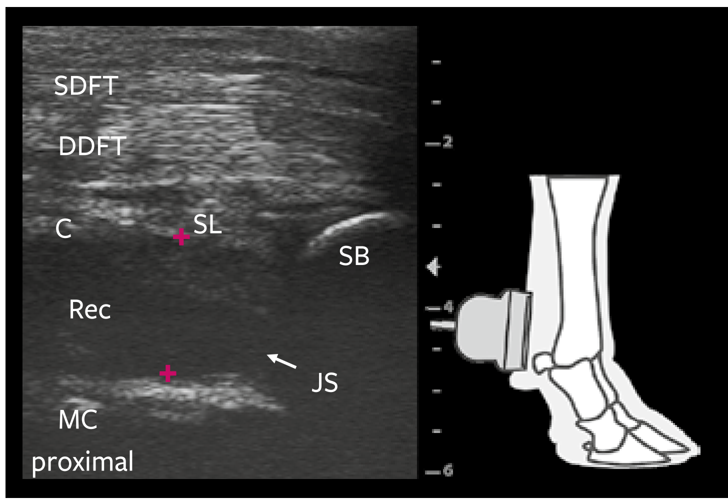
Johann Kofler (ed.)

Ultrasonography of the Bovine Musculoskeletal System

Indications, Examination protocols, Findings





VET PRACTICE

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Johann Kofler (ed.)

Ultrasonography of the Bovine Musculoskeletal System

"Dedicated to my mentors
and all my enthusiastic teachers"

Johann Kofler (ed.)

Ultrasonography of the Bovine Musculoskeletal System

Indications, Examination protocols, Findings

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454 Figures and 5 Tables

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Preface

Ultrasonographic examination of the bovine musculoskeletal system was described in the mid-nineties for the first time and has become today a routinely applied ancillary diagnostic imaging technique in many veterinary teaching hospitals worldwide.

The goal of this textbook is to demonstrate to all cattle veterinarians the large variety of indications for ultrasonographic examination in bovine patients with musculoskeletal disorders. In particular, we want to provide detailed guidance on how the region of interest can be scanned correctly, which type and frequency of probes are adequate, to present the normal ultrasonographic appearance and to illustrate the most common pathological conditions.

We are required to make decisions during each clinical/orthopedic examination. However, clinical/orthopedic findings alone are often not sufficient to reach a diagnosis in bovine orthopedic patients. The additional use of diagnostic ultrasound may enable the clinician to state a definitive diagnosis, and to make a well-founded decision regarding prognosis and treatment. This includes the targeted administration of antimicrobial agents.

"Ultrasonography is the continuation of the clinical examination with other tools": This statement was made in 1976 by the medical internist G. Rettenmaier, and still today I believe it precisely describes the paramount value of diagnostic ultrasound for the clinician in daily practice. It can be applied independently of location and time. Similar to the clinical exam, which follows a given examination schedule, the accurate ultrasonographic examination adheres to a standardized protocol, where the sonographer scans all the structures located in the region of interest in a certain sequence, in order to not overlook lesions, masses, or incriminated structures, which may not be clinically apparent.

Furthermore, the ultrasound probe is employed by the sonographer much like the fingers of his/her own hand during a clinical exam: The sonographer uses the probe for so-called sonopalpation, to classify the content of synovial cavities or other swellings as liquid, semi-solid, or solid effusions, to differentiate limb arteries and veins, and to diagnose thrombus formation.

The advantage of uniting the clinician and sonographer is that this person is fully familiar with the anatomic site in question as well as the clinical findings. Diagnostic ultrasound is a safe and non-invasive procedure for the patient, the sonographer and nearby personnel. Moreover, it is well suited for serial examinations to monitor the progression of the condition and response to treatment.

This is the first textbook on bovine musculoskeletal ultrasound composed by international experts that covers all parts of the bovine musculoskeletal system that can be involved in patients presented with lameness. The chapters in this textbook focus on specific joint regions of the limbs (e.g. fetlock, carpal, tarsal and other joint regions). These correspond to common experience with bovine orthopedic patients, where mainly one limb region is affected, but also occasionally where there is more than one defined limb region involved (most frequently in calves).

Each chapter is structured in the same manner: After a brief introduction, important indications for the ultrasonographic examination of individual regions are listed, followed by a brief anatomical overview, the presentation of anatomical landmarks and standard ultrasonographic views for the region of interest. This is followed by a detailed description of the ultrasonographic examination method for the particular region, and the normal ultrasonographic appearance of the most important anatomical structures. Finally, the ultrasonographic findings of the most common pathological conditions of the particular region are presented. Many sonograms illustrating normal appearances and the ultrasonographic findings of the most frequent disorders complete each chapter.

Additionally, there is an introductory chapter explaining the most important principles of diagnostic ultrasound, and the most common artifacts encountered during ultrasonographic examination. This textbook also contains a chapter on ultrasonographic imaging and measurement of the thickness of sole horn and the sole's soft tissue layer, which is an important research topic today. This is completed by a chapter on the ultrasonographic measurement of the back fat thickness.

Besides the description of the ultrasonographic inspection of all (joint) regions of the limbs, additional chapters focus on the general ultrasonographic evaluation of synovial cavities, tendons and ligaments, muscles, vessels, large peripheral nerves and the spinal cord. These structures are important for the physiological function of the bovine musculoskeletal system. Maybe surprising for ultrasound newcomers, one chapter focuses on the ultrasonographic examination of bone surfaces and imaging of numerous associated bone alterations. The textbook is completed by a chapter on ultrasound-guided centesis of synovial cavities, ultrasound-guided fine-needle aspiration and biopsy collection.

I want to sincerely thank all the internationally recognized experts and authors for their contributions to this textbook, enabling a unique and comprehensive overview of all the indications and possible applications of diagnostic ultrasound in bovine orthopedic patients.

The authors of this textbook would like to encourage all cattle veterinarians in clinics and, in particular, in bovine practice, to improve their ultrasonographic regional skills of the bovine musculoskeletal system. We want to inspire bovine practitioners to use their already available ultrasound units and probes already used for bovine reproduction to improve diagnosis of bovine musculoskeletal disorders.

My proposed slogan for enthusiastic colleagues all over the world engaged in cattle (and of course with other species) health management is: *Diagnostic ultrasound is the best friend of the clinician, it is available everywhere and at any time,* and it is well suited to support immediate decision making in clinics and on-farm settings.

When a thorough clinical/orthopedic examination does not lead to a final diagnosis, *always ask your best friend*. When you visit an orthopedic bovine patient, follow the slogan *"yes, we scan"*!

Vienna, February 2021
Johann Kofler

Acknowledgements

I wish to thank Cameron R. McCulloch, PhD, University of Veterinary Medicine Vienna, for reading the text and providing language assistance.

I would like to acknowledge Mrs. Anna E. Vogl (Mödling, Austria); she designed all the illustrations that are attached to all sonograms demonstrating the exact placement of the probe to achieve the presented ultrasonographic image.

1 Principles of ultrasonographic imaging of the bovine musculoskeletal system

Sébastien Buczinski, Isabelle Masseau

1.1 Introduction

Ultrasonography is an imaging technique based on the reflection and refraction of acoustic waves as they are transmitted through the tissues (Kirberger 1995). In veterinary medicine, it was initially applied to the diagnosis of pregnancy, to assess reproductive organs prior to insemination or in an attempt to determine causes of failure to induce pregnancy in cattle. Its affordable cost and ease of use have contributed to its popularity and explain that today many veterinary practitioners are equipped with an ultrasound machine dedicated to cattle reproduction management programs (King 2006, DesCôteaux et al. 2009, Fricke et al. 2016).

In parallel with the development and sophistication of ultrasonographic examinations in the field of reproduction, a number of clinical conditions have emerged for which ultrasonography has been evaluated for its potential aid as a complementary imaging diagnostic tool. Over time, numerous research studies and growing expertise have resulted in diversification of ultrasound use in cattle leading to the recognition of its diagnostic utility for various indications, including examinations of musculoskeletal structures in cases of lameness, joint instability or penetrating wounds, among others (Flückiger 1997, Buczinski 2009a, Kofler 2009, Braun and Attiger 2016, Re et al. 2016b).

Ultrasonographic evaluation of musculoskeletal structures is facilitated by the superficial location of a majority of them. Consequently, **most rectal probes (transducers) employed today for ultrasonography of the reproductive system can also be utilized for the evaluation of musculoskeletal structures.** Since most practitioners are already equipped with ultrasound units, they do not have to pay additional costs for acquisition of new probes. Another important advantage of ultrasonography is its portability, allowing for musculoskeletal examinations to be performed directly on the farm (Ollivett and Buczinski 2016).

Like any other diagnostic imaging tool, it is important to understand the physical principles responsible for generating ultrasound images and commonly encountered artifacts (Kirberger 1995, Blond and Buczinski 2009). Understanding how artifacts occur can help their avoidance whenever possible or to use them advantageously to document the nature of the tissues from which they originate (e.g. gas in an abscess, osteophytes, dystrophic mineralization within a tendon, etc.). A few parameter settings that optimize image quality will also be briefly discussed. Therefore, the aim of this introductory chapter is to provide the reader with a brief overview of these important topics.

1.2 Physics and acoustic principles

Ultrasound consists of high frequency vibrations generated by the crystals within a probe. When subjected to an electric field, the crystals inside the probe become excited, which triggers a movement or vibration, generating the emission of the ultrasound wave. This phenomenon is based on the inverse piezo-electric effect of certain materials. The speed at which transmitted ultrasound waves are propagated through a structure of interest varies according to the type of medium.

> The **speed of ultrasound waves through soft tissues is generally constant at approximately 1,540 m/s** (Blond and Buczinski 2009).
>
> A wave can be **transmitted** through a medium, as well as **reflected, refracted and attenuated**. Other types of effects such as **diffraction, polarization, dispersion and interference** can also occur.

The interference effect mentioned above is of particular interest for ultrasound examinations that are performed in the proximity of other wave-generating materials or electronic devices, such as ventilation fans in a barn (Kirberger 1995, Blond and Buczinski 2009, Hindi et al. 2013).

A transducer (probe) emits ultrasound waves for only a very small fraction of the time (< 0.1 %). The remaining time (99.9 %) is devoted to reception of ultrasound echoes

1

reflected back to the probe from tissues. This returning signal will then be converted electronically to form an ultrasound image (sonogram). As a general concept, the time interval between the emission of ultrasound waves and their return as echoes is used to estimate the depth of a specific structure. Information derived from returning echoes and their depth estimation is converted into different shades of white/grey pixels over a black background, generating an image that can be displayed on an ultrasound monitor.

Tissues commonly encountered during ultrasonography of the musculoskeletal system include articular components (capsule, synovial cavities, articular cartilage, menisci), tendons, muscles, ligaments and bones. Although most of these tissues are considered to comprise "soft tissues", with the exception of bones, they have slightly different acoustic properties that will in turn influence the speed of propagation of ultrasound waves and the behavior of these waves as they travel through different types of media. ▶Fig. 1-1 summarizes the basic principles of ultrasound propagation within a tissue consisting of two different media (ex: muscle/tendon interface).

1.2.1 Specular reflection

Specular reflection is defined as the mechanism by which ultrasound waves, after encountering a smooth surface, return back to the probe in one direction (Hindi et al. 2013). Indeed, when the incidence of the ultrasound beam strikes a surface with an angle other than perpendicular, the waves can then be reflected with a similar angle (α), but in an opposite direction (▶Fig. 1-2). The probe would, in turn, not receive any echoes and therefore, no image would be obtained. When a reflected wave actually reaches the probe, then the image of this point will be falsely represented due to the angles of reflection. Reflection only occurs when ultrasound waves reach an interface between two tissues with different acoustic characteristics (or impedance [Z]). Each tissue is characterized by a unique impedance measured in Rayl (for Dr. Rayleigh) equivalent to a unit in $kg/(s \times m^2)$ (Bushberg et al. 2012). ▶Tab. 1-1 summarizes the impedance of musculoskeletal tissues of interest examined with ultrasound (Sanches et al. 2012).

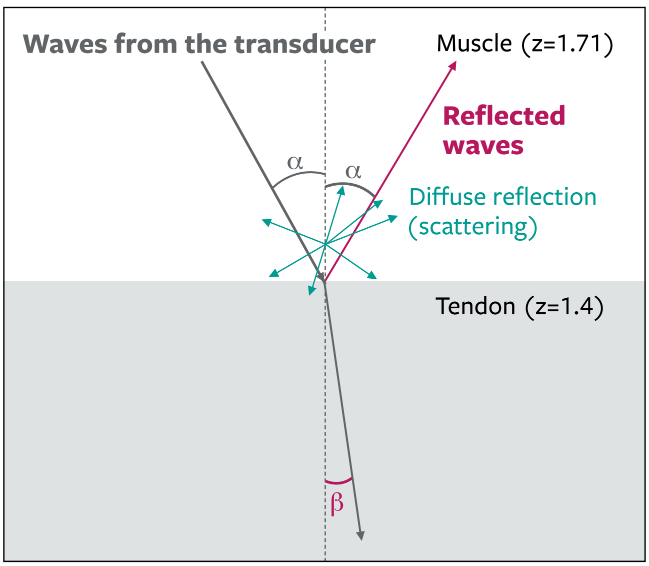

Fig. 1-1: Schematic image of ultrasound propagation characteristics: When a probe is applied over an interface between two tissues of different acoustic impedances, such as a muscle-tendon interface, the ultrasound waves emitted by the transducer strike the interface at an angle alpha (**α**). Since the impedance difference (**z**) between these two media is very small, a portion of the emitted ultrasound waves is reflected back to the probe at the same angle as the incident angle. A significant part of the waves is transmitted within the tendon at a refraction angle beta (**β**). Scattering generally occurs when ultrasound waves strike a diffuse reflector such as blood cells or an irregular organ surface.

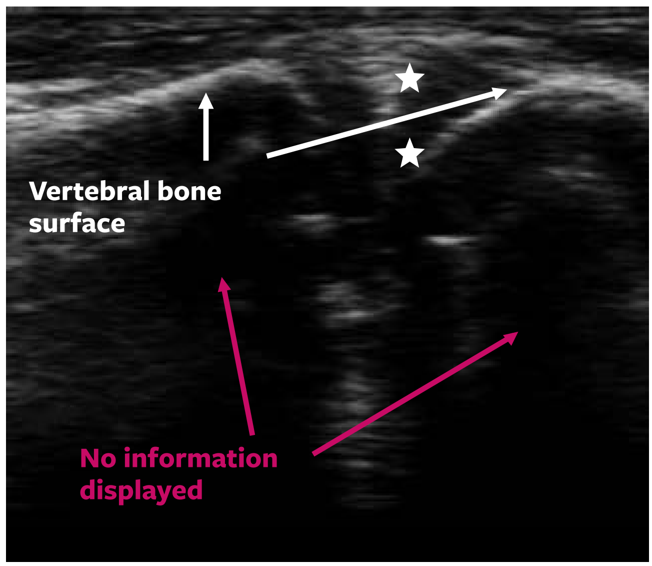

Fig. 1-2: Specular reflection associated with the bone/soft tissue interface: Transrectal sonogram of the lumbosacral joint of an adult Holstein cow with schematic interpretation. The ventral borders of both vertebrae are represented by the hyperechoic lines (**white arrows**). When ultrasound waves strike the soft tissue/bone interface, the high difference in impedance between the two tissues results in their reflection back to the probe. Consequently, there is no information from the deeper parts of the vertebrae and no image can be obtained distal to the vertebral hyperechoic borders. The intervertebral disc space and joint are illustrated (**white stars**).

Tab. 1-1 Impedance of tissues encountered in musculoskeletal ultrasound

Tissue	Impedance* (×10⁶ Rayl)
air	0.0004
fat	1.34
blood	1.65
muscle	1.71
cartilage	1.84
tendon	1.4
bone	7.8

* The impedance values have been reproduced from human references (Sanches et al. 2012).

1.2.2 Diffuse reflection (scattering)

In contrast to specular reflection, diffuse reflection (scattering) occurs when ultrasound waves strike irregular or "rough" surfaces, allowing low amplitude reflection in multiple directions. This type of reflection also leads to attenuation of the ultrasound waves that are transmitted deeper into the tissues.

1.2.3 Attenuation

Attenuation of ultrasound waves, with reflection and refraction, constitutes an important component of image generation in ultrasonography. It is defined as a decrease in the amplitude of the ultrasound beam as it travels through a medium. Attenuation is influenced by absorption of wave energy by the tissue, and therefore varies according to the nature of the tissue. Since attenuation is positively correlated with frequency, high frequency probes will generate higher attenuation and hence permit a lesser maximal depth of examination than low frequency probes. Further, for the same frequency, ultrasound attenuation is lower for liquids (e.g. blood, synovial fluid) than for muscles or other soft tissues (Duck 2002). Attenuation is greater when produced by bones and fibrotic tissue.

The frequency of ultrasound waves emitted by the probe has an important impact on the image quality and its penetration (▶ Fig. 1-3a, b). High quality diagnostic images have high spatial resolution, which facilitates the ability to distinguish two structures located next to each other as two individual structures.

As a general rule, high frequency acoustic waves are associated with higher resolution, but they are attenuated more rapidly than low frequency waves. Therefore, depth of imaging is greater with low frequency probes, but it comes at the expense of lower resolution (Bushberg et al. 2012).

1.2.4 Axial, lateral and elevational resolution

Resolution is a general term associated with any optical device. The resolution is defined as the minimal distance between two reflectors allowing for a distinct echo to be returned back to the probe. **The resolution is grossly related**

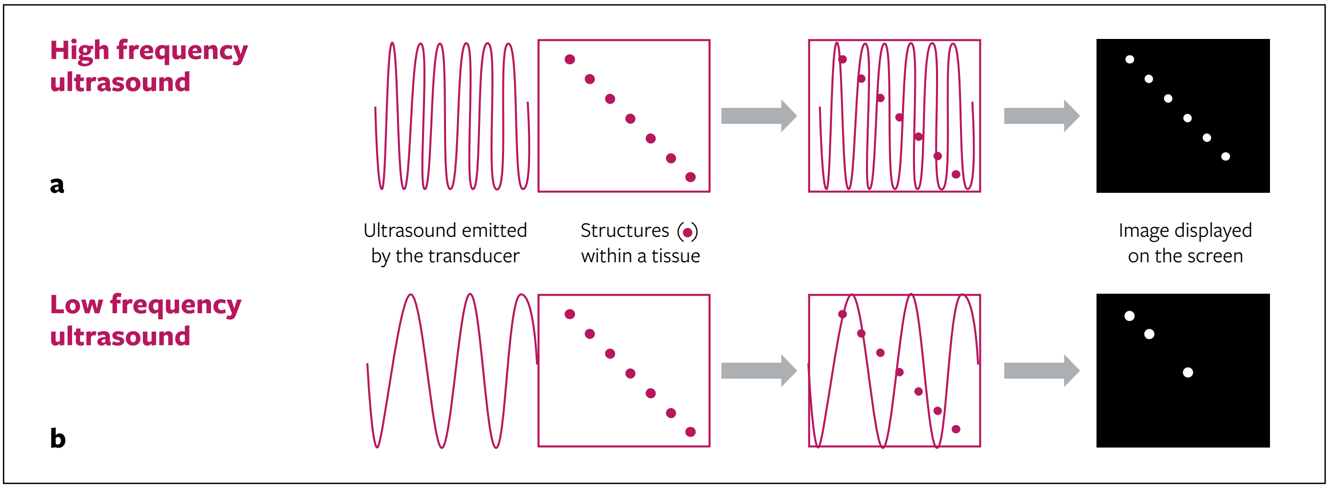

Fig. 1-3a, b: Image quality on using high *versus* low frequency probes: This figure schematically illustrates the main difference between the capacities of ultrasound waves to discriminate several small structures individually according to their frequencies. The high frequency pulse (**a**) is able to hit more distinct structures than a low frequency pulse. Consequently, a more detailed image is obtained. In contrast, a low frequency pulse (**b**) gives a less detailed image, but allows higher wave penetration.

3 Ultrasonographic examination of the distal and proximal interphalangeal joint regions

Maike Heppelmann, Alexander Starke, Johann Kofler

3.1 Introduction

Disorders involving the synovial structures of the distal digit are a common cause of lameness in dairy and beef cattle. Septic arthritis is the most common disease involving the distal (DIJ) and proximal interphalangeal joints (PIJ) (Köstlin and Nuss 1988, Pejsa et al. 1993, Kofler 1995a, Dirksen 2006, Kofler et al. 2007a, Starke et al. 2007a, Burgstaller and Kofler 2016). However, there is evidently a much higher prevalence for infections of the DIJ (Desrochers et al. 1995, Heppelmann et al. 2009a, b, Chamorro et al. 2019). In a study conducted at a Veterinary teaching hospital in cattle with orthopaedic disorders, the ten-year incidence of PIJ infection was 2.4 % and that of DIJ infection was 22.8 % (Kofler 1995a). Similarly, of 85 cattle that required claw amputation because of infection, the DIJ was affected in 32 cases, whereas only six cases involved the PIJ (Pejsa et al. 1993).

The incidences of DIJ and PIJ infection vary because of a difference in the pathogenesis of the disease at each location. Infection of the DIJ usually results from complicated claw disorders, such as sole ulcer, white line disease and interdigital phlegmon, which spread to deeper structures of the claw. Most of these cases are characterised by a communicating tract between the primary claw lesion and the DIJ, whereas septic DIJ infections resulting from penetrating injuries or hematogenous spread of infection are less common (Köstlin and Nuss 1988, Kofler et al. 2007a, Heppelmann et al. 2009a, b, Chamorro et al. 2019).

Septic arthritis of the PIJ usually results from penetrating wounds at the level of the joint pouches or from ascending interdigital phlegmon, or in rare instances it may be acquired by hematogenous spread (Kofler 1995a, Burgstaller and Kofler 2016, Nuss et al. 2019a). Septic arthritis of the PIJ is often accompanied by infection of other synovial structures of the digit, such as the DIJ and/or the close adjoining digital flexor tendon sheath (Hund et al. 2020). One potential source of infection results from communication between the PIJ and the digital flexor tendon sheath, which may exist rarely in some cattle (Peters 1965). In fact, of eleven cattle with septic arthritis of the PIJ, the infection was limited to this joint in only six cases (Kofler 1995a).

The main differential diagnoses of infection of the DIJ and PIJ include infection of close adjoining synovial structures, such as the digital flexor tendon sheath (▶ Chap. 11), the fetlock joint (▶ Chap. 4) and phalangeal fractures. Epiphysitis and osteitis of the phalanges, interphalangeal joint arthrosis (older cows and breeding bulls) and subluxation and distortion are less common (Fischerleitner and Stanek 1987, Kofler 1995a, Nuss et al. 2018, Nuss et al. 2019a, b, Hund et al. 2020).

3.2 Indications for ultrasonographic examination

Ultrasonographic examination of the DIJ/PIJ regions is indicated in cattle with diffuse swelling of the digit when differentiation of the affected structures is not possible by clinical examination alone and/or when there is suspected involvement of multiple synovial structures, including the DIJ and PIJ, one or both digital flexor tendon sheaths or the fetlock joint. An ultrasonographic diagnosis reduces or eliminates the need for arthrocentesis, which carries the risk of joint infection, particularly when the needle is passed through infected tissue. When indicated, arthrocentesis should be performed after ultrasonographic examination because the latter allows for preliminary assessment of the accurate location of liquid joint effusion. This is of practical importance in cases in which arthrocentesis is not successful, for instance in fibrinous arthritis. In addition, arthrocentesis often results in pneumarthrosis, which can severely impede subsequent ultrasonographic examination (Kofler 2009). Most importantly, ultrasonography allows for safe and targeted (indirect) ultrasound-guided arthrocentesis (Heppelmann et al. 2009a, Starke et al. 2009, Kofler et al. 2014).

3.3 Anatomy

The DIJ is a saddle joint that primarily accommodates extension and flexion. The joint is formed by the distal articular surface of the middle phalanx (P2), the articular surface of the distal phalanx (P3) and the articular surface of the distal sesamoid bone. Its dorsal pouch extends proximally along P2 to approximately 2 cm above the coronet near the dorsal pouch of the PIJ and is superimposed by the common digital extensor tendon. At the palmar/plantar aspect, the pouch of the DIJ extends along P2 to just below the flexor tuberosity of P2 and is bounded on the palmar/plantar aspect by the deep digital flexor tendon sheath (▶Fig. 3-1) (Stanek 1987, Dyce et al. 2002, Nickel et al. 2004a, König and Liebich 2014, Maierl et al. 2019).

The PIJ is also a saddle joint, which is formed by the distal articular surface of the proximal phalanx (P1) and the proximal articular surface of P2 and allows predominantly flexion and extension of the joint. Dorsally the joint pouch extends 2–3 cm proximally, and distally it extends mostly axially along P2 to the region of the pouch of the DIJ. The pouch is superimposed dorsally by the two digital extensor tendons. Abaxially, the pouch of the PIJ extends proximally above the middle of P1 where it is bordered by the digital flexor tendon sheath (▶Chap. 11). The palmar/plantar pouch of the PIJ is located dorsally of the digital flexor tendon sheath and extends proximally one third of the length of P1 (▶Fig. 3-1) (Stanek 1987, Dyce et al. 2002, Nickel et al. 2004a, König and Liebich 2014, Maierl et al. 2019). In rare cases, there is communication between the PIJ and the digital flexor tendon sheath of the pelvic limbs (Peters 1965).

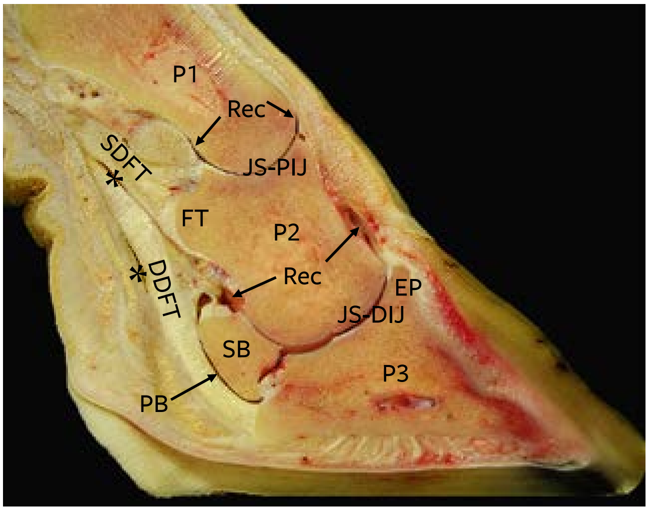

Fig. 3-1: Sagittal anatomical section of a normal hind digit of a cow showing all the relevant structures: the joint space of the distal (**JS-DIJ**) and the proximal interphalangeal joint (**JS-PIJ**), the dorsal and plantar joint pouches (**Rec**) of DIJ and PIJ; proximal phalanx (**P1**), middle phalanx (**P2**), distal phalanx (**P3**), extensor process (**EP**) of P3, distal sesamoid bone (**SB**), podotrochlear bursa (**PB**), superficial digital flexor tendon (**SDFT**) with its insertion at the flexor tuberosity (**FT**) of P2, deep digital flexor tendon (**DDFT**), and small normal lumen of the digital flexor tendon sheath (*).

3.4 Ultrasonographic examination procedure and anatomical landmarks

Ultrasonographic examination of the DIJ and PIJ regions can be carried out in standing cattle. However, it is highly recommended that the examination is performed in a restrained animal in a chute with the limb securely lifted or on the restraint animal in lateral recumbency on a tilt table. For personal safety reasons and to protect the ultrasound equipment from damage, the limb to be examined should always be secured. Sedation of the animal may be required. The region of interest is clipped or shaved, and the skin is cleaned with water. Then liberal amounts of acoustic coupling gel are applied to the skin and the probe.

Linear probes with a frequency of 7.5 to 12 MHz are suitable for imaging the dorsal, lateral and palmar/plantar aspects of **the DIJ and PIJ regions** because in most cases the structures of interest are located within 1–5 cm of the skin surface (Heppelmann et al. 2009a, Kofler 2009, Kofler 2011, Gonçalves et al. 2014, Kofler et al. 2014, Chapuis et al. 2020).

The **standard examination plane of choice for imaging the DIJ and the PIJ** is the longitudinal plane with the probe placed on the dorsal and palmar/plantar aspects of the digit proximal to the coronary band. Imaging of the structures from the palmar/plantar aspect in the longitudinal plane is sometimes difficult, in particular in adult cattle, because of folding of the skin between the dew claws and the bulbs of the heel and the frequent occurrence of swelling in the heel region, which makes good contact between the (too long) linear probe and the skin nearly impossible (Heppelmann et al. 2009a, Kofler 2009, Kofler et al. 2014).

ANATOMICAL LANDMARKS

The anatomical landmarks for ultrasonographic examination of the PIJ and DIJ are:

- the joint space of the PIJ between the proximal and middle phalanx,
- the joint space of the DIJ between the middle and distal phalanx,
- the bone surfaces of the proximal and middle phalanx, the extensor process of the distal phalanx and the distal sesamoid bone,
- the flexor and extensor tendons.

The following structures of the PIJ and DIJ regions should be evaluated ultrasonographically (Kofler and Edinger 1995, Tryon and Clark 1999, Heppelmann et al. 2009a, Kofler 2009, Kofler 2011, Gonçalves et al. 2014, Kofler et al. 2014):

1. **joint space, joint capsule and dorsal and palmar/plantar joint pouch of the PIJ** using the longitudinal plane over the dorsal and palmar/plantar aspect of the PIJ;
2. **joint capsule and dorsal and palmar/plantar joint pouch of the DIJ** using the longitudinal plane: the dorsal and palmar/plantar aspects, proximal to the coronary band;
3. **the maximum dorsopalmar/-plantar dimension of the dorsal joint pouch** of the DIJ and the PIJ using the longitudinal plane for diagnosis of septic arthritis;
4. **bone surfaces** of the phalangeal bones (P1, P2, P3) and the distal sesamoid bone: echogenicity and characteristics of the bone surfaces using the longitudinal (and transverse) planes on the dorsal and palmar/plantar aspects;
5. superficial and deep digital flexor **tendons** and common and lateral digital extensor tendons with their **tendon sheaths**: the dorsal and palmar/plantar aspects in transverse and longitudinal planes (▶ Chap. 11).

3.5 Normal ultrasonographic appearance of the anatomical structures

The normal ultrasonographic appearance of the anatomical structures of the bovine musculoskeletal system is listed in ▶ Tab. 2-1 (▶ Chap. 2). In the longitudinal plane, the dorsal bone surfaces of P1 and P2 appear as slightly curved, smooth and hyperechoic lines. The joint space of the PIJ appears as a small anechoic interruption of the bone contour similar to a stylized seagull (▶ Fig. 3-2a–c) (Kofler and Edinger 1995, Tryon and Clark 1999, Heppelmann et al. 2009a, Gonçalves et al. 2014). The joint space of the normal DIJ could be visualised only rarely in adult cows because it is located within the horn capsule (Kofler and Edinger 1995, Heppelmann et al. 2009a), but has been imaged in healthy six-month-old Girolando calves together with the proximal part of P3, the extensor process (Gonçalves et al. 2014). The distal sesamoid bone is imaged at the palmar/plantar aspect as a slightly convex, smooth and hyperechoic contour close to the skin surface (▶ Fig. 3-2a–c).

The joint capsules of the PIJ and DIJ appear as thin echoic structures immediately adjacent to the joint surface (Gonçalves et al. 2014). The normal dorsal and palmar/plantar pouch of the PIJ cannot be visualised (▶ Fig. 3-2a–c) (Kofler and Edinger 1995). In the longitudinal plane, the dorsal pouch of the DIJ appears as an elongated, semicircular structure that runs proximally along the dorsal aspect of P2 (▶ Fig. 3-2a–c). In healthy adult cows, the maximum dorsopalmar/-plantar dimension of the dorsal joint pouch of the DIJ is 4.1 mm (± 0.7). The normal dorsal joint pouch of the DIJ appears as a small anechoic area. The echogenicity of the normal dorsal joint pouch of the DIJ may be sometimes higher (hypoechoic or echoic) so that it does not differ from that of a septic joint (Heppelmann et al. 2009a). This phenomenon is based on a noise artifact caused by the proximity of the structures to the probe (Kirberger 1995), and has to be kept in mind to avoid misinterpretation. Provided that there is optimal contact between the probe and the skin between the dew claws and coronary band, the palmar/plantar pouch of the DIJ can be visualised dorsal of the deep digital flexor tendon as a semicircular area that appears hypoechoic relative to the surrounding tissues (▶ Fig. 3-2a–c).

The common and lateral digital extensor tendons appear as echoic bundles of parallel fibres located directly under the skin (Gonçalves et al. 2014). Provided there is optimal contact between the probe and skin between the dew claws and coronary band, the superficial and deep digital flexor tendons, surrounded by the distal compartment of the digital flexor tendon sheath, can be visualised in the longitudinal (▶ Fig. 3-2b, c) and transverse planes (▶ Chap. 11).

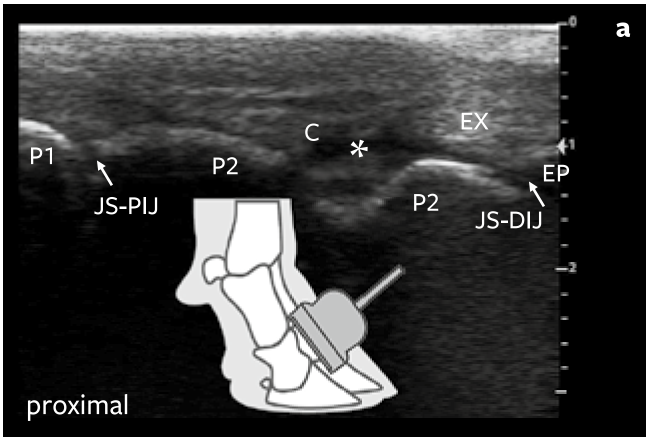

Fig. 3-2a: Longitudinal sonogram (5.0 MHz linear) of the dorsal aspect of a healthy bovine digit of a six-month-old Simmental heifer showing the joint spaces of distal (**JS-DIJ**) and proximal interphalangeal joints (**JS-PIJ**); the normal small dorsal pouch of the PIJ cannot be differentiated, the normal small dorsal pouch of the DIJ is indicated by a small anechoic area (*), joint capsule (**C**); smooth hyperechoic dorsal contour of proximal (**P1**) and middle phalanx (**P2**); extensor tendon (**EX**) inserting at the extensor process (**EP**) of the distal phalanx.

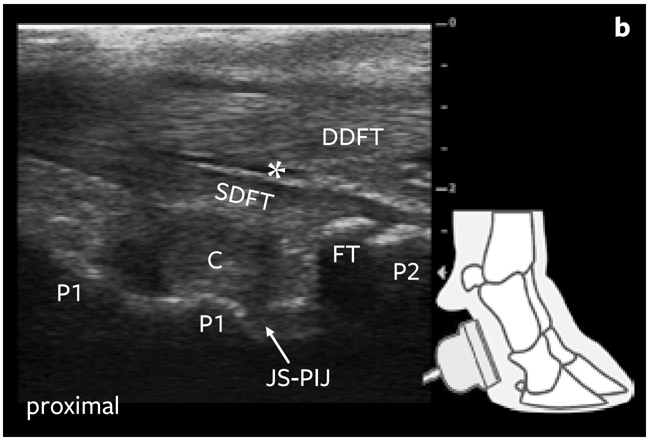

Fig. 3-2b: Longitudinal sonogram (5.0 MHz linear) of the plantar aspect of a healthy bovine digit of the same heifer showing the smooth hyperechoic plantar contour of P1 and P2, the joint space (**JS-PIJ**) in-between, deep digital flexor tendon (**DDFT**), superficial digital flexor tendon (**SDFT**) with its insertion at the flexor tuberosity (**FT**) of P2. The small anechoic area (*) indicates the normal amount of synovial fluid in the digital flexor tendon sheath; the plantar joint capsule (**C**) and the plantar joint pouch cannot be differentiated.

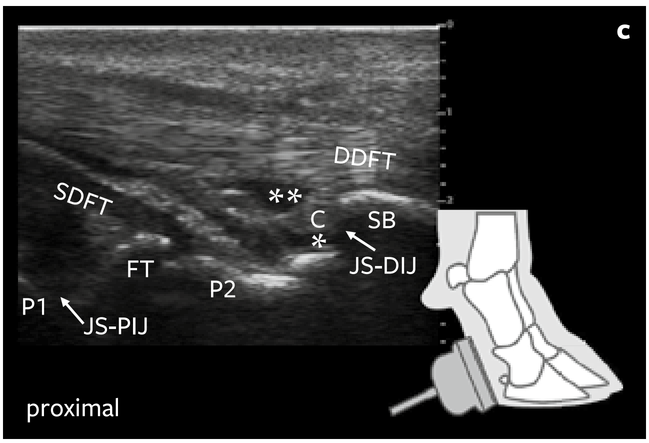

Fig. 3-2c: Longitudinal sonogram (5.0 MHz linear) of the distal plantar aspect of a healthy bovine digit of the same heifer showing the smooth hyperechoic plantar contour of P1 and P2, the distal sesamoid bone (**SB**), both joint spaces (**JS-PIJ, JS-DIJ**), the deep digital flexor tendon (**DDFT**), superficial digital flexor tendon (**SDFT**) with its insertion at the flexor tuberosity (**FT**) of P2. The small anechoic area (*) indicates the normal amount of synovial fluid in the DIJ and the joint capsule (**C**) of DIJ. The small anechoic area indicates the normal amount of synovial fluid in the proximal part of the podotrochlear bursa (**).

3.6 Sonopathological findings

Common ultrasonographic findings in cases of septic (rarely aseptic) arthritis of the DIJ and the PIJ and septic osteitis and osteomyelitis of the joint-forming bones have been described (Kofler 1995a, Heppelmann et al. 2009a, Kofler 2009, Kofler 2011, Kofler et al. 2014, Burgstaller and Kofler 2016, Nuss et al. 2019b).

3.6.1 Arthritis of the DIJ

Septic arthritis of the DIJ is always associated with distension (▶Fig. 3-3 to 3-6) of the dorsal (and palmar/plantar) joint pouch (Kofler and Edinger 1995, Kofler et al. 2007a, Starke et al. 2007a, Heppelmann et al. 2009a, Nuss et al. 2019b). Ultrasonographic examination of the dorsal joint pouch is the diagnostic method of choice because folding of the skin between the dew claws and the bulbs of the heel and/or moderate to severe swelling of the heel bulbs have been shown to impair visualisation of the palmar/plantar joint pouch of the DIJ in 54 % of cattle with septic arthritis (Heppelmann et al. 2009a). The maximum dorsopalmar/-plantar dimension of the dorsal joint pouch was measured in the longitudinal plane approximately 1 cm axial to the midline of the digit (▶Fig. 3-3 to 3-6). At this location the sensitivity and specificity of a measurement greater than the threshold value of 6 mm for the diagnosis of septic arthritis of the DIJ exceeds 0.95 in adult cows. The echogenicity of the effusion of the dorsal pouch of the DIJ has low specificity and sensitivity for the diagnosis of septic arthritis, partly because hypoechoic joint fluid seen in septic arthritis may also be observed in a normal DIJ. Hemarthrosis should be included in the differential diagnosis when the joint fluid is homogenously hypoechoic (Heppelmann et al. 2009a).

Inducible flow phenomena were visualised in 30 % of DIJs with septic arthritis (Heppelmann et al. 2009a). This variable had a high specificity (1.0) for diagnosis of septic arthritis of the DIJ because flow phenomena could not be induced in normal DIJs. However, the sensitivity of this variable was low at 0.3.

Based on the specific aetiology, a communication channel between the joint pouch and a sole defect (sole ulcer, white line lesion) is common in cases of septic arthritis of the DIJ. Interestingly, this does not seem to have a significant effect on the dorsopalmar/-plantar dimension of the dorsal joint pouch and thus on the ultrasonographic visibility of joint effusion (Heppelmann et al. 2009a).

Arthrocentesis of the dorsal pouch of the DIJ is performed approximately 1 cm proximal to the coronet, axially or abaxially to the common digital extensor tendon in a slightly distal direction (Desrochers et al. 2001, Nuss et al. 2002a, Heppelmann et al. 2009a, Kofler 2018).

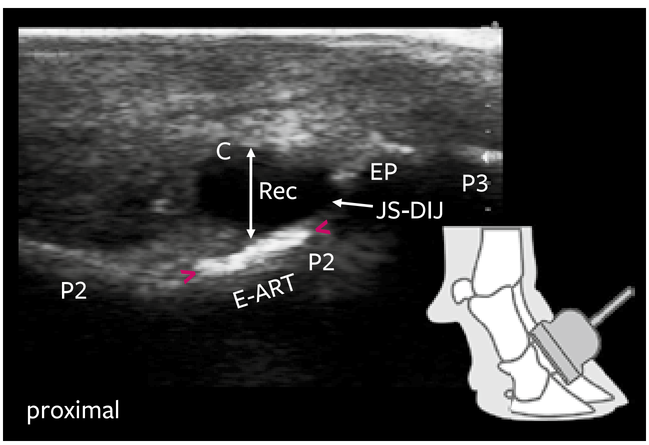

Fig. 3-3: Longitudinal sonogram (5.0 MHz linear) of the dorsal aspect of the distal digital region of a 3.5-year-old Simmental cow with septic serous arthritis of the DIJ resulting from a white line abscess; the **white arrow** demarcates the dorsoplantar width (approximately 6.6 mm) of the distended dorsal pouch (**Rec**) showing an anechoic effusion; therefore an enhancement artifact (**E-ART**) can be seen directly distally (**between the pink arrows**), depicting this particular part of the smooth dorsal bone contour of the middle phalanx (**P2**) much more hyperechoic as the same bone contour more proximally; the joint capsule (**C**), the joint space of the DIJ (**JS-DIJ**) and the extensor process (**EP**) of distal phalanx (**P3**).

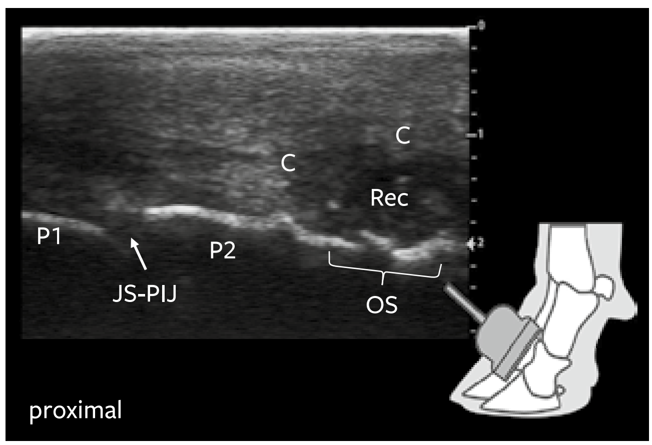

Fig. 3-4: Longitudinal sonogram (5.0 MHz linear) of the dorsal aspect of the distal digital region of a 3.5-year-old Aberdeen Angus cow with purulent arthritis of the DIJ and bone infection resulting from an interdigital phlegmon. The distended dorsal pouch (**Rec**) shows a heterogeneous effusion, joint capsule (**C**), smooth hyperechoic dorsal contour of the proximal phalanx (**P1**) and of the proximal contour of the middle phalanx (**P2**), joint space of PIJ (**JS-PIJ**); the irregular and rough distal contour of P2 indicates osteolysis (**OS, bracket**).

7 Ultrasonographic examination of the shoulder region

Birgit Altenbrunner-Martinek, Karl Nuss, Alexander Starke, Johann Kofler

7.1 Introduction

Disorders of the bovine shoulder and scapular region have been rarely reported in cattle, and are usually unilateral and only affect individual animals (Buergelt et al. 1996). Septic or aseptic arthritis of the shoulder joint may be difficult to diagnose exclusively by clinical examination (Desrochers et al. 2001, Nuss 2003, Desrochers and Francoz 2014, Kofler et al. 2018). Scapulohumeral arthritis, bursitis of the infraspinous and the bicipital bursae, fractures of the scapula and scapulohumeral luxation are responsible for most shoulder lameness (Tulleners et al. 1985, Ferguson 1997, Nuss 2000, Dirksen 2006). All of these disorders are clinically characterized by swing-phase lameness, a localized or diffuse swelling of the shoulder region and a painful response to palpation. Direct evaluation of the joint pouch by palpation is not possible due to its location some centimeters under the skin surface (Desrochers et al. 2001, Kofler et al. 2018).

Over the last few years, ultrasonography has been widely used for diagnosis of joint, tendon, ligament and muscle disorders in cattle, but also for diagnosing bone lesions such as fractures, luxation, fissures, bone sequestration and osteomyelitis involving the growth plates (Nuss 2000, Kofler 1996a, Kofler 1997a, Nuss et al. 2007, Starke et al. 2008, Nuss et al. 2018). In particular, in cattle, where diagnostic imaging of the shoulder joint with other modalities such as radiography, computed tomography or magnetic resonance imaging is usually not practical, ultrasonography should be used as the standard examination tool in clinics and practice (Nuss 2003, Kofler 2009, Kofler et al. 2014, Altenbrunner-Martinek et al. 2017, Nuss et al. 2018).

7.2 Indications for ultrasonographic examination

Ultrasonographic examination of the shoulder is always indicated for differentiation of any soft tissue swelling located in this region (Nuss 2003, Nuss et al. 2007, Kofler 2009, Kofler 2011, Kofler et al. 2014, Altenbrunner-Martinek et al. 2017). Clinically evident swelling of the shoulder region, combined with localized pain and lameness as leading symptoms, can be seen in cases with septic or aseptic arthritis, bursitis of the infraspinous bursa and/or the bursa underlying the biceps tendon respectively, periarticular abscesses and hematomas, lesions of the lateral shoulder muscles – that serve as collateral ligaments in this area – and other muscles located in this region or bone lesions including osteomyelitis of the growth plates of the distal scapula, the greater tubercle and the humeral head, articular subchondral bone infection, fractures of the scapula or the proximal aspects of the humerus and luxation of the scapulohumeral joint (Ferguson 1997, Dirksen 2006, Nuss et al. 2007, Kofler et al. 2016, Altenbrunner-Martinek et al. 2017).

7.3 Anatomy

The shoulder joint is composed of the junction of the distal end of the scapula (glenoid cavity) with the proximal end of the humerus. The large tendons of the infraspinous and supraspinous muscles laterally, the subscapularis muscle medially and the biceps brachii muscle cranial of the shoulder joint region serve as functional "collateral" ligaments in the absence of proper collateral ligaments. The bicipital (intertubercular) bursa lies between the humeral tubercles cushioning the bicipital tendon (▶Fig. 7-1a, b). The supraspinous muscle is covered by the trapezius, omotransverse muscle and brachiocephalicus muscles. The supraspinous muscle originates from the supraspinous fossa and inserts with a larger branch at the greater tubercle and with a smaller branch at the minor tubercle of the humerus. These two branches have a predominantly tendinous character.

The infraspinous muscle originates at the scapular spine and the infraspinous fossa of the scapula, crosses the shoulder joint space laterally and inserts with a deeper located muscular branch on the lateral aspect of the greater tubercle. The superficial tendinous part crosses the proximal rim of the greater tubercle and the subtendinous infraspinous bursa as a firm and flat tendon and inserts on the lateral part of

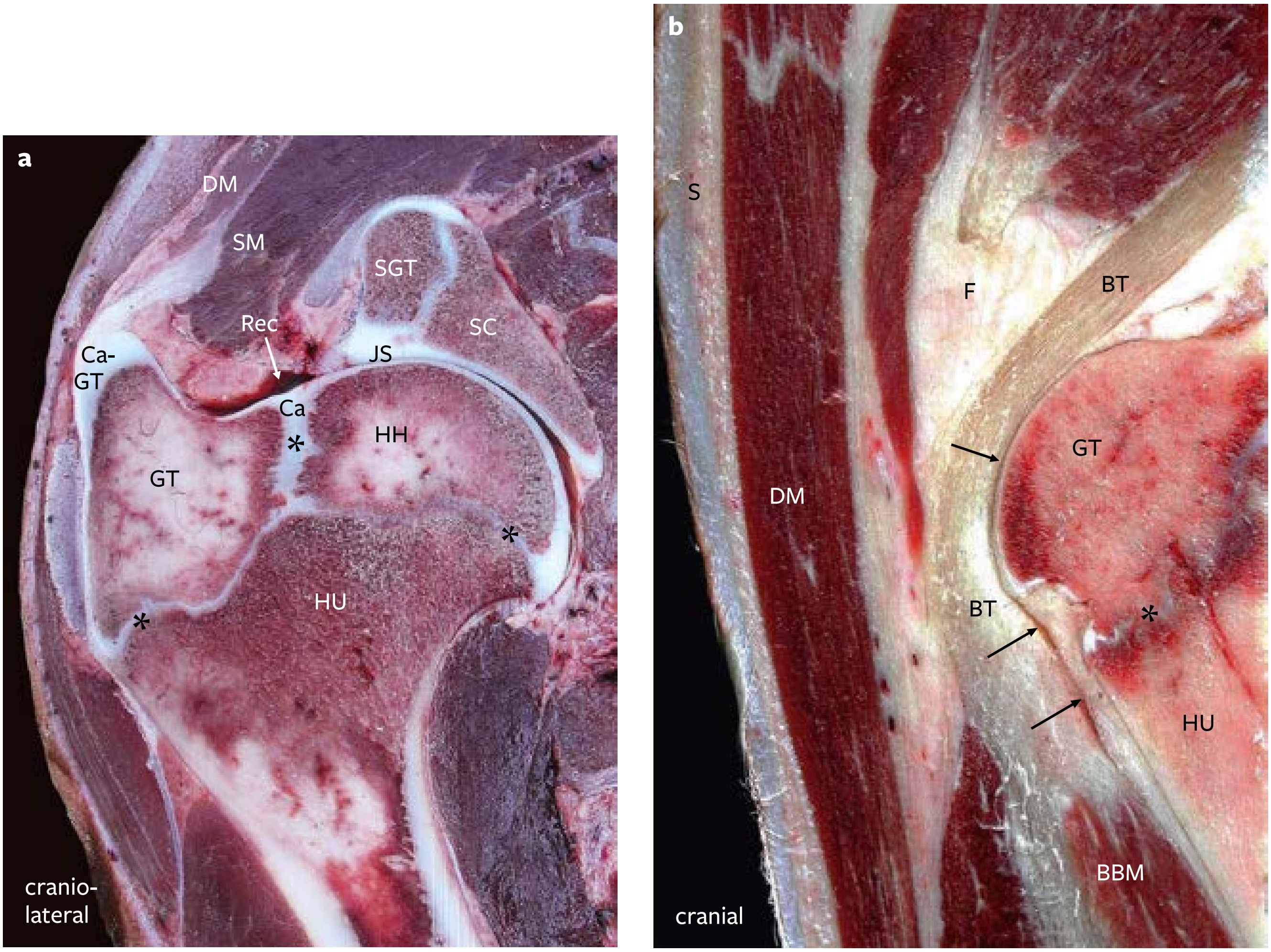

Fig. 7-1a, b: Longitudinal anatomical section (transected in a craniolateral-caudomedial plane) (**a**) of the shoulder joint region of a five-month-old calf showing some important anatomical structures of the scapulohumeral joint: the greater tubercle (**GT**) of the humerus, humeral head (**HH**), humerus (**HU**), cartilaginous growth plate (*) between the greater tubercle and humerus and the humeral head respectively, the joint space (**JS**), scapula (**SC**), glenoid tubercle of the scapula (**SGT**), normal joint pouch (**Rec**), cartilage (**Ca-GT**) covering the greater tubercle, articular cartilage (**Ca**), supraspinous muscle (**SM**) and the deltoid muscle (**DM**).

Longitudinal anatomical section of the shoulder joint region of a six-month-old calf (**b**) showing the course of the bicipital tendon running over the greater tubercle (**GT**); the bicipital tendon (**BT**), lumen of the bicipital bursa (**black arrows**), biceps brachii muscle (**BBM**), deltoid muscle (**DM**), fatty tissue (**F**), cartilaginous growth plate (*) between greater tubercle and humerus (**HU**) and skin (**S**).