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Examination of the navicular region of the horse by using magnetic resonance imaging (Methodical study)

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ABSTRACT

Over the past ten years, noninvasive imaging techniques used in human medicine have shown extremely rapid progress in terms of increased resolving power and improved visualisation. Magnetic resonance imaging (MRI) is a technique which, unlike computed tomography (CT), enables accurate visualisation of soft tissues in addition to bones. Therefore, MRI facilitates are used for early recognition and accurate localisation of pathological changes developing in soft tissue structures constituting the navicular region in the horse. By the use of different MRI modalities (spin echo, gradient echo and inversion recovery sequences) the anatomical structures of the navicular region (navicular bone, impar ligament, navicular bursa, deep digital flexor tendon) are excellently visualised. On T1 weighted images the tissues characterised by rapid T1 relaxation (spongy substance of bone, pars torica pulvinis digitalis, synovia, corium) show high signal intensity, while T2 weighted sequences facilitate detailed evaluations of the fluid spaces and the study of pathological processes causing small changes in water content. Owing to the above characteristics, MRI enables accurate evaluation of the soft tissue structures of the navicular region on the basis of signal intensity differences specific of the individual tissue types. Its routine use in the everyday practice would thus result in more accurate differential diagnosis of diseases affecting that anatomical region, helping equine practitioners select the appropriate therapeutic procedures and monitor their success.
(Keywords: magnetic resonance imaging, horse, podotrochlosis, computed tomography, hoof)

ÖSSZEFOGLALÁS

A patahengert alkotó anatómiai képletek ábrázolási lehetőségei mágneses rezonancián /MR/ alapuló képalkotó eljárással (Metodikai közlemény)

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A humán orvosi non-invazív képalkotó diagnosztika az elmúlt tíz évben rohamos fejlődést mutatott a felbontóképesség növekedése és a megjelenítés terén. Az MR képalkotás – amely a CT-vel szemben nemcsak a csontszövetet, hanem a lágyszöveti részeket is pontosan mutatja – lehetővé teszi a patahengert alkotó lágyszöveti struktúrákban kialakuló kóros elváltozások korai felismerését, illetve azok pontos *lokalizációját. Különböző MRI mérési metodikák (spin-echo, gradiens-echo és inversion-recovery szekvenciák) alkalmazásával a patahengert alkotó anatómiai képletek (nyírcsont, ligamentum-impar, bursa podotrochlearis, mély ujjhajlító ín) kiválóan ábrázolódnak. A T1 súlyozott szekvenciával készült felvételeken magas jelintenzitást mutatnak a gyors T1 relaxációval jellemezhető szövetek (csont spongiosa állománya, pars torica pulvinis digitalis, synovia, corium), T2 súlyozott szekvenciával pedig a folyadékterek részletes vizsgálata lehetséges, illetve a kis víztartalom-változást okozó kóros folyamatok jól vizsgálhatók. Ezért az MRI képalkotó diagnosztikai eljárás a patahenger lágyszöveti struktúráinak pontos megítélését teszi lehetővé az egyes szövettípusokra specifikus jelintenzitás eltérés alapján, így mindennapos, rutin gyakorlati elterjedése esetén az anatómiai régió sokkal pontosabb differenciál diagnosztikáját eredményezné, ezzel elősegítve a terápiás eljárás kiválasztását és annak nyomonkövetését.*

(Kulcsszavak: mágneses rezonanciás képalkotás, ló, podotrochlosis, computer tomográfia, pata)

INTRODUCTION

Podotrochlosis (navicular syndrome) is a chronic, progressive disorder of horses (especially sports horses), characterised by pathological changes developing in the navicular bone, its ligaments, the deep digital flexor tendon and the navicular bursa (*Wright and Douglas*, 1993). Of the diagnostic imaging techniques, conventional radiography and ultrasonography have been used for the study of anatomical structures responsible for locomotion. Despite its known limitations, summation radiography provides good visualisation of the bony structures. Because of the anatomical structure of the equine foot, it is difficult to study soft tissue structures associated with the osseous substance by ultrasonography (*Hauser et al.,* 1982; *Hauser,* 1986). 3D computed tomographic (CT) studies enable more accurate evaluation of osseous changes than does conventional radiography (*Peterson and Bowman*, 1988; *Poulos and Smith*, 1988; *Tietje*, 1995). Magnetic resonance (MR) based 3D cross-sectional imaging is the most accurate noninvasive method for the examination of joints and soft tissues, and that method is extensively used in human medicine for the diagnosis of pathological changes developing in locomotor structures (*Moon et al*., 1983; *Berquis*t, 1984). With the different MR imaging techniques the bones, the hyaline cartilage and the soft tissues can be distinguished accurately and their contrast conditions can be optimised. The objective of this work was to identify the anatomical structures constituting the navicular region by magnetic resonance imaging (MRI) and to select the optimal and most rapid measuring sequences.

MATERIALS AND METHODS

The right hind-digit of a 14-year-old gelding that had died of 180° torsion of the ascending colon was studied. The foot was frozen at –18°C temperature, defrosted at room temperature for 36 hours and then subjected to MRI studies in the Institute of Diagnostic Imaging and Radiation Oncology, University of Kaposvár. The MRI was performed using a Siemens Magnetom Vision Plus (1.5 T) scanner and the sample was measured in a CP-Helmholtz circular coil. The technical parameters of the MR scanner are presented in *Table 1*. Spin echo, gradient echo and inversion recovery sequences were used in sagittal, transversal and coronal planes defined in relation to the flexor surface of the navicular bone. The parameters belonging to the individual sequences are shown in *Table 2*.

Table 1

Main technical parameters of the Siemens Magnetom Vision Plus MR scanner

Superinduction closed magnet(1)	
Magnetic-field strength(2)	1.5 T
Resonance frequency(3)	63.6 MHz
Coil(4)	CP-Helmholtz circular coil(6)
Gradient intensity(5)	25 mT/m

1. táblázat: A Siemens Magnetom Vision Plus MR készülék főbb műszaki paraméterei

Szuperinduktív zárt mágnes(1), Térerő(2), Rezonancia frekvencia(3), Tekercs(4), Grádiens erősség(5), Cirkuláris tekercs(6)

Table 2

Names and parameters of the sequences applied

Sequences(1)	**TR (ms)**	**TE (ms)**	**Flip angle (°)**	**TA (min)**	**FoV (mm)**	**Matrix (pixel)**	**Slice thickness (mm)(2)**
T1 spin echo	570	14	70	4.14	130	256×256	3
T2 weighted gradient echo(3)	944	25.8	30	3.01	160	256×256	3
T1 inversion recovery	5100	30	180	3.1	145	256×256	3
T2 turbo spin echo	5000	90	180	2.46	130	256×256	3

2. táblázat: Az alkalmazott szekvenciák nevei és paraméterei

Szekvenciák(1), Szeletvastagság(2), T2 súlyozott gradiens-echo(3)

For the selection of sequences the following criteria were taken into consideration:

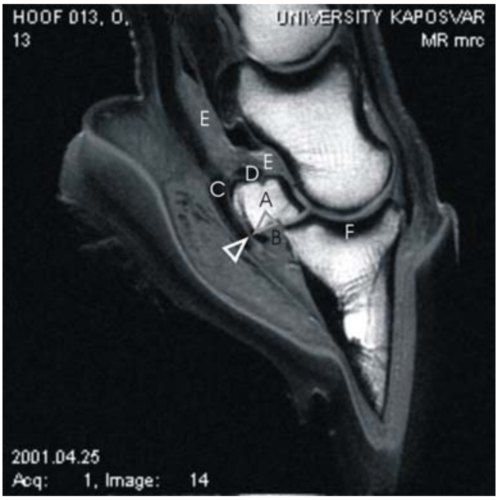
- visual identification of anatomical structures constituting the navicular region,
- optimisation of the contrast of different tissues to enable accurate visualisation,
- visualisation of the fluid spaces,
- visualisation of the spongy substance of bone and of the bone marrow,
- accurate visualisation of the articular surfaces covered by hyaline cartilage and of the flexor surface covered with fibrocartilage.

RESULTS

On *T1 spin echo images* (*Figure 1*) taken in *sagittal* plane the spongy substance of bone was visualised with expressly high signal intensity, while the synovial fluid present in the joints and navicular bursa, as well as the entire impar ligament and the deep digital flexor tendon at the area of insertion showed medium signal intensity as a consequence of the T1 relaxation time difference arising from disparities in the water and/or fat content of the tissues. The compact substance of the bone, parts of the deep digital flexor tendon outside the insertion area and the collateral sesamoid ligaments had extremely low signal intensity.

Figure 1

T1 spin echo image, sagittal plane



A: navicular bone (*os sesamoideum distale*), B: distal sesamoid ligament (*lig. sesamoideum distale*), C: deep digital flexor tendon (*tendo m. flex. dig. prof.*), D: collateral sesamoid ligaments (*ligg. sesamoidea collateralia*), E: palmar recess (recessus palmaris) F: subchondral bone plate of the distal phalanx and the articular cartilage covering it (*a patacsont subchondralis csontlemeze és az azt borító ízületi porc)*, Between white triangules: navicular bursa (*Fehér háromszögek között: bursa podotrochlearis*)

1. ábra: T1 spin-echo szekvenciával sagittalis síkban készült felvétel

B: lig. Sesamoideum distale, D: ligg. Sesamoidea collateralia, E: recessus palmares

On *gradient echo, T2-weighted images* (*Figure 2*) taken in *sagittal* plane the synovial fluid present in the joint cavities (including the palmar recess of the distal interphalangeal joint) and in the bursa, the impar ligament and the insertion area of the deep digital flexor tendon show extremely high signal intensity. The compact substance of bone and the structures consisting of dense connective tissue (collateral sesamoid ligaments, deep digital flexor tendon) are characterised by extremely low signal intensity also with this sequence. The spongy substance of bone exhibited reduced signal intensity.

On *T1 inversion recovery images* (*Figure 3*) obtained in *sagittal* plane the synovial fluid present in the joint cavities and bursa was seen in extremely sharp contrast. The corium showed medium signal intensity. The spongy substance of bone, the impar ligament, the insertion areas of the deep digital flexor tendon and common digital extensor tendon appeared with reduced signal intensity, while the collateral ligaments, other parts of the above-mentioned tendons and the compact substance of bone were almost completely devoid of signals.

Figure 2

T2-weighted gradient echo image taken in sagittal plane

The symbols of anatomical structures are the same as in *Figure 1. (Az egyes anatómiai képletek jelölései megegyeznek az 1. ábrán alkalmazott jelekkel.)*

2. ábra: T2 súlyozott gradiens-echo szekvenciával sagittalis síkban készült felvétel

Figure 3

T1 inversion recovery image taken in sagittal plane

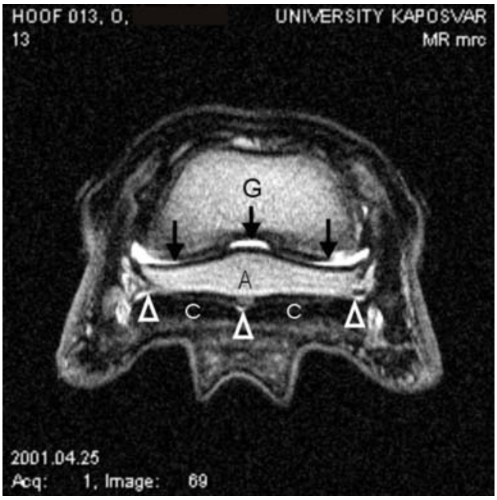
The symbols of anatomical structures are the same as in *Figure 1*. *(Az egyes anatómiai képletek jelölései megegyeznek az 1. ábrán alkalmazott jelekkel.)*

3. ábra: T1 Inversion recovery szekvenciával sagittalis síkban készült felvétel

On *T2 turbo spin echo images* (*Figure 4*) taken in *transversal* plane the cavities containing synovial fluid (the synovial fossa between the navicular bone and the middle phalanx, and the navicular bursa appearing as a thin line) had increased signal intensity. The spongy substance of bone showed medium signal intensity. The deep digital flexor tendon and the compact substance of bone were expressly signal deficient.

Figure 4

T2 turbo spin echo image taken in transversal plane



A: navicular bone (*os sesamoideum distale*), C: deep digital flexor tendon (*tendo m. flex. dig. prof.*); G: middle phalanx (*os coronale*); Between white triangules: navicular bursa (*Fehér háromszögek között: bursa podotrochlearis*), Black arrows: synovial fluid in the synovial fossa between the middle phalanx and the navicular bone *(Fekete nyilak: a pártacsont-nyírcsonti ízületi résben lévő synovia)*

4. ábra: T2 turbospin-echo szekvenciával transzverzális síkban készült felvétel

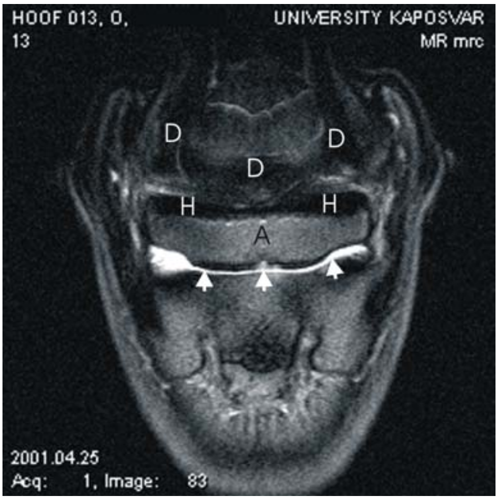
On *T2 turbo spin echo images* (*Figure 5*) taken in *coronal* plane the expressly signal intense articular space between the distal phalanx and the navicular bone, the subchondral bone plate of the navicular bone covered with almost signal-free fibrocartilage and the collateral sesamoid ligaments also showing low signal intensity were well visualised. The spongy substance of the navicular bone and the distal phalanx had medium signal intensity. In the distal phalanx, the arcus terminalis and the nutritive vessels originating from it were well distinguishable from the spongy substance.

DISCUSSION

It is known from human medical studies that MR images provide much better differentiation of soft tissues from each other and from other tissues than do ultrasound or CT scans made of the same region. Thus, MRI as a diagnostic procedure is suitable primarily for the study of soft tissues, fluid spaces and tissue structures between which there are expressed signal intensity differences arising from differences in water or fat

Figure 5

T2 turbo spin echo image taken in coronal plane



A: navicular bone (*os sesamoideum distale*); D: collateral sesamoid ligaments (*ligg. sesamoidea collateralia*); H: Proximal margin of the fibrocartilage-covered flexor surface of the navicular bone and the subchondral bone plate located beneath it (*a nyírcsont cartilago fibrosával fedett facies flexoriájának margo proximalisa, illetve az alatta elhelyezkedő subchondralis csontlemez),* White arrows: synovial fluid in the synovial fossa between the distal phalanx and the navicular bone (*Fehér nyilak: patacsont-nyírcsonti ízületi résben lévő synovia)*

5. ábra: T2 turbospin-echo szekvenciával koronális síkban készült felvétel

content (synovia – hyaline cartilage; wall of bursa – synovia present in its cavity; spongy substance of bone – compact substance of bone; collagenous substance of tendons and ligaments – pathological changes developing in the collagenous substance). The method is based on the physical phenomenon of nuclear magnetic resonance, when nuclei having magnetic properties (such as protons) get into interaction with an external strong magnetic field, resulting in the splitting of energy levels of magnetic spins. As a result of external transfer of energy (radio-frequency electromagnetic wave) the spins go from a low to a higher energy level and become activated. After the cessation of energy transfer, the spins return to a status of low energy level; this process is termed relaxation. The waves (signals) emitted during relaxation are detected by an antenna system and processed into MR images. The appearance of different tissues and structures on the screen are determined by their relaxation time and the imaging method used; as a result, the signal-intense structures will appear as white while those of low signal intensity as black. MR images provide very complex information: depending on the imaging method used, specific structures may give different contrast; at the same time, some important parameters affecting the appearance of anatomic and pathological structures can be defined.

The factors responsible for the contrast (i.e., signal intensity difference) obtained during MR imaging are as follow:

– water content of the tissues and changes thereof (e.g. tissues affected with oedema, tumours and inflammation have different water content);

– movement characteristics of water molecules (e.g. cellular-extracellular water, free-bound water, faster-slower movement);
– movement and organisation of macromolecules (e.g. cytoskeleton);
– fat content of the tissues (e.g. difference of signals emitted by subcutaneous and intramuscular adipose tissue; the phospholipids of the central nervous system have typical relaxation);
– paramagnetic substances (e.g. iron in methaemoglobin, manganese, copper, and other trace elements, contrast media used for imaging).

It is known that MRI is suitable for studying the musculoskeletal system in addition to the nervous system and the parenchymal organs. The majority of lesions developing in the cartilage covering articular surfaces, in the ligaments, tendons and bone marrow (e.g. microfracture, cartilage fracture, avascular necrosis, chondromalacia, inflammatory processes of bones, early bone tumours) can be detected only by this diagnostic method. The diversity of applicable MRI measurements (as a result of which a given tissue type shows different but typical signal intensities), the multiplanar capability and high resolving power of the method facilitate exact identification and detailed examination of the anatomic structures constituting the equine foot, enabling highly accurate visualisation of even pathological changes restricted to extremely small areas and showing very small signal intensity differences. For human medical use, manufacturers have developed MR scanners suitable for examination of the musculoskeletal system and providing comfort of use for both the patient and the physician. These so-called open MRI machines can be used for the examination of large animals as well.

Numerous changes in the navicular bone have been associated with navicular disease (*Ruohoniemi et al*., 1997; *Wright et al*., 1998). It is known that in many horses found to be sound on physical examination for lameness the radiographic findings are positive (*Kaser-Hotz and Ueltschi*, 1992). The opposite of this statement is also true: numerous horses show typical clinical signs without any radiographic changes (*Widmer et al*., 2000). In navicular disease, the examination of soft tissues constituting the navicular region (deep digital flexor tendon, impar ligament, navicular bursa, fibrocartilage covering the flexor surface) would be extremely important for accurate diagnosis, therapy and prognosis; however, these structures can only indirectly, or not at all, be examined by conventional radiography (*Denoix et al*., 1993). Even with multiple radiographic projections and careful technique, important degenerative changes can be missed (*Wright*, 1993). The appearance and spread of CT as a 3D diagnostic imaging modality markedly increased the accuracy of examination of the equine foot, more closely of the navicular bone constituting the navicular region, in the diagnosis of lameness in horses (*O'Brien et al*., 1975; *Wright*, 1993), but it still did not bring a breakthrough in the examination of soft tissues.

The use of MRI enables a noninvasive, highly accurate 3D examination of soft-tissue and osseous anatomical structures constituting the navicular region. On T1-weighted sequence images the tissues characterised by rapid T1 relaxation, such as the spongy substance of bone, the loose connective tissue containing a large amount of adipose tissue (pars torica pulvinis digitalis), the synovia and the abundantly vascularised tissues (e.g. the corium), are signal intense. In contrast, tissues with lower water content (such as the compact substance of bone, the cartilage covering articular surfaces, the ligaments and tendons) have low signal intensity. The use of T2-weighted sequence enables extremely detailed examination of the fluid spaces and accurate evaluation of pathological changes causing only minor changes in water content.

From relevant data of the literature and findings of the present studies the following conclusions can be drawn:

- T1 spin echo sequence proved to be the most suitable imaging method for examination of the spongy substance of bone,
- T2-weighted and T1 inversion recovery sequences provided the most accurate information on the fluid spaces,
- of the five sequences listed, the T2-weighted gradient echo and the T1 inversion recovery sequences used in human medicine are the most suitable for high-contrast visualisation of the articular surfaces covered with hyaline cartilage and of the flexor surface covered with fibrocartilage.

The five sequences and three planes applied facilitated a high-contrast and extremely detailed examination of the navicular region. The advantages of the MRI method presented in this paper can be summarised as follows.

- The different anatomical structures can be delineated in 3D with high accuracy.
- The tissue types constituting the navicular region are visualised in 3D in more detail than by any diagnostic procedure used earlier.
- Fat suppression sequences permit the detection of any local oedema, contusions, haemorrhages, and their penetration.
- Cavities filled with synovial fluid and articular surfaces covered with hyaline cartilage or fibrocartilage can be studied in extremely great detail.
- Pathological changes developing in tendons and ligaments and causing small differences in water content can be well localised.
- The shape, wall thickness and synovial fluid content of the navicular bursa can be visualised in high contrast.
- Currently open MR machines are being used increasingly widely for the examination of the locomotor system. These machines facilitate examination of the head and upper third of the neck in addition to the extremities of animals.

Besides the advantages, there are certain factors that hinder the practical use of this diagnostic procedure.

- The examination must be performed in general anaesthesia and all the necessary equipment must be non-magnetisable.
- The diagnostic procedure is costly, and at present only few facilities in Europe have the technical conditions required for the examination of large animals.

Studies of the pathological changes associated with navicular disease increasingly indicate that abnormalities developing in the deep digital flexor tendon, in the fibrocartilage covering the flexor surface of the navicular bone and in other neighbouring soft tissues play an important role in the pathogenesis of this syndrome (*Wright and Douglas*, 1993; *Wright et al*., 1998). As this diagnostic method permits an extremely detailed study of the soft-tissue structures of the navicular region, it may greatly facilitate research on the aetiology and pathology of navicular disease, while its successful application for the examination of live animals could enable the early diagnosis of the disease.

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