

Three-Dimensional Musculoskeletal MR Imaging with *syngo* SPACE

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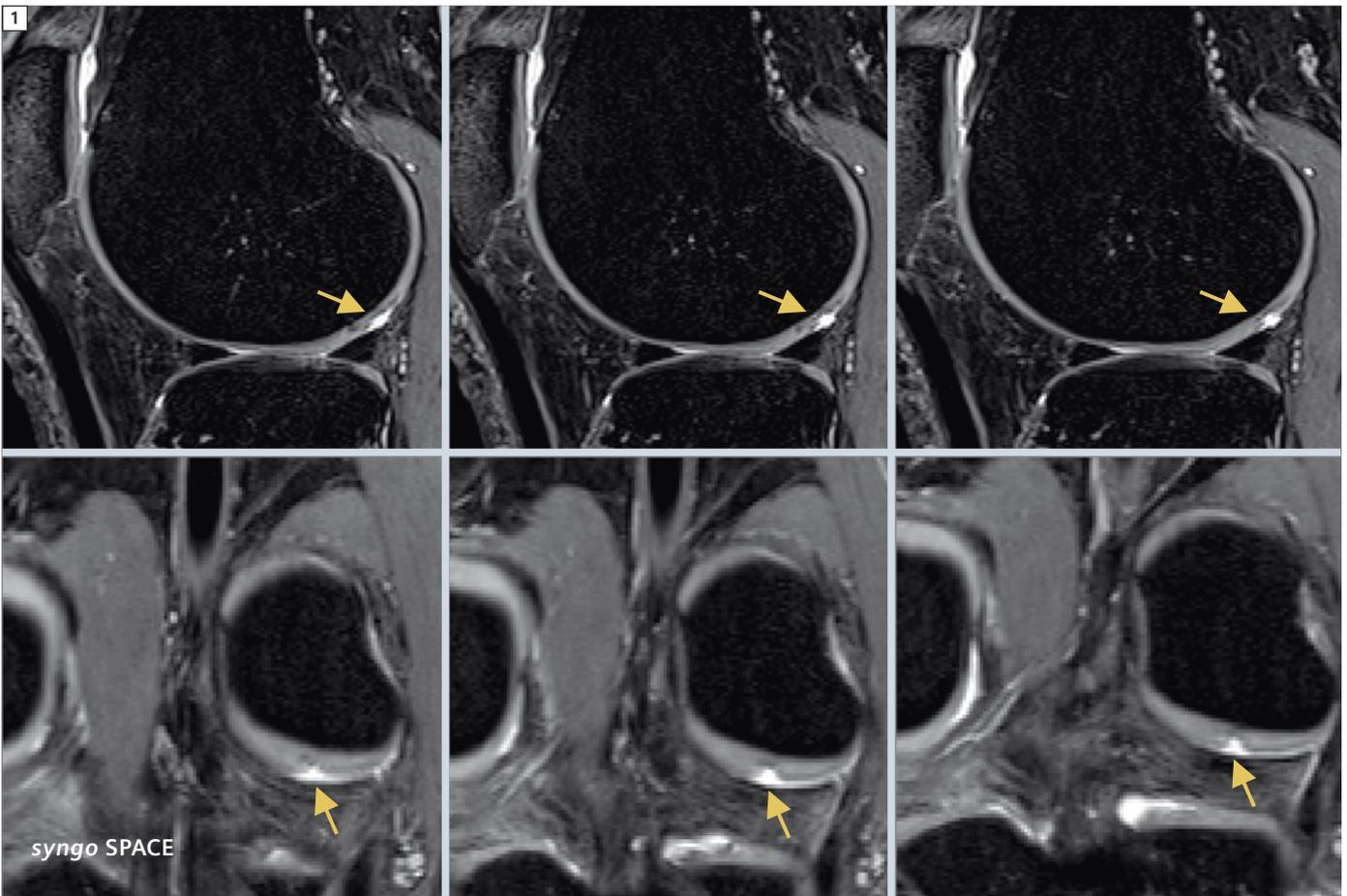
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Background

Due to the excellent soft-tissue contrast MRI is the primary modality in musculoskeletal (MSK) imaging. It offers excellent direct depiction of bone marrow,

fibrous, ligamentous and cartilaginous structures as well as of the periarticular soft tissue. However, many anatomical structures such as ligaments and tendons are obliquely oriented. These struc-

tures and lesions / signal alterations are hence difficult to assess with two-dimensional (2D) sequences oriented in the standard planes. At a standard slice thickness of 3–5 mm [1], depiction is



1 Subtle III°-cartilage defect of the dorsal lateral femoral condyle. Left knee of a 52-year-old female patient: The cartilage defect is mostly obscured and was missed in the 2D TSE reading (upper row, arrow) because of partial volume effects. While only visible on 1 2D FSE slice, the defect is clearly visible in *syngo* SPACE (bottom row). (With permission from [8].)

also often comprised by partial volume effects, which may mimic signal alteration. Three-dimensional (3D) reconstructions of the standard planes are an alternative to additional sequences [2], although image quality is limited due to the anisotropic voxel-dimensions and interslice gaps of conventional 2D sequences. Acquisition of an isotropic source-dataset reducing partial volume effects and eliminating interslice gaps is therefore desirable and has been shown feasible and useful in previous studies [3–9]. Anatomical understanding and depiction of small lesions may particularly benefit from this approach.

Multi-channel extremity coils and higher field strengths facilitate time-efficient acquisition and allow to acquire isotropic 3D Turbo Spin Echo (TSE) sequences [10, 11], such as *syngo* SPACE (Sampling Perfection with Application optimized Contrasts using different flip angle Evolutions). With these 3D sequences, the whole area of interest is covered by an isotropic volume, which can be subsequently reconstructed in any desired orientation and slice thickness. Such a primary 3D approach for MSK imaging has been performed in several studies with a T2 or Proton Density-weighted 3D TSE sequence [7–9]. However, a T1-weighted (T1w) contrast is still required for a comprehensive MSK protocol. This article demonstrates our experiences with *syngo* SPACE in musculoskeletal MR examinations, also in combination with a T1-weighted protocol.

Technical considerations

An exemplary isotropic *syngo* SPACE-protocol is provided in Table 1. The 3D blocks cover the whole area of interest, so that exact orientation along important anatomical structures, e.g. the supraspinatus tendon or anterior cruciate ligament, is not required with these isotropic sequences [8]. The acquisition time of 3D sequences would have to be the same or at least similar to conventional 2D sequences, so that implementation of these sequences is justifiable. The compromise between acquisition

time and image quality is fundamental to all MRI approaches, and 3D TSE techniques have been struggling with either long acquisition times or low resolution. Longer acquisition times improve image quality but increase the susceptibility for motion artifacts. To shorten acquisition time we have performed parallel imaging with the *k*-space based technique *syngo* GRAPPA. The average examination time was 6–10 minutes per sequence depending on the organ of interest and the size of the joint [7–9]. This is

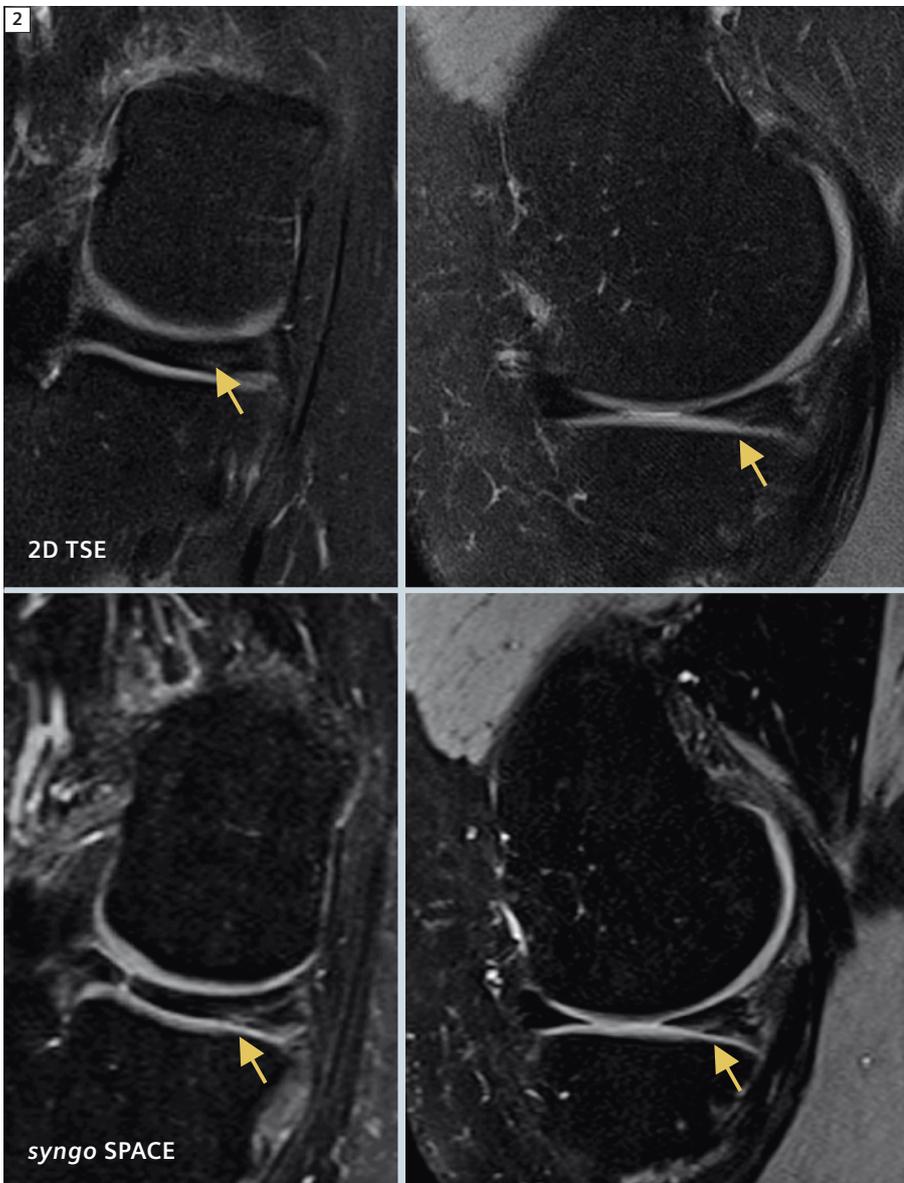
approximately 2–5 minutes longer than the acquisition of a single conventional anisotropic 2D sequence but still considerably faster than acquisition of three separate sequences. We observed motion artifacts similarly in both conventional and 3D sequences [7–9]. Compared to Gradient Echo sequences metal artifacts did not negatively affect image quality.

The isotropic resolution of *syngo* SPACE allows for free arbitrary online reconstruction. However, because of signal-

Table 1: Sequence parameters

Parameter	T1w <i>syngo</i> SPACE	T2w <i>syngo</i> SPACE
Orientation	Coronal	Coronal
TR (ms)	700	1100
TE (ms)	26	37
FA (°)	130	120-100-80
Matrix	230 x 230	256 x 256
FOV (mm)	160 x 160	160 x 160
Slice thickness (mm)	0.6	0.6
Number of slices (n=)	120	120
Bandwidth (Hz/pixel)	543	430
Echo train length	142	30
PAT (R=)	2	3
Number of averages	1	1
Acquisition time (min)	6:24	6:43

TR = repetition time; TE = echo time; FA = flip angle; FOV = field-of-view; PAT = parallel acquisition technique (GRAPPA).



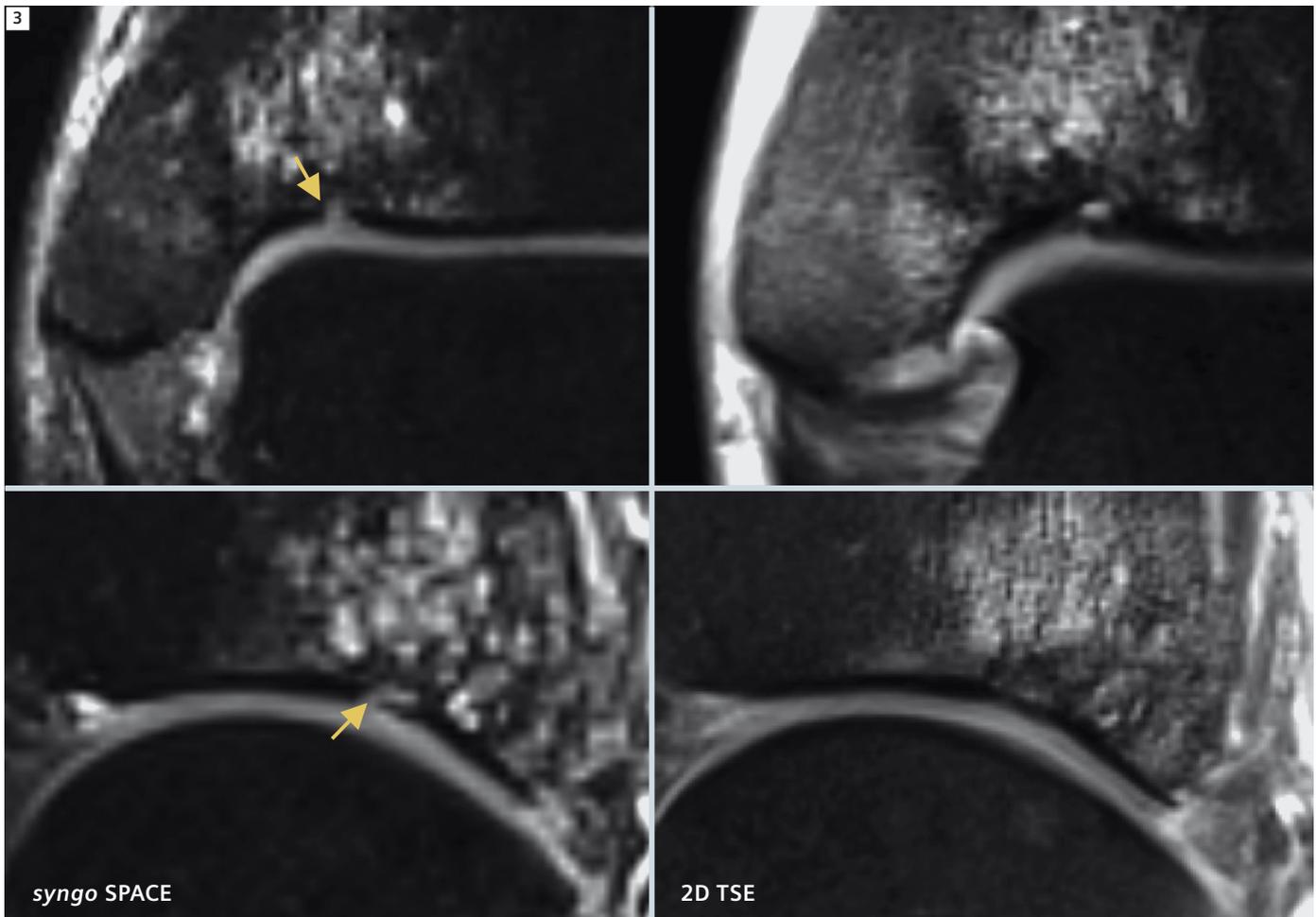
2 III°-lesion of the dorsal portion of the medial meniscus. Left knee of a 21-year-old female patient: The III°-tear of the dorsal portion of the medial meniscus is clearly visible in *syngo* SPACE (bottom row). The involvement of the meniscus surface is obscured in 2D TSE (upper row) and was regarded as a II° degeneration. (With permission from [8].)

related constraints or missing 3D reconstruction abilities of the PACS system, several previous studies featured time-consuming, standardized, retrospective reconstructions of the isotropic source data set in thicker slices, sacrificing the major asset of this sequence technique [3, 8]. Radial k-space acquisition and elliptical scanning were recently introduced in *syngo* SPACE, so that it provides excellent signal and contrast [7, 9]. In our department we now use the online 3D reconstruction capabilities of the PACS-integrated imaging software *syngo.via* to assess the original 3D data set, so that no additional reconstruction time is required [9].

Clinical application

We primarily use *syngo* SPACE protocols at 3T (MAGNETOM Verio, Siemens Healthcare, Erlangen, Germany) in combination with dedicated multi-channel coils for the MRI-examination of joints, such as the knee, shoulder and ankle, but also for the assessment of bone marrow changes of the jaw (here only T1w). In previously published studies we have shown that a moderately T2-weighted sequence is feasible for time-efficient isotropic assessment of the knee and ankle [7-9]. In the knee, *syngo* SPACE has been shown superior to conventional 2D sequences for the depiction of the cartilage of the femoral trochlea and the meniscus root ligaments [7, 8]. Small lesions of femoral trochlea or peripheral condyles or talus can be readily depicted with *syngo* SPACE with a higher diagnostic confidence than for conventional sequence (Fig. 1). However, a small additional number of cartilage and meniscus lesions were detected with *syngo* SPACE, which was mainly attributed to a reduction of through-plane partial volume effects. Sensitivity for meniscus lesions was higher for *syngo* SPACE compared to conventional 2D sequences (Fig. 2).

The ankle is one of the most complex human joints and most ligaments and tendons are oriented obliquely, so that



3 Osteochondral abnormalities. A small osteochondral lesion of the medial tibia can be clearly delineated in *syngo* SPACE (arrow). In the 2D TSE sequence the discontinuity of the subchondral bone cannot be detected. Depiction of bone marrow edema is similar in both sequences. (With permission from [9]).

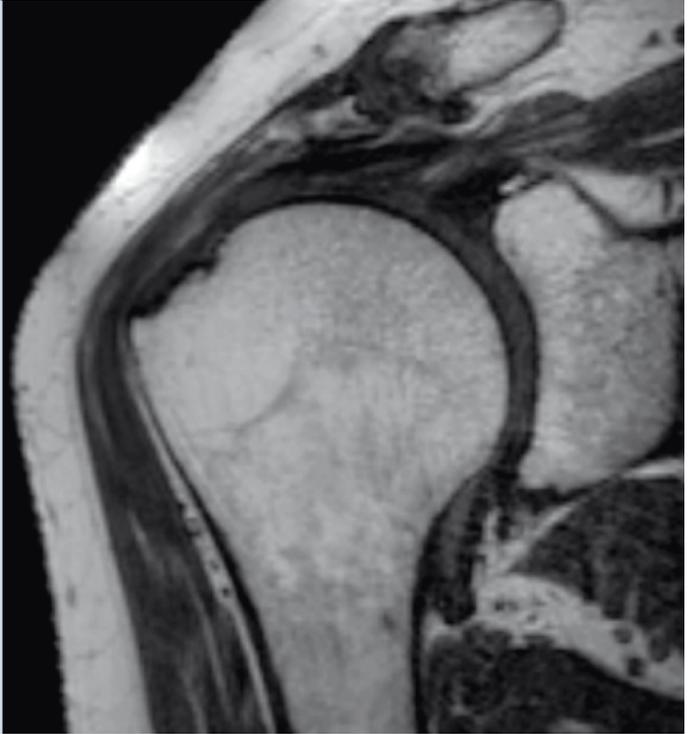
syngo SPACE appears particularly promising. Indeed *syngo* SPACE was superior to 2D sequences for the depiction of the spheric tibial and talar cartilage (Fig. 4) as well as for the spring ligament complex. The complete three-dimensional approach facilitated good depiction of those ligaments usually difficult to assess with standard 2D sequences. No abnormality detected with conventional 2D TSE was missed when using *syngo* SPACE and intersequence- and inter-reader correlation showed no significant differences, so that implementation of *syngo* SPACE in clinical routine protocols appears justified [9].

A T1-weighted 3D approach appears particularly promising to achieve a complete 3D protocol. Our first results show that T1w *syngo* SPACE yields a very similar contrast to conventional 2D SE sequences, so that a need for any significant adjustment of the radiologist's reading and interpretation habits to the new sequence is unlikely. Assessment of tendons and the subchondral bone is readily possible with T1w *syngo* SPACE. The T1w contrast allows for an improved anatomical understanding and is useful for verification of findings in the T2w sequence (Fig. 5). The anatomically complex jaw appears particularly promising for the application of the T1w sequence. T1w sequences show the

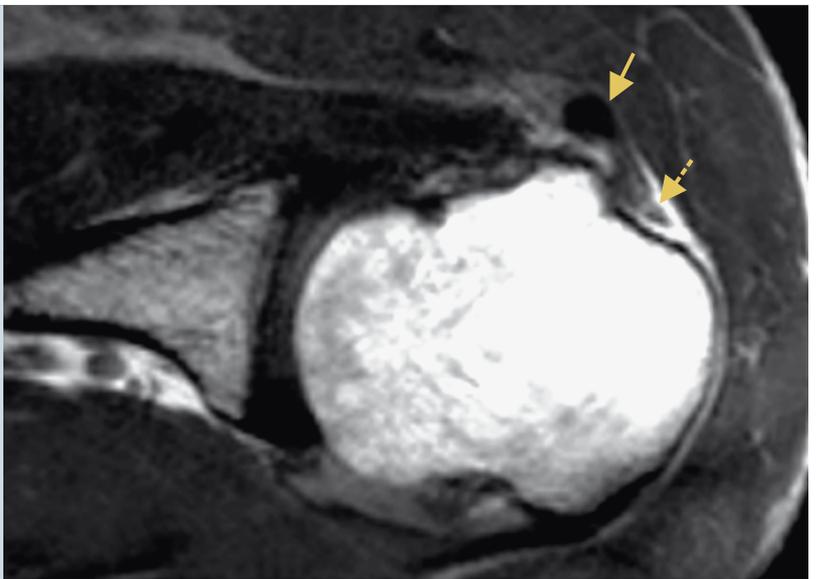
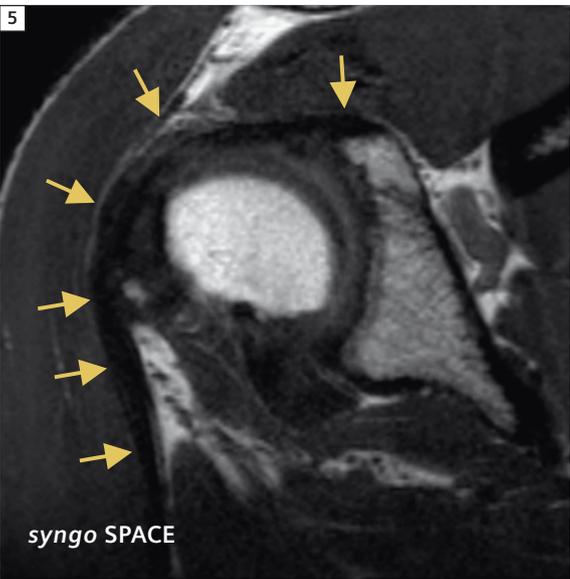
highest sensitivity for diseases affecting the structures of the bone, which are commonly found in the jaw bone [12]. The isotropic resolution allows for a convenient analysis of the jaw bone, even with curved multiplanar reconstructions (MPRs) very similar to an orthopantomogram (Fig. 6).

Conclusion

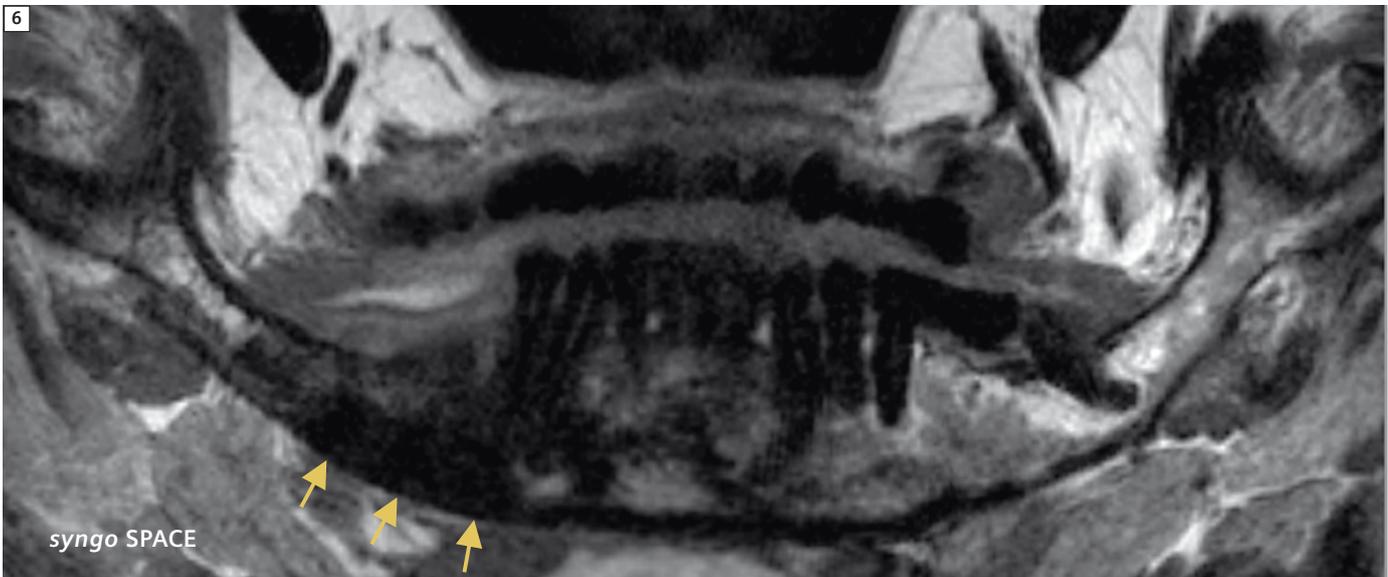
Isotropic 3D imaging with *syngo* SPACE is a promising approach to assess musculoskeletal pathologies. Previous technical constraints such as low SNR, CNR and blurring have been compensated by flip angle optimization and radial



4 Combined T1w and T2w *syngo* SPACE dataset of the shoulder. T1w and moderately T2w *syngo* SPACE can be combined for a comprehensive 3D protocol. Right shoulder of a 45-year-old male patient: Small partial tear of the supraspinatus tendon (arrow). *syngo* SPACE provides excellent contrast between joint fluid and tendons/muscle.



5 Luxation of the biceps tendon. 46-year-old male patient with tear of the subscapularis muscle and consecutive anteromedial luxation of the biceps tendon (arrows). The biceps sulcus is empty (dotted arrow) *syngo* SPACE allows to conveniently display the full course of the tendon in one slice.



6 Curved MPR of the jaw. 62-year-old female patient with osteonecrosis of the jaw. A curved MPR along the oral midline was created to display the mandible and maxilla in one slice. The large osteonecrosis of the right mandibular ramus (arrows) can be readily depicted in this T1w syngo SPACE sequence.

k-space sampling. The theoretical susceptibility of this technique to motion artifacts did not become evident in our experience. The identification of anatomical structures at least equals the conventional sequence and allows superior discrimination of relevant small ligamentous and cartilaginous structures. The image contrast is comparable to conventional 2D sequences, so that no considerable adjustment by the radiologist is necessary.

A combined isotropic T1w and moderately T2w 3D protocol will take approximately 12–16 minutes. In combination with arbitrary multiplanar reformation, no other additional sequences are necessary. Therefore, syngo SPACE has become an appropriate alternative for substantially shortened routine MSK protocols.

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