Applications of Technical Fusion in Uroradiology

Einsatzmöglichkeiten der technischen Fusion in der Uroradiologie

Authors
F. Aigner¹, T. De Zordo¹, L. Pallwein-Prettner², D. Junker¹

Affiliations
¹ Radiology, Medical University Innsbruck, Austria
² Radiology, Sisters of Charity Hospital, Linz, Austria

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- fusion imaging
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- prostate cancer
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Introduction
Currently the radiologist’s clinical practice is generally structured as follows: if a lesion previously detected via computer tomography (CT) or magnetic resonance imaging (MRI) and is also monitored using ultrasound (US) should be reevaluated or biopsied, the examiner first examines the static CT or MRI data records on an imaging console in order to get a solid impression of the morphology and localization of the lesion. In the subsequent ultrasound examination, information is recalled from memory in order to find the lesion and characterize it, for example. This approach is called visual or cognitive fusion (CF). In contrast, technical fusion (TF) allows not only the simultaneous display of real-time ultrasound images with the previously obtained CT or MRI data records on an imaging console in order to get a solid impression of the morphology and localization of the lesion. In the subsequent ultrasound examination, information is recalled from memory in order to find the lesion and characterize it, for example. This approach is called visual or cognitive fusion (CF).

Abstract
Technical fusion is defined as the ultrasound-guided navigation through a previously generated 3D imaging dataset such as a computed tomography (CT) or magnetic resonance imaging (MRI). This technique allows for moving the fused CT/MRI datasets synchronously with the real-time ultrasound in the same plane. Established and furthermore not yet described applications, the technical principles and the limitations of this promising technique will be introduced.

Key points:
- improves detection rates of lesions on ultrasound
- more reliable size controls at different time points
- may be an alternative to in bore biopsies
- can be used for focal therapy

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Zusammenfassung
Unter technischer Fusion versteht man das ultraschallgeführte Navigieren durch einen zuvor generierten 3D-Bildatensatz wie beispielsweise einer Computertomografie (CT) oder Kernspin- tomografie (MRT). Diese Technik erlaubt es, die in das Ultraschallgerät eingespielten CT/MRT-Datensätze simultan mit dem durchgeführten Echzteilultraschall zu bewegen, nachdem selbe Schichtpositionen anhand bestimmter anatomischer „Landmarken“ registriert wurden. In der vorliegenden Arbeit werden etablierte, aber auch noch nicht beschriebene Einsatzmöglichkeiten, die Technik und die Limitationen dieser interessanten Methode auf dem Gebiete der Uroradiologie beschrieben.
biopsy, as well as present new, yet unestablished or unevaluated procedures, such as fused imaging of kidneys and the retroperitoneal region for monitoring tumor development. In addition, the limitations of this technology will be critically evaluated.

**Technology**

**Prerequisites**
The following 3 components are required to perform technical fusion: 1. An ultrasound unit with fusion software; 2. Sensors attached to the ultrasound probe; 3. A transmitter generating a low magnetic field (Fig. 1).

**Procedural steps**
First the 3D image data sets are uploaded to the ultrasonic instrument, e.g. via an external data medium such as a USB stick or locally from the database. Next is a slice comparison between the B image and 3D data set for the position at which certain landmarks can be detected in both modalities (e.g. bladder neck during prostate fusion) (Fig. 2). If the comparison is satisfactory, the fusion mode begins.

**Principle**
In fusion mode, the transmitter three-dimensionally localizes the position of the sensors attached to the ultrasound probe and continuously sends their coordinates to the ultrasound unit. In this way the 3D data record can be moved simultaneously with the real-time ultrasound examination on the monitor of the ultrasound unit (Fig. 1). In addition, the system transfers designated targets to the 3D data record of the examination to be fused; these targets appear directly on the live ultrasound image.

**Prostate**
Due to the deficiencies of systematic biopsy (SB) and the PSA value for diagnosing prostate cancer, visualization of the prostate carcinoma (PCa) is playing an increasingly important role in diagnosis [4, 5]. In particular, MRI appears to be a stable technology, and in contrast to transrectal ultrasound (TRUS), is reproducible independently of the examiner [6].

Initially in the biopsy setting, in addition to systematic tissue cores, targeted samples were acquired via cognitive fusion of suspicious areas identified in the MRI; in such cases, a suspected lesion in the MRI is attributed as exactly as possible to a topographical region; TRUS is then performed in this area, and subsequently additional tissue samples are obtained. A recently published study by Boesen et al. emphasized the diagnostic value of CF, even when – as in this case – the authors had little experience with MRI-guided biopsies [7]. Their study population consisted of 83 males with earlier negative systematic prebiopsies who also underwent both SB and an MRI-targeted biopsy using CF. Consequently they achieved a total PCa detection rate of 47% for the combined systematic biopsy and cognitive fusion approach, while CF detected an additional 13% clinically significant cases of PCa that had eluded systematic biopsies alone.

Therefore urologists in private practice are increasingly desirous of exact localization data of MRI findings so that in their practice they can obtain additional tissue samples from these regions.

In order to counteract possible MRI image information loss via CF, some working groups started to perform MRI-guided biopsies in magnetic resonance scanners (so-called “inbore” biopsies) [8]. This procedure is currently reserved for a few centers with the appropriate equipment.

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**Fig. 1** Setting of fusion imaging with split screen (1 real-time TRUS on the left and MRI data set on the right), prostate phantom 2, transmitter near the sensors on the probe 3 and investigator 4.

**Fig. 2** Because urethra, seminal vesicle or bladder neck are visible on both MRI and ultrasound they may be used as reference points for slice registration.

Aigner F et al. Applications of Technical... Fortschr Röntgenstr 2015; 187: 331–337
In this regard, the possibilities offered by technical fusion are increasingly interesting, since after the MRI data sets have been uploaded to the ultrasound device, the suspected lesion can be biopsied by radiologists and urologists using TRUS independently of large-scale equipment (Fig. 3). In addition, TF combines the advantage of two imaging procedures, real-time TRUS and MRI. However, this requires close collaboration and communication between the urologist and radiologist. Wysock et al. reported the comparative advantages of TF over CF with respect to prostate biopsies: 1. TF reduces the learning curve for CF; 2. More histological information is made available; 3. TF improves the detection of small carcinomas [3].

An additional useful option offered by technical fusion mode is that, in addition to ultrasound-guided selection of the MRI-targeted lesion in the B image, reevaluation of the suspected MRI lesion can be made possible using new ultrasound techniques such as ultrasound elastography or contrast-enhanced ultrasound (CEUS) [9, 10]. Thus Brock et al. reported improved visualization of PCa when the strengths of MRI and ultrasound elastography can be simultaneously combined [9]. Further, Durmus et al. were able to achieve good focus characterization with parallel employment of a B image, ultrasound elastography, color Doppler, CEUS and MRI [10] (Fig. 4).

In general, compared with SB, the following advantages of an MRI-guided biopsy should be emphasized: (1) Better estimation of the actual tumor load; (2) Detects more clinically significant prostate cancers; (3) Requires fewer tissue cores for tumor verification; (4) Detects fewer indolent prostate cancers; (5) Indicates prostate cancer in difficult cases of localization [7, 11, 12]. Due to these advantages, technical fusion also appears to be suitable for patients in active surveillance [13].

**Kidneys**

**Identifying renal lesions**

Due to reasons of cost and radiation-reduction purposes, frequently in cases of unclear CT or MRI findings a second-look B image ultrasound examination (B-US) is performed to obtain additional clarification of various lesions. For incidental enhancing breast lesions in a contrast-enhanced MRI, Nakano et al. showed that using technical fusion of the B-US is not only more independent of the examiner, but also that the detection rate of these lesions using TF is
significantly higher than for those relying on cognitive fusion (83% for TF vs. 30% for CF) [1]. The same appears to apply to the discovery and characterization of indistinct renal lesions previously detected by a CT or MRI. Thus Helck et al. were able to demonstrate that using technical fusion provided significantly improved identifiability of renal lesions, compared to B-US alone (2.7 ± 1.2 vs. 2.0 ± 1.3) [14]. Interestingly this also applies to CEUS which in the same study likewise more reliably discovered renal lesions using technical fusion (CEUS-TF). An analysis of 29 consecutive renal lesions at our institute confirmed the results of the above study, whereas in our cohort the identifiability of lesions for sole B-US was 44.8% and 86.2 % for TF (p = 0.002) (unpublished data).

Characterizing renal lesions

Unclear CT or MRI findings for renal lesions can result from e.g. purely monophasic examinations (due to contrast agent dynamics?), in the case of minimal contrast agent absorption (partial volume effect? septal enhancement?), or in the case of the presence of hemorrhagic renal cysts in the MRI [14 – 16]. If such an indistinct renal lesion has been successfully discovered by means of the fusion mode, an ultrasound contrast agent can be applied to further characterize the lesion. Due to the high sensitivity of CEUS, this technology possesses great potential in the differentiation of solid and cystic renal lesions, differentiating solid renal lesions and pseudotumors as well as characterizing complex cysts [16 – 23]. In their study population, Helck et al. demonstrated the superiority of CEUS-TF compared to CT/MRI examinations in the characterization of renal lesions [14].

Radiofrequency ablation

Recently published studies of ablation of liver lesions indicate that the use of technically fused radio frequency ablations under real-time conditions is technical possible, safe and efficient. Thus, in many cases, technical fusion could be employed as alternative to CT-guided ablation [24, 25]. Unlike liver studies, there is little literature regarding fusion-guided renal intervention, although study groups followed by Ukimura and Amalou demonstrated that this is technically feasible [26, 27].

Follow-Up

Size controls

In principle every 3D-reconstructible DICOM image data set can be used for fusion imaging. This means that in addition to CT/MRI data sets, PET-CT volumes or so-called TRUE 3 D ultrasound volumes created using fusion imaging techniques could be employed. Thus Nakano et al. initially created a US-3 D data set for BI-RADS 3 lesions of the breast which they then used for size progression controls (6, 12, and 24 months) in fusion mode for comparison with the real-time ultrasound image [2]. The primary diameter of the lesions initially and after 6, 12 and 24 months was indi-

**Fig. 5** CEUS-TF: high-attenuation lesion of the kidney on monophasic CT (arrow; right image) with absence of contrast agent uptake on CEUS (arrow; left image); therefore cancer could be ruled out.

**Fig. 6** Fusion of real-time ultrasound (left image) and TRUE-3D-US data set generated 10 days before (right image); follow-up shows the abscess of the prostate with a smaller size.
cated to be 8.2 ± 4.2, 8.4 ± 4.5, 8.1 ± 4.5 and 8.3 ± 5.0 mm (p = 0.785). The authors concluded that using TF, BI-RADS 3 lesions could be reliably reproduced at various points of time, independent of the examiner.

We employ US/TRUE 3D-US fused examinations for size progression monitoring of e.g. renal lesions, prostate abscesses or verified PCa for patients under active surveillance. Fig. 6 illustrates one of our patients with a prostate abscess for whom we initially established a US-3 D volume, and whom we monitored 10 days later using TF. However, technical fusion also demonstrated its value to us for the following issues, and is therefore used routinely in this regard.

Restaging
US/CT-TF can be used for restaging of e.g. seminoma patients in the course of ultrasound progression monitoring months after an initial CT scan as a supplement to a simple B image ultrasound. This offers greater certainty in the assessment of ambiguous changes, during the discovery of sonographically difficult to detect changes (e.g. retroperitoneal lymph nodes), or in cases of size progression evaluation such as described by Nakano et al. [2] (Fig. 7).

Additional applications
Technical fusion can prove useful for more independent progression assessment of e.g. nephropyeloplasty (Fig. 8), prostate volume and abscesses, renal trauma (Fig. 9), or ureteral calculus.

Limitations
As a rule, the purely technical aspects of TF present no difficulty after a short learning phase [2]. However, in its current state of development, TF still exhibits a few shortcomings and imprecision. In addition to the general limitations of ultrasound such as the presence of fat deposits, non-compliance or overlying bowel gas [14], the following difficulties are specifically related to technical fusion. First, the majority of currently available ultrasound units with integrated TF functionality have not been able to compensate for inaccuracies resulting from breathing movements or deformation of organs or body parts. Thus if a CT or MRI of the abdomen has been generated during deep inspiration, it can be difficult to achieve the same breathing position during the ultrasound examination. Additional problems can occur during an MRI/TRUS-TF of the prostate, since the organ is deformed as a function of the pressure applied by the TRUS probe. Further, movements of the probe displace the prostate. Currently, these inaccuracies can be only cognitively offset by good anatomical familiarity and sufficient practice by the examiner. This can be made somewhat easier on new instruments by the possibility of re-

Fig. 6
Fig. 7
Good slice correlation between real-time ultrasound (left image) and a 6-month-old CT data set (right image); note that the gallbladder (yellow arrow) and 2 hepatic cysts (white arrows) are in the same plane.

Fig. 8
Follow-up of a UPJ stenosis surgically treated in 1999; real-time ultrasound of 2014 (left image) fused with a CT data set from 2008; no loss of parenchyma and no growth of dilatation visible.
cording different images in various layer positions, respira-
tion positions or varying contact pressure, then accessing
them later. With respect to deformation and intracorporeal
movement of the prostate, Schilling et al. suggested apply-
ing constant contact pressure as well as multi-point regis-
tration [28]. Software which can compensate for inaccuracy
causd by e.g. organ deformation would be desirable for
genuine technical fusion after proper image recording. It
should be further considered that when using an endfire
TRUS probe, other layer angles are generated in the ultra-
sound image, in comparison with MRI depending upon the
angle of inclination [29].
Another source of TF imprecision is posed by the attach-
ment and placement of the position sensors on the distal
grip of the ultrasound probes made by most manufacturers.
In particular, when long ultrasound probes such as the TRUS
probe (Fig. 10) are used, the movement areas of the end of
the transducer which generates the real-time US images
differ from the sensors coupled to the movement of the 3 D
image data sets. Multi-point registration would be a means
to a solution; however, ultrasound probes with sensors al-
ready integrated into the end of transducer would be a de-
sirable improvement.
Currently it is difficult to provide an exact quantification of
registration errors/deviations in millimeters for TF, since a
wide variety of software platforms are used (rigid, elastic,
electromagnetic needle tracking) as well as biopsy types
(transperineal, transrectal), and in addition, there is insuffi-
cient published data regarding the precision of technical fu-
sion (particularly for biopsies) [30]. Pokorny et al. report
that a registration precision of 3.1 mm would be required
to hit a 1 cm large lesion with 95 % probability on the initial
examination [31]. Ekimura et al. achieved a deviation error
of 2.92 mm as well as a success rate of 84 % using a
3-dimensional elastic registration system on a prostate
phantom with integrated tumor clusters [32].
Finally, most manufacturers offer fusion software only for
premium-segment ultrasound units, which has an indirect
effect of making technical fusion relatively expensive.

**Conclusions**

The use of technical fusion in uroradiology opens numerous
possibilities and simplifications. TF-guided biopsies and ab-
lations of the prostate, for example, are a possible alternative
to interventions guided by large-scale equipment especially
in the private urological private practice, offering examiner-
independent therapy monitoring as well as the identification
of changes difficult or impossible to detect using only B im-
age ultrasound. Affordable ultrasound units and technical
developments would be desirable.

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Aigner F et al. Applications of Technical... Fortschr Röntgenstr 2015; 187: 331–337

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