Comparative evaluation of the geometrical accuracy of intravascular MRI

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Introduction

Intravascular MRI using miniaturized endovascular imaging coils offers the potential of an enhanced visualization of vessel morphology [1] and atherosclerotic plaque structure [2] due to an increase in signal-to-noise ratio (SNR) in comparison to traditional surface MRI. However, to our knowledge, whether this increase in SNR leads to a higher accuracy in the context of geometrical measurements of the vessel morphology as not been entirely investigated. Accordingly, the aim of the current study was to evaluate and quantify the geometrical accuracy of intravascular MRI in comparison to traditional surface MRI in the situation of vessel diameter measurements. Furthermore, as balanced Steady-State Free-Precession (bSSFP or TrueFISP) sequences were shown to offer the highest image quality in the context of intravascular imaging [1], several bSSFP sequence parameters were investigated to identify their influence on the achieved geometrical accuracy. Intravascular ultrasound (IVUS), a clinically validated imaging modality, was used as the gold standard in all experiments.

Methods

All experiments were performed on a multi-modality vascular phantom [3] consisting of a multi-step vessel embedded in an agar-based tissue mimicking material. The vessel consisted of cylindrical segments of diameters ~8.6 mm, ~6.4 mm, ~4.9 mm, ~3.3 mm and ~8.7 mm. It was filled with a gadolinium solution of concentration 1.8 mmol/L.

Sequences parameters for the different bSSFP acquisitions are presented in Table 1. A custom-made loopless antenna [4] was used for all intravascular MRI acquisitions while surface MRI sequences were performed using commercial array coils. For all sequences, 4 contiguous cross-sectional slices were acquired for each vessel segment. All measurements were performed on a clinical 1.5 T scanner.

The IVUS experiment was performed under fluoroscopic guidance using a 20 MHz probe. Images were acquired during a mechanical pull-back at a speed of 0.5 mm/s. Cross-sectional images with a slice thickness of 1 mm and an in-plane resolution of 50 µm were extracted from the 3D data set for all positions corresponding to the MRI slices locations.

All vessels diameters measurements were performed using an automated vessel segmentation algorithm [5].

#	Acq. time (s/slice)	Matrix	FOV (mm)	Resol. (µm)	TR (ms)	TE (ms)	BW (Hz/pixel)	NEX (iPAT)
Intravascular MRI sequences								
1	4.6	192 x 192	32 x 32	167	11.84	5.92	199	2
2	2.3	192 x 192	32 x 32	167	11.84	5.92	199	1
3	4.5	128 x 128	32 x 32	250	8.81	4.41	266	4
4	3.4	128 x 128	32 x 32	250	8.81	4.41	266	3
5	2.3	128 x 128	32 x 32	250	8.81	4.41	266	2
6	1.1	128 x 128	32 x 32	250	8.81	4.41	266	1
7	4.4	64 x 64	32 x 32	500	6.79	3.40	266	10
8	3.5	64 x 64	32 x 32	500	6.79	3.40	266	8
9	2.6	64 x 64	32 x 32	500	6.79	3.40	266	6
10	1.7	64 x 64	32 x 32	500	6.79	3.40	266	4
11	0.9	64 x 64	32 x 32	500	6.79	3.40	266	2
12	0.4	64 x 64	32 x 32	500	6.79	3.40	266	1
Surface MRI sequences								
13	4.1	1024 x 1024	350 x 350	342	7.82	3.91	257	(2)
14	4.8	704 x 704	350 x 350	497	6.83	3.41	263	1
15	2.5	704 x 704	350 x 350	497	6.83	3.41	263	(2)
16	4.5	384 x 384	350 x 350	911	5.89	2.95	266	2
17	2.3	384 x 384	350 x 350	911	5.89	2.95	266	1
18	1.2	384 x 384	350 x 350	911	5.89	2.95	266	(2)

Table 1 : bSSFP sequences parameters for intravascular and surface MRI. Flip angle = 70°, slice thickness = 3mm.

Results and Discussion

Mean relative differences in comparison to IVUS are presented in Table 2 for all MRI sequences. It can be observed that all MRI sequences show a slight tendency to underestimate vessel diameters in comparison to IVUS. However, all intravascular MRI sequences show a higher degree of agreement with IVUS than surface MRI sequences.

Overall, sequence 3 leads to the highest degree of agreement with IVUS. While having a higher resolution, sequences 1-2 suffer from lower SNR values while the decreased spatial resolution of sequences 7-11 also lead to a slight decrease in accuracy. Furthermore, while sequences 7-12 demonstrated a relatively good accuracy for circular vessels, it can be expected that their 500 µm in-plane resolution might not be sufficient to clearly depict small morphological features in real vessels.

While the results presented in Table 2 give a good assessment of the geometrical accuracy obtained with the different sequences, some effects are hidden by the averaging process over all segment sizes. In particular, intravascular MRI has the intrinsic characteristic of generating images showing a rapid decrease in SNR as a function of the distance to the antenna. As such, for the same imaging parameters, a much higher vessel wall SNR is expected for a smaller vessel, which should lead to a more precise vessel wall depiction. This effect is illustrated in Figure 1, where absolute diameter differences from IVUS are shown as a function of vessel wall SNR, for all intravascular MRI sequences using a resolution of 250 µm. It can be observed that for smaller vessels, faster sequences generating lower SNR values can still be used without a significant geometrical accuracy penalty.

#	Mean relative difference from IVUS	95 % confidence interval
Intravascular MRI sequences		
1	-2.21 %	-2.93 % / -1.49 %
2	-2.60 %	-3.32 % / -1.89 %
3	-1.61 %	-2.36 % / -0.86 %
4	-1.77 %	-2.52 % / -1.02 %
5	-1.80 %	-2.62 % / -0.99 %
6	-2.15 %	-2.90 % / -1.40 %
7	-1.95 %	-2.77 % / -1.13 %
8	-1.96 %	-2.79 % / -1.13 %
9	-1.94 %	-2.81 % / -1.08 %
10	-2.03 %	-2.85 % / -1.20 %
11	-2.22 %	-3.03 % / -1.39 %
12	-2.59 %	-3.31 % / -1.88 %
Surface MRI sequences		
13	-4.19 %	-5.07 % / -3.31 %
14	-4.33 %	-4.86 % / -3.80 %
15	-4.62 %	-5.54 % / -3.71 %
16	-7.36 %	-8.97 % / -5.76 %
17	-7.51 %	-8.74 % / -6.22 %
18	-7.72 %	-8.99 % / -6.45 %

Table 2 : Mean relative diameters differences in comparison to IVUS.

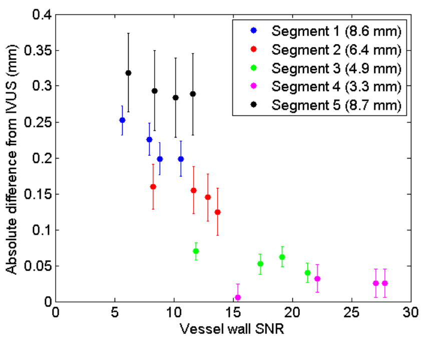

Figure 1 : Absolute differences from IVUS as a function of SNR, for intravascular MRI sequences with a spatial resolution of 250 µm.

Conclusion

The presented results indicate that intravascular MRI using a bSSFP sequence can provide highly accurate and precise vessel diameter measurements, with a relative deviation from IVUS of the order of 2% being achievable. Furthermore, using IVUS as the gold standard, intravascular MRI shows a significantly higher geometrical accuracy than traditional surface MRI. The added value of intravascular MRI indicates that the use of an intravascular imaging coil during a MR-guided interventional procedure appears as a valuable help to either perform pre-treatment measurements or assess the outcome of the procedure. Acquisition parameters should be tailored to vessel size and procedural time constraints.

References

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