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Technical feasibility of 2D–3D coregistration for visualization of self-expandable microstents to facilitate coil embolization of broad-based intracranial aneurysms: an in vitro study

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Abstract
Introduction The use of self-expandable microstents for treatment of broad-based intracranial aneurysms is widely spread. However, poor fluoroscopic visibility of the stents remains disadvantageous during the coiling procedure. Flat detector angiographic computed tomography (ACT) provides high resolution imaging of microstents even though integration of this imaging modality in the neurointerventional workflow has not been widely reported.
Methods An acrylic glass model was used to simulate the situation of a broad-based sidewall aneurysm. After insertion of a self-expandable microstent, ACT was performed. The resulting 3D dataset of the Microstent was subsequently projected into a conventional 2D fluoroscopic roadmap. This 3D visualization of the stent supported the coil embolization procedure of the in vitro aneurysm.
Results In vitro 2D–3D coregistration with integration of 3D ACT data of a self-expandable microstent in a conventional 2D roadmap is feasible.
Conclusions Unsatisfying stent visibility constrains clinical cases with complex parent vessel anatomy and challenging aneurysm geometry; hence, this technique potentially may be useful in such cases. In our opinion, the clinical feasibility and utility of this new technique should be verified in a clinical aneurysm embolization study series using 2D–3D coregistration.

Keywords Aneurysm · Coil embolization · Self-expandable microstent · Angiographic CT · Flat detector CT

The concepts and information presented in this paper are research-based and not commercially available.

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Introduction

The use of a self-expandable stent to scaffold the broad-based aneurysm neck with subsequent coiling through the stent interstices prevents coil prolapse into the parent artery [1,2]. Most of the currently available intracranial self-expanding microstents are characterized by poor fluoroscopic visibility, especially the single stent struts, which are hardly visible in fluoroscopy. This appears to be disadvantageous, especially when parent vessel anatomy is complex, in fusiform aneurysm geometry, or when microcatheter navigation in the aneurysm sac is demanding.

Angiographic computed tomography (ACT) uses rotational, C-arm mounted flat-panel detector technology capable of high spatial resolution volumetric imaging, which supports neurointerventional procedures [3]. The utility of ACT in neurointerventional procedures, especially for stent imaging, is described previously [4–6]. Systematic assessment of Neuroform stents after coil embolization of cerebral aneurysms is described, as well as ACT based 3D reconstructions of intracranially inserted Neuroform stents

provide valuable visualization of stent deployment and single stent struts [7]. To our knowledge real-time integration of this ACT stent imaging data in the aneurysm coiling procedure is not reported until now.

The aim of our in vitro study was to evaluate the technical feasibility of real-time 2D–3D fusion of 3D ACT data and 2D roadmap in stent-assisted aneurysm coil embolization procedures. An acrylic glass model was used to simulate the situation of an intracranial sidewall aneurysm.

Technical report

Angiography suite

The procedure was performed on a Siemens AXIOM Artis dBA Twin C-arm angiography system (Siemens AG, Healthcare Sector, Forchheim, Germany), which is equipped with flat panel X-ray detectors giving distortion free images and is capable of producing CT-like images. Interfaced to the system was a Leonardo syngo workplace (Siemens AG, Healthcare Sector, Forchheim, Germany) for 2D and 3D image processing. Subsequent transfer of the projection images to the Leonardo syngo workplace works automatically and without temporal delay.

A second Leonardo syngo workplace (Clinical Prototype) was connected to the AXIOM Artis which contained the prototype software for 2D–3D image registration and fusion. The Leonardo prototype was also connected to the C-arm to ensure a real-time transfer of the entire C-arm parameters under which the 2D images were acquired, including angulations, table positions, etc. This provides adaptation of the superimposed visualization of 2D and 3D data automatically and in real time adapted to the current C-arm and table geometry. In case of external movement (e.g., patient movement which may occur in clinical applications) reregis-

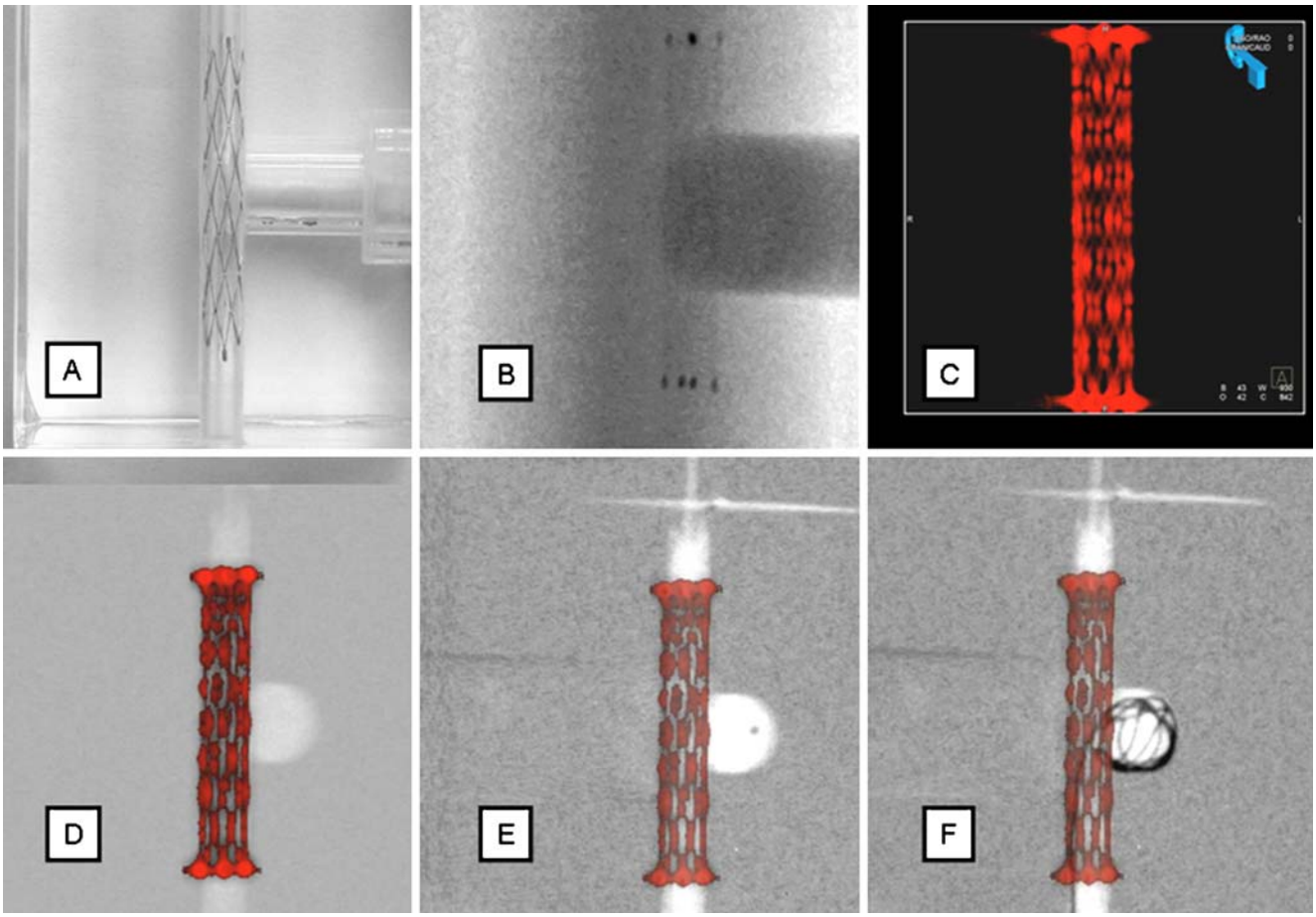

Fig. 1 **a** Acrylic glass model with *longitudinal* 3.5 mm diameter and deployed Neuroform stent, 3.5×20 mm in size. The *lateral hole*, 5 mm in diameter, represents the model sidewall aneurysm. **b** Plain fluoroscopy after stent insertion. The proximal and distal radiopaque stent markers are visible. The single stent struts are visible rudimentary. In vivo (intracranially inserted Neuroform stent), the stent struts are almost not visible, other than the radiopaque proximal and distal stent markers. **c** The 3D reconstruction of the deployed Neuroform stent is displayed in *red color* in order to be *silhouetted* against the 2D roadmap. **d** Coregistration of the 3D reconstruction of the Neuroform stent and the conventional 2D roadmap showing the sidewall aneurysm. **e** Radiopaque *tip* of the microcatheter in the aneurysm model. **f** Platinum microcoils in the aneurysm

tration can be achieved either manually or by using image-based methods. This technique was previously described [8].

In vitro aneurysm model

To simulate a concise sidewall aneurysm situation, an acrylic glass cuboid (5.0×2.5×1.5 cm in volume) was used with a 3.5 mm bore hole and a second 5 mm lateral bore hole laterally locked-up. The resulting lateral cylindrical volume had an extension of 5 mm in width and of 7 mm in length. The shape of the in vitro aneurysm neck was oval (diameter range 3.5–5.0 mm; Fig. 1a).

Stent application

A conventional 2D roadmap was prepared with a single contrast flush and the C-arm in a standard posterior–anterior orientation. Under fluoroscopy, a Neuroform stent (Boston Scientific Corp., Fremont, California, USA), 3.5 mm×20 mm in size, was placed across the in vitro aneurysm to cover the neck of the aneurysm model.

Angiographic CT

Subsequently, a noncontrast ACT was performed using the following parameters: acquisition time, 20 s; 1,240×960 projection matrix; projection on 30×40 cm flat panel size; and 217° rotation angle, 538 images in total, increment 0.4°/image, and standard system dose 0.36×10^{-6} Gy/image.

Postprocessing

After primary reconstruction of the ACT data, secondary reconstruction of the volume containing the Neuroform stent was performed with a resulting isotropic voxel size of about 0.15 mm. The 3D reconstruction of the stent was then transferred to the prototype Leonardo workplace.

2D–3D coregistration

Assuming there is no patient movement, the position of the reconstructed volume relative to the C-arm is known (so-called extrinsic parameters), since the 3D acquisition takes place on the angiography system. Additionally, the intrinsic imaging parameters of the system (focal length, pixel spacing, and the position of the central beam) are given from the calibration of the system [9] with a geometrical phantom. With this information, the reconstructed 3D can be projected into the 2D image as if imaged from the angiography system (Figs. 1d-f and 2). In cases of extreme angulations or external movements (e.g., patient head movement), a mismatch between 2D and projected 3D may be observed. In these cases, a reregistration (i.e., the readjustment of the projected 3D to match 2D again) has to be performed either manually by adjusting the volume or by algorithms, which automatically compare the contents of the images [8]. The 3D VRT (Volume rendering technique) of the stent was then projected into the conventional 2D fluoroscopic roadmap.

Coil embolization

Under roadmap and with the superimposed stent overlay, the coil embolization was performed by using conventional 0.014-inch microguidewire and microcatheter, with a total of four microcoils (Figs. 1e, f). To ensure correct insertion of the coils, the C-arm was angulated repeatedly. The repeated repositioning of the C-arm resulted in immediate

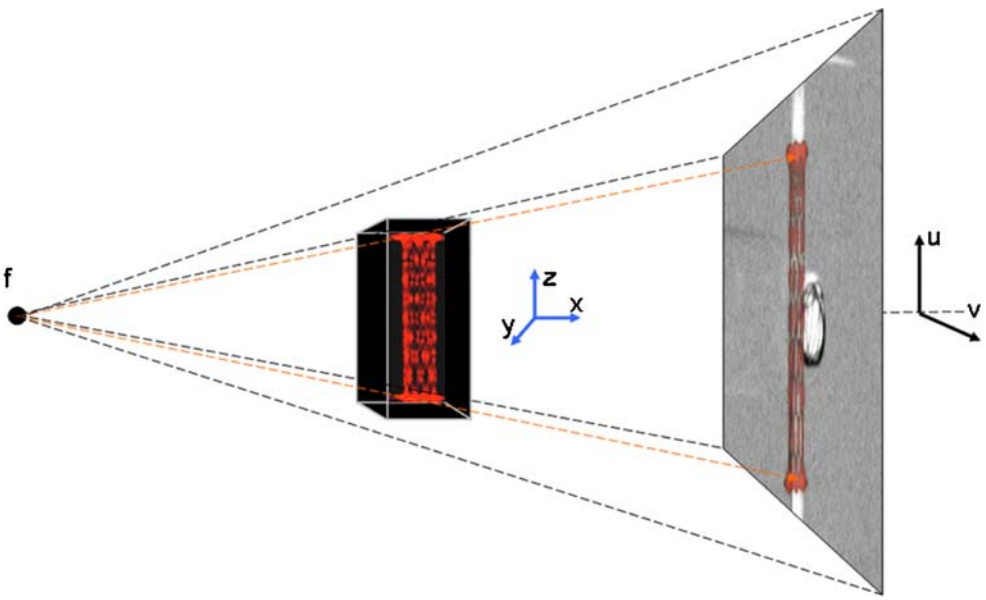

Fig. 2 Established parameters are the reconstructed dataset of the microstent including its actual spatial position and the internal parameters of the C-arm (such as distance between X-ray focus and detector; *pixel size*). Hence, it is possible to project the 3D volume dataset of the microstent into the 2D roadmap correctly

reregistration of the 3D VRT of the stent. The time needed for preparation of the 2D–3D coregistration, including acquisition of ACT and postprocessing, was less than 10 min.

Discussion

Treatment of broad-based intracranial aneurysms is sometimes challenging even for the experienced neurointerventionalist. Among other remodeling techniques, the use of self-expandable microstents is the cardinal alternative.

The high trackability, flexibility, and the low profile of current stent systems designed for aneurysm treatment resulted to limited fluoroscopic visibility of the single stent struts. The proximal and distal markers of the Neuroform3 stent allow an assessment of stent position in relation to the longitudinal dimension of the parent vessel, though apposition of the the stent to the vessel wall and the spatial position of the stent struts remain unclear. Based on our experience in cases with curvy parent artery anatomy or with complex or even fusiform aneurysm geometry, the poor radiopacity of the stent struts are disadvantageous.

The goal of this in vitro study was to demonstrate the technical feasibility of 2D–3D coregistration of ACT data of a Neuroform microstent in a 2D roadmap. The study showed that this 2D–3D coregistration technique is feasible.

Particularly in case of repeated changes of C-arm positions with acquisition of new 2D roadmaps, the unproblematic adaption of the covisualization of the 3D reconstruction of the microstent into the 2D roadmap is persuasive. The ability to respond to external (e.g., examination table or even patient head) motion with reregistration seems to be promising. The coregistration results in a combination of real-time (conventional) 2D roadmap and the 3D VRT of the stent. Movement of the stent during the procedure is hardly visible in the 2D–3D roadmap, as well as in a conventional roadmap. When the stent shifts under the conditions of 2D–3D roadmap, the stent will move out of the 3D projection, and therefore, will show visibility characteristics comparable to a situation in conventional roadmap. In the rare case of significant stent migration during microcatheter navigation into the aneurysm or aneurysm coiling, it may be advisable to perform a new ACT acquistion and use the resulting VRT for a newly arranged 2D–3D roadmap.

Due to a close interaction with the C-arm, the display update (i.e., the 2D–3D overlay) is done in real time with no user interaction. As soon as the C-arm angulation is changed, the 3D adapts to the new angulation and is correctly overlaid to fluoroscopy.

To our knowledge, integration of this imaging technique in a real-time 2D roadmap and with it in the workflow of stent-assisted aneurysm coil embolization is not previously reported. The in vitro superimposition of the ACT-based 3D reconstruction of an inserted self-expandable microstent into a conventional 2D roadmap in terms of a 2D–3D coregistration seems to be an efficient tool to overcome the problem of poor fluoroscopic stent visibility.

Conclusion

In vitro 2D–3D coregistration with integration of 3D ACT data of a self-expandable microstent in a conventional 2D roadmap is feasible. Unsatisfying stent visibility is unfavourable especially in clinical cases with complex parent vessel anatomy and challenging aneurysm geometry, hence, this technique potentially may be useful in such cases. Thus, in our opinion, the clinical feasibility and utility of this new technique has to be verified in a clinical aneurysm embolization study series using 2D–3D coregistration.

Conflict of interest statement We declare that we have no conflict of interest.

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