3D Road-Mapping in the Endovascular Treatment of Cerebral Aneurysms and Arteriovenous Malformations

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Summary

3D road-mapping with syngo iPilot was used as an additional tool for assessing cerebral aneurysms and arteriovenous malformations (AVMs) for endovascular therapy. This method provides accurate superimposition of a live fluoroscopic image (native or vascular road-map) and its matching 2D projection of the 3D data set, delivering more anatomic information on one additional display. In the endovascular management of cases with complex anatomy, 3D road-mapping provides excellent image quality at the intervention site. This method can potentially reduce intervention time, the number of DSA runs, fluoroscopy time and the amount of contrast media used in a procedure, with reservation for these factors being mainly operator-dependent. 3D road-mapping probably does not provide any advantage in the treatment of cerebral aneurysms or AVMs with very simple configuration, and it should not be used when acquisition of an optimum 3D data set is not feasible.

Introduction

Navigation of catheters through the cerebral vasculature for endovascular interventions is usually done under real-time, rapid-sequence fluoroscopic x-ray imaging using the road-mapping technique. Reference images from 2D or 3D diagnostic studies are often displayed dur-

ing the procedure, providing support for the choice of working projections as well as for improved visualization of the vascular anatomy at the therapeutic target. 3D road-mapping is feasible by computerized image fusion of the live 2D fluoroscopic image and its matching 2D projection of the 3D data set^{1,2}, providing assembled imaging on a single display that is potentially useful in complex interventions.

The aim of this paper is to evaluate the clinical application of a flat-panel detector-based 3D road-map system as an additional tool for assessing cerebral aneurysms and arteriovenous malformations (AVMs) for endovascular therapy.

Methods

Technical description of syngo iPilot 2D3D image fusion

The imaging geometry of a C-arm is usually described as a pinhole camera model³⁻⁶, where an x-ray source S at a focal point with distance f to a detector D creates a perspective projection of the volume located in between S and D , so each 3D point v is projected onto a 2D point d on the detector D (Figure 1). The parameters P describing the corresponding projection can be divided into two different sets. The so-called *extrinsic parameters* basically describe the rotation and translation of the detector coordinate system relative to the volume's coordinate system. The second set, the five *intrinsic c-arm camera*

Figure 1 Pinhole camera model of a C-arm. An X-ray source S , located at a focal point with distance f to a detector D creates a perspective projection of each 3D point v on to a 2D point d on the detector.

Figure 2 Principle of 2D3D Overlay. Since all the imaging parameters are known, the 3D volume can be rendered as imaged from the X-ray focus. When the resulting image is then fused with the live fluoroscopic image, anatomical correctness is maintained.

Figure 3 Principle of the 2D3D registration. The (known) intrinsic parameters fixed for the actual X-ray image and the external parameters (rotation and translation) are adjusted to achieve a match between 2D and perspective projection of the 3D.

parameters (focal length f , the coordinates of the central beam (u_0, v_0) and the detector pixel spacing (dx, dy)) contains knowledge of the c-arm imaging geometry. For angiography c-arm systems, the focal length f is usually denoted by SID (Source Image Distance). Due to mechanical reasons (e.g. bending of the c-arm), the intrinsic parameters usually show small variations depending on the actual c-arm angle.

For the trajectory used to acquire 3D images (CRAN/CAUD = 0° , RAO = 100° to LAO = 100°), the intrinsic parameters can be obtained with very high accuracy using a geometry calibration procedure⁵⁻⁸. An extension of this calibration, similar to that described by Gorges et Al.⁹, gives an overall model of the c-arm to estimate the intrinsic camera parameters for each given set e of extrinsic C-arm parameters, also outside the 3D trajectory. This means that, for any given c-arm angulation and translation, any virtual 3D point with known coordinates can be projected “correctly” into a 2D x-ray image acquired under these angles as if it was imaged from the c-arm (Figure 2). This technique can also be used to produce the kind of anatomically correct 2D3D overlay as previously described^{2,9,10}. Patient movement is an actual limitation when using 2D3D image fusion. In case a mismatch between the perspective projection of the 3D and the actual 2D x-ray image occurs (mainly due to patient movement) the registration needs to be updated by adjusting the volume, as illustrated in Figure 3. Since the intrinsic parameters for the actual x-ray image are known, the six external parameters of the volume (location and orientation) have to be adjusted to re-achieve a match between 2D and 3D. This can either be done manually by the identification and manual alignment of anatomical landmarks, but also with the use of sophisticated automatic algorithms^{3,4,11,12}, which iteratively adjust the volume projection until a certain error criterion is minimized. Preconditions for these methods are matching features which can be seen in both the x-ray image and the corresponding 3D volume, such as the bony structures of the skull or a 2D angiogram to compare to the 3D vessel tree.

– *Study population:* 3D road-mapping has been used in our institution since September 2008 as an additional tool during endovascular treatment of intracranial aneurysms, brain AVMs, and in one instance of direct carotid-cavernous fistula. Data on patient selection, ad-

Figure 4 Direct carotid-cavernous fistula on the right side. 3D RA in antero-posterior (A) and view shows bilateral venous drainage. On lateral projection the dilated cavernous sinus and intracranial outflow veins on the left side projected on the target vessels, making the reference images unclear. The 3D volume was reduced to the essential target vessels by punching the volume of interest (B), and used for 3D road-map. The lateral 2D vascular road-map (C) shows also the contralateral veins, but the 3D road-map (D) permits a clearer definition of the target vessels. The fistula was occluded with GDC and Matrix coils.

ditional radiation dose to the patients due to the 3D RA run, and availability of the 3D road-map over time were assessed over the first three-month period after implementation of the technique.

Equipment and imaging workout

An X-ray system Artis zee Biplane Twin, and a workstation *syngo* X Workplace with DynaCT reconstruction software *syngo* iPilot (all from Siemens AG, Healthcare Section, Forchheim, Germany) were used. The procedures were performed in an operation room under surgically sterile conditions, general anesthesia

(inclusive of muscle relaxation), and using a percutaneous transfemoral approach. Endovascular procedures, anticoagulation therapy and post-operative care were carried out according to our standard techniques and routines for each case. The imaging workout consisted of digital subtraction angiography (DSA) of the vessels of interest in postero-anterior and lateral projections before and after the therapeutic procedure, 3D rotational angiography (3D RA), biplane vascular 2D road-mapping and simultaneous monoplane live 2D3D *syngo* iPilot image fusion during microcatheter navigation and therapy, and additional DSA through the

Figure 5 3D road-maps showing catheterization of aneurysms at anatomical sites with complex branching pattern of the parent vessels. (A) Aneurysm of the left middle cerebral artery on the in an angulated lateral projection. (B) Aneurysm of the anterior communicating artery in a lateral projection after punching the 3D volume with deletion of the data corresponding to the middle cerebral artery, which projected on the aneurysm (the microcatheter tip is into the aneurysm, and the guidewire was withdrawn about one centimeter; this aneurysm was not optimally viewed on anterior-posterior or oblique projections, and would hardly be safely catheterized and coiled without 3D road-mapping). In cases such as these, the advantage of the 3D RA in choosing a working projection is combined with using the 3D rendering to monitor aneurysm catheterization.

guidecatheter or microcatheter performed as necessary for procedure evaluation and documentation. 3D RA was performed with the anatomy of interest positioned in the system isocentrum. The patient's head was kept immobile during the 3D RA run and as long as the 3D road-map was being used. The c-arm circular trajectory covered 200°, and a series of 133 frames were exposed over five seconds at intervals of 1.50° with 0° angulation around the axis perpendicular to the detector plane, with a zoom of 42 cm diagonally. During image acquisition contrast agent (Hexabrix® 320 mgI/ml; Laboratoire Guerbet, Roissy, France) was injected into the vessel of interest (internal carotid of vertebral artery) usually at a rate of 3 ml/s (20 ml total) with a delay between injection start and first frame of 2 s and injection rate rise of 0.2 s. Injection rates and total volumes were adjusted according to vessel caliber and hemodynamic properties of the vascular lesion to be targeted as evaluated in the previous DSA. For each case 3D RA was done with native or subtracted data acquisition. When subtracted data acquisition was the case a mask rotational run was done before the fill run during injection of contrast agent. The 3D vascular reconstruction can also be obtained with a syn-

go DynaCT rotational run (496 frames over 200°) with contrast agent dilution, injection rate, and total volume adjusted for this technique. Source images were transferred automatically to the workstation, and the primary 3D reconstruction (512x512 slice matrix) was available within 18 seconds for high contrast RA images. A translucent, orange-colored modality preset window was optimized for 3D road-mapping and used as default, and necessary window adjustments for each case were minimal, if any. If desired, further optimization of the 3D reconstruction can be done by restricting the volume of interest (VOI) manually to enhance visualization of the site of intervention in the iPilot image, e.g. in case of a pathological target in a branch of a posterior cerebral artery (PCA) the contralateral PCA can be removed from the VOI by using a clip plane. Live 2D3D image fusion with *syngo* iPilot could then be started. Live fluoroscopy and its matching 2D projection of the 3D volume could be faded on each other, and displayed in one image. The degree of fading could be smoothly adjusted using a joystick. The best working projection and zoom was then chosen by rotating the C-arm. When a lateral projection was considered ideal for 3D road-map-

Figure 6 3D road-maps showing catheterization of AVMs. A cerebellar AVM fed by a branch of the left superior cerebellar artery is shown in (A). The arrow points to the microcatheter tip, and the AVM was embolized with glue from this point. Note that the 3D data set is fixed and cannot be adjusted for organ movement or distortion. The guidewire and microcatheter deformed the arteries and are projected partially outside the vessel contour in the 3D volume. Figure parts (B,C) show embolization of an AVM in the right thalamus, fed by a posterior choroidal branch of the right posterior cerebral artery (PCA). The contralateral PCA was deleted from the 3D data set before 3D road-mapping. Embolization of the AVM was done with balloon-assisted technique. 3D road-map from a lateral position (B) shows the balloon-catheter (arrow on the left) placed in the right PCA overlapping the AVM feeder, into which the microcatheter's guide wire is introduced. The balloon occluded temporarily the right PCA, and the AVM was embolized with Onyx-18 (C); the arrow points to the microcatheter tip.

ping, the c-arm was rotated 90° and a mirror image of the usual lateral projection was used, and the other flat detector was rotated to the frontal projection. A biplane vascular road-map was then obtained by the X-ray system, and microcatheter navigation into the cerebral vessels to the target site was performed using three image displays consecutively or simultaneously: conventional 2D vascular road-maps were displayed in two monitors, and a third monitor showed the c-arm road-map faded into its matching 2D projection of the 3D volume; the used x-ray system has also four additional monitors for live unsubtracted fluoroscopy and reference images. In case of mismatch between 3D projection and 2D image, the image on the iPilot monitor was adjusted with reference to anatomical landmarks, either manually or by using automatic algorithms ("Adjust to Patient" functionality).

Results

Over the first three-month period after implementation of 3D road-mapping this technique was used as an additional imaging tool in 24 endovascular procedures. This patient group is described here in more detail concerning patient selection, radiation dose to the patient due to the 3D RA run, and availability of the 3D road-map over time. Fifteen patients with intracranial aneurysms (17 aneurysms were oc-

Figure 7 Aneurysm of the anterior communicating artery just after endosaccular embolization with coils. The 3D road-map (A) shows a coil mesh that is smaller than the aneurysm as shown in the reformatted 3D data set. However, the aneurysm was completely obliterated in a DSA run (B). The choice of the rendering mode and windowing influence the volume of the 3D data set.

cluded in 15 procedures) and eight patients with brain AVMs (nine procedures) were treated. This patient group corresponded to 62% of all patients with these pathologies treated with endovascular techniques during the same period in our institution (26 patients with 31 treated aneurysms, and 11 patients with AVM that underwent 14 procedures). Twenty-five 3D RA runs were done and used for 3D road-mapping. One patient with an AVM in the cerebellum and a ruptured dissecting aneurysm in a feeder artery was treated for both pathologies in the same procedure and using the same 3D data set. One patient was treated for two aneurysms in the anterior circulation and for one aneurysm in the posterior circulation, and thus two 3D image acquisitions for road-mapping were done. The radiation dose to the patient (kerma-area product) due to the 3D RA runs (N=25) was an average 956.5 Gy cm^2 (minimum 677.4 Gy cm^2 ; maximum 1312.2 Gy cm^2 ; SD 161), and the predicted skin dose was 44.6 mGy (minimum 31.6 mGy; maximum 61.1 mGy; SD 7.5). The technical procedure was successful,

there was no hardware or software difficulty, and a realistic 3D road-map was obtained in all cases. In these cases, the 3D roadmaps could be used as long as needed during microcatheter navigation in all cases, and useful road-mapping was possible up to the end of the procedure (duration 66.9 minutes in average, ranging from 27 to 166 minutes; N=24) in all but one procedure that was interrupted to place an external ventricular drainage before the procedure could be continued.

Once the site of pathology had been defined in diagnostic studies, the use of 3D road-mapping provided excellent image quality at the site of intervention. The use of a 2D vascular road-map for image fusion and not only plain fluoroscopy was especially helpful in this aspect, since the 3D data set could be cut down to the target lesion's essentials, which enhances visibility and definition of the target anatomy (Figure 4). 3D road-mapping was helpful for catheterization and coil deployment into cerebral aneurysms located in complex branching anatomy (Figure 5) as well as for feeder artery

recognition and selection in the catheterization of complex cerebral AVMs (Figure 6). The simultaneous use of a 2D vascular road-map is essential for biplane fluoroscopic guidance, since the 3D volume can be displayed on only one monitor.

Slight mismatch between the projection of the 3D volume and the 2D vascular road-map developed over time in longer interventions, and in case of need for airway care or other occasion when the anesthesiologist touched the patient's head. 3D2D mismatch was not perceived as a major drawback. When a mismatch was noticed the 3D2D fusion could be satisfactorily adjusted in all cases by manual alignment of anatomical landmarks using a joystick, and in some cases obtaining a new 2D vascular road-map was also helpful.

The guide wires used varied in diameter from 0.007 in (0.18 mm) to 0.014 in (0.37 mm). Visualization of guide wires and microcatheter tip markers was satisfactory in all cases, but adjustment of the 3D2D fusion, with some fading of the 3D volume, was done as necessary when the microcatheter and wire projected over the temporal bone, where the skull is more dense and irregular. On these occasions fading adjustment, as well as return to the previous fading level, could be done swiftly using a joystick, and it did not disturb the procedure.

The 3D volume is fixed at the time of the 3D RA acquisition, and it does not show changes in the target vessels that appear over time, for example when vasospasm develops in small arteries during catheter navigation. Thus, dynamic changes in the target vessels or in the lesion occurring during the procedure are not evident. The deformation of the cerebral blood vessels provoked by microcatheter navigation can be more impressive when observed through the 3D volume compared to the usual 2D vascular road-map, especially during catheterization of AVM feeder arteries distal to the circle of Willis (Figure 6A) or during navigation of a stent. In coiled aneurysms, a final checking on the 3D road-map can show discrepancy in shape or volume of an aneurysm when comparing the 3D volume and the coil mesh (Figure 7).

Discussion

3D road-mapping with *syngo* iPilot provides accurate superimposition and fading between a live fluoroscopic image (native of vascular

road-map) and its matching 2D projection of a 3D data set, delivering more anatomic information on one additional display. In the endovascular management of cerebral aneurysms and AVMs 3D road-mapping provides a superior image quality at the intervention site compared to conventional x-ray-guided techniques alone that is useful in cases with complex anatomy. The advantages of this technical tool are more evident in aneurysm treatment. 3D RA and volume-rendering software, by now routine in planning endovascular aneurysm therapy in many institutions, improved the efficiency of this type of procedure by optimizing case selection, analysis of aneurysm morphology, and choice of optimum working projections¹³. Using 3D road-mapping, these benefits become accessible directly in the virtual operating field.

The term "3D road-mapping" deserves further examination. In the present report 3D road-mapping was not done with a 3D monitor, but with a 2D monitor. So it could be called "intermediate 3D road-mapping" as well. With current technology, it would not make sense to use a 3D monitor, since the image 3D volume is to be fused with a 2D vascular road-map or plain fluoroscopy. "True" 3D road-mapping will need the 3D localization of the interventional devices, that is the guidewire or coils would be displayed directly in the 3D volume so that they could be visualized directly in 3D, even from angles that are not physically possible with current systems. Such a hypothetical system would not necessarily require a 3D monitor.

The new features of *syngo* iPilot compared to an earlier 3D road-mapping system² are the possibility to adjust the 3D volume to patient movement, and the possibility to use a 2D vascular road-map (not only plain fluoroscopy) for image fusion. A drawback of 3D road-mapping has been the necessity to avoid any spatial misalignment of the patient's head once the 3D data set is acquired.

General anesthesia, muscular relaxation, careful fixation of the patient's head on a firm head support, and avoidance of unnecessary patient manipulation are essential for safe intracranial 3D road-mapping, but slight misalignment of the 3D volume is unavoidable in lengthy procedures, e.g. when airway care is necessary. If the patient has moved, with *syngo* iPilot it is not necessary to acquire a new 3D data set in order to re-establish an exact anatomical alignment. Correction for patient movement

can be done either by a quick manual adjustment of anatomical landmarks using the *syngo* iPilot joystick, or by doing an automatic image based re-registration of the 3D volume (so-called "Adjust to Patient" functionality).

It has been proposed that 3D road-mapping potentially shortens intervention time and reduces the number of DSA runs, fluoroscopy time and amount of contrast media used in a procedure^{1,2}, but on closer scrutiny such considerations are pointless because these factors rely to a large extent on the interventionist's experience and technique. However, two aspects of this problem still seem worth discussing. First, in current practice a 3D RA acquisition of the vessel tree focused on the target lesion is done routinely in most cases for diagnostic purposes as well as for reference during the procedures. Thus, no extra amount of contrast agent and no extra radiation dose to the patient are necessary to obtain the 3D RA run to be used for road-mapping as far as this image acquisition would be part of the procedural routine. Otherwise, the 3D run adds to the procedural contrast

agent and radiation load. Second, while the possibility to use a 2D vascular road-map for image fusion and not only plain fluoroscopy is a especially helpful tool in *syngo* iPilot that can potentially shorten fluoroscopy time and the number of DSA runs to check the ongoing procedure, contrast agent has to be used as usual to obtain the 2D vascular road-map.

A last word on operator-dependent decisions: 3D road-mapping should be reserved not only for the cases when it is feasible, but also for the cases in which it brings benefits. It probably does not provide any advantage in the treatment of cerebral aneurysms or AVMs with plain configuration that do not pose difficulties in finding good working projections, and when the navigation of microcatheters is undemanding, for example in most carotid siphon aneurysms at the origin of the posterior communicating artery. Moreover, this technique should not be attempted when acquisition of an optimum 3D data set is impractical, for example in cerebral AVMs presenting with extremely high-flow arteriovenous fistulous components.

References

- 1 Bakker NH, den Heeten GJ et Al: Image guidance for neurovascular intervention: proposed setup for a 3D-roadmap system. *Min Invas Ther & Allied Technol* 12: 304-309, 2003.
- 2 Söderman M, Babic D et Al: 3D roadmap in neuroangiography: technique and clinical interest. *Neuroradiology* 47: 735-740, 2005.
- 3 Wolff R: 2D-3D Registrierung medizinischer Bilddaten. Master Thesis, Universität Koblenz-Landau, 2004.
- 4 Penney GP: Registration of tomographic images to X-ray projections for use in image guided interventions. PhD Thesis, King's College London, 1999.
- 5 Wiesent K, Barth K et Al: Enhanced 3D-reconstruction algorithm for c-arm systems suitable for interventional procedures. *IEEE Trans Med Imaging* 19: 391-403, 2000.
- 6 Galigekere RR, Wiesent K: Cone beam reprojection using projection matrices. *IEEE Trans Med Imaging* 22: 1202-1214, 2003.
- 7 Strobel N, Heigl B et Al: Improving 3D image quality of X-ray c-arm imaging systems by using properly designed pose determination systems for calibrating the projection geometry. *Proceedings of SPIE* 5030: 943-954, 2003.
- 8 Wiesent K, Schwierz G: X-ray computed tomography apparatus having marks for geometrical image correlation. US Pat. No. 5,706, 324, 1996.
- 9 Gorges S, Kerrien E et Al: Model of a vascular C-arm for 3D augmented fluoroscopy in interventional radiology. *Med Image Comput Comput Assist Interv Int Conf Med Image Comput Comput Assist Interv* 8 (Pt 2): 214-222, 2005.
- 10 Richter G, Pfister M et Al: Visualization of selfexpandable stents using 2D3D coregistration of angiographic computed tomography data to facilitate stent assisted coil embolization procedures of broad based intracranial aneurysms: in vitro feasibility study. *Clin Neuroradiol* 2007; 17(Spec Issue 1): 36 [Abstract].
- 11 Khamene A, Bloch P et Al: Automatic registration of portal images and volumetric CT for patient positioning in radiation therapy. *Medical Image Analysis* 10: 96-112, 2006.
- 12 Prümmer M, Hornegger J et Al: Multi-modal 2D-3D non-rigid registration. *Proceedings of SPIE* 6144(1): 61440X1-61440X12, 2006.
- 13 Loh Y, McArthur DL et Al: Safety of intracranial endovascular aneurysm therapy using 3-dimensional rotational angiography: a single-center experience. *Surg Neurol* 69: 158-163, 2008.

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