

ROADMAPPING IN ANGIOGRAPHY: IMAGING PHYSICS, TECHNICAL PRINCIPLES, RADIATION CONSIDERATIONS AND ITS IMPACT ON PROCEDURAL EFFICIENCY—A NARRATIVE REVIEW

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Abstract

Background: Angiographic roadmapping retains contrast-defined vascular anatomy and superimposes it on subsequent fluoroscopy, allowing real-time navigation of catheters and guidewires after intravascular contrast has cleared.

Aim: To review the imaging physics, technical implementation, radiation implications and clinical evidence for conventional two-dimensional roadmapping and three-dimensional image-fusion roadmapping, with emphasis on arterial cannulation time, fluoroscopy and procedure duration, radiation exposure, contrast use and angiography-suite/table time.

Methods: A narrative synthesis of peer-reviewed literature on digital subtraction angiography (DSA), fluoroscopic roadmapping, radiation dosimetry and image-fusion-guided endovascular procedures was undertaken. Comparative studies and systematic reviews reporting procedural or dosimetric outcomes were prioritized.

Findings: Roadmapping can reduce repeated high-dose angiographic acquisitions and improve target-vessel localization, but its radiation effect depends on pulse rate, acquisition mode, field size, patient habitus, projection geometry, registration accuracy and whether roadmap guidance truly replaces DSA. In carotid artery stenting, 3D fusion reduced mean time to common carotid cannulation from 31 ± 8 to 21 ± 9 min and radiation exposure from 300 ± 26 to 207 ± 23 mGy, while total in-room time was unchanged. Meta-analytic evidence in complex endovascular aortic repair demonstrates reductions in fluoroscopy time, procedure duration and contrast use, with more heterogeneous radiation findings. Conclusion: Roadmapping is best understood as a navigation strategy rather than an intrinsically low-dose imaging mode. Its principal value is the reuse of previously acquired vascular information to guide device movement, potentially reducing repeated contrast injections, DSA acquisitions and time spent identifying target arteries.

1. INTRODUCTION

Fluoroscopy-guided angiography requires the operator to navigate radiopaque catheters and guidewires through a vascular system that is poorly visible without contrast enhancement.

Digital subtraction angiography (DSA) solves the diagnostic visibility problem by suppressing stationary background anatomy, whereas roadmapping extends that information into a navigational tool: a contrast-defined vascular

image is retained and displayed with subsequent live fluoroscopy. In practical terms, the operator can continue to see the vessel course after contrast washout while advancing a device toward a selected branch (1,2).

The concept is clinically attractive because repeated localization angiograms consume time, iodinated contrast and radiation. However, roadmapping itself requires image acquisition and therefore cannot be assumed to reduce dose automatically. Radiation burden depends on the relative contribution of fluoroscopy, roadmap runs, DSA, cone-beam CT or rotational angiography, magnification, pulse/frame rate, collimation, patient thickness and projection geometry (3–6). The correct question is therefore not whether roadmapping uses radiation, but whether a roadmap changes the overall imaging strategy sufficiently to reduce total imaging burden while preserving procedural safety.

This narrative review examines the physical basis of roadmapping, conventional 2D and 3D fusion techniques, registration and misregistration, radiation-dose metrics, and clinical evidence comparing roadmap/fusion-guided procedures with conventional guidance. Particular emphasis is placed on outcomes directly relevant to workflow: arterial cannulation or wiring time, fluoroscopy time, procedure duration, radiation exposure, contrast volume and patient in-room/table time.

2. METHODS: NARRATIVE REVIEW APPROACH

This article is a narrative review. Peer-reviewed literature addressing DSA physics, fluoroscopic roadmapping, radiation protection and image-fusion roadmapping was identified with emphasis on PubMed-indexed studies, systematic reviews, meta-analyses, professional radiation-protection guidance and comparative clinical cohorts. Priority was given to studies reporting quantitative outcomes for roadmap/fusion guidance versus conventional angiographic guidance. Because the available evidence spans conventional 2D roadmapping, CT/fluoroscopy fusion, cone-beam CT registration and different vascular territories, formal statistical pooling was not performed in this narrative review. The findings are

interpreted according to the imaging technology and clinical context in which they were generated.

3. PHYSICS OF ANGIOGRAPHY AND ROADMAP FORMATION

3.1 X-ray attenuation and iodinated vascular contrast

X-ray image formation is governed by differential attenuation. For an ideal monoenergetic beam traversing homogeneous material, transmitted intensity follows the Beer-Lambert relationship:

$$I = I_0 e^{-\mu x} \quad (1)$$

where I_0 is incident intensity, I is transmitted intensity, μ is the linear attenuation coefficient and x is material thickness. For multiple materials, attenuation can be represented as:

$$I = I_0 \exp[-\sum \mu_i x_i] \quad (2)$$

Taking the negative logarithm converts multiplicative attenuation into an approximately additive representation:

$$-\ln(I/I_0) = \sum \mu_i x_i \quad (3)$$

This logarithmic behavior is central to DSA. Iodine has a high atomic number and a K-edge near 33.2 keV, producing strong photoelectric attenuation within diagnostically useful energies and therefore high vessel-to-background contrast. The angiographic system exploits this difference while digital processing suppresses nonvascular anatomy (1,3).

3.2 Digital subtraction angiography

In DSA, a pre-contrast mask and a contrast-containing image are aligned and subtracted after logarithmic processing. If $M(x,y)$ is the mask and $C(x,y)$ the contrast image, the simplified subtraction operation is:

$$S(x,y) = C(x,y) - M(x,y) \quad (4)$$

In an idealized model, the common soft-tissue and osseous attenuation terms cancel, leaving a signal dominated by iodine. This greatly increases vascular conspicuity, particularly where vessels overlap the skull base, spine, pelvis or other dense structures. The trade-off is noise propagation. If the mask and contrast frames have independent noise σ_M and σ_C , subtraction noise is approximately:

$$\sigma_S^2 = \sigma_M^2 + \sigma_C^2 \quad (5)$$

For equal noise in the two frames, $\sigma_S \approx \sqrt{2}\sigma$. Thus, subtraction can require greater detector exposure than low-dose fluoroscopy to maintain

adequate signal-to-noise ratio. This helps explain why DSA runs can contribute disproportionately to cumulative patient dose even when they occupy only a small fraction of total procedure time (1,3,7).

3.3 Roadmap generation

A conventional roadmap uses contrast opacification to establish a vessel tree, retains an appropriate vascular frame or processed mask, and combines that information with subsequent fluoroscopy. A conceptual display model is:

$$R(x,y,t) = F(x,y,t) + \alpha V(x,y) \quad (6)$$

where R is the displayed roadmap, F is live fluoroscopic information, V is the stored vascular map and α represents the relative display weighting of the stored vascular information. This is a conceptual expression rather than a manufacturer-specific reconstruction equation. The essential physical advantage is information reuse: the vessel need not be continuously re-opacified for the operator to understand the device-to-vessel relationship. The potential procedural saving can be expressed conceptually as a reduction in repeated localization:

$$T_{\text{procedure}} = T_{\text{access}} + T_{\text{localization}} + T_{\text{navigation}} + T_{\text{therapy}} + T_{\text{verification}} \quad (7)$$

If a stable roadmap decreases repeated localization angiography and shortens target-vessel selection, $T_{\text{localization}}$ and $T_{\text{navigation}}$ may decrease. This hypothesis is supported most directly by studies reporting cannulation or wiring time rather than total procedure time alone (8,9).

4. 2D ROADMAPS, 3D FUSION AND REGISTRATION

Conventional 2D roadmapping is generated from intraprocedural contrast angiography in a fixed projection. Three-dimensional fusion roadmapping extends the same navigational principle by segmenting vascular anatomy from preprocedural CTA or MRA, or from intraprocedural cone-beam CT/rotational angiography, and registering the resulting 3D model to live fluoroscopy. The overlay can then follow C-arm angulation and table position within the capabilities of the system (10,11).

The advantage of 3D fusion is that target branches and optimal working projections can

be planned before contrast injection. The limitation is registration error. Respiratory motion, patient movement, table displacement, C-arm movement, vessel deformation by stiff wires and endografts, and differences between preoperative and intraprocedural anatomy can produce mismatch. In TEVAR, randomized comparison of 3D/3D versus 2D/3D registration showed smaller proximal landing-zone error with 3D/3D fusion, illustrating that registration method itself affects navigation accuracy (12).

A roadmap should therefore be regarded as a dynamic navigational aid rather than an infallible representation of current anatomy. When device behavior, patient motion or anatomic deformation suggests mismatch, the operator must re-register or confirm anatomy with contrast rather than continue on an inaccurate overlay.

5. RADIATION PHYSICS AND DOSE METRICS

Fluoroscopy time is an incomplete surrogate for radiation dose. Cumulative reference air kerma (K_a, r) is related to the magnitude of radiation delivered near a defined interventional reference point, whereas kerma-area product (PKA, historically dose-area product) incorporates both air kerma and irradiated field area (4–6).

$$P_{KA} = K_a \times A \quad (8)$$

where K_a is air kerma and A is beam area. Neither metric is identical to peak skin dose, and fluoroscopy time alone cannot capture the effects of projection, magnification, patient size, automatic exposure control, acquisition frame rate or DSA runs. International and professional guidance therefore emphasizes monitoring dose indicators rather than relying on fluoroscopy time alone (4–6,13).

Roadmapping can lower total exposure when it replaces repeated higher-dose acquisitions, but it can increase exposure if roadmaps are repeatedly reacquired or performed at unnecessarily high pulse rates. Phantom work in cerebral angiography demonstrated that lower roadmap pulse rates reduce dose and that DSA protocols can deliver substantially higher exposure than fluoroscopy-based approaches (14). Consequently, roadmap optimization should

include low pulse rates compatible with navigation, tight collimation, avoidance of unnecessary magnification, detector positioning close to the patient, and minimization of steep projections where clinically feasible (4,14,15).

6. CLINICAL OUTCOMES: ROADMAP/FUSION VERSUS CONVENTIONAL GUIDANCE

6.1 Target-vessel cannulation and wiring time

Cannulation time is arguably the most direct measure of whether a roadmap improves navigation. In carotid artery stenting, 3D fusion guidance reduced mean time to common carotid artery cannulation from 31 ± 8 to 21 ± 9 minutes ($P < 0.001$), while also reducing fluoroscopy time and radiation exposure (8). In aorto-iliac chronic total occlusion, CT-fused 3D roadmapping reduced wiring time from 44.6 ± 35.3 to 15.6 ± 10.23 minutes ($P = 0.0052$) and reduced the number of guidewires used, although differences in total procedure time and radiation did not reach statistical significance in the small cohort (9).

These observations support a mechanistic interpretation: the roadmap is most valuable when the principal challenge is locating an origin, selecting a branch or maintaining orientation through tortuous or occluded anatomy. In such settings, navigation time can fall even when the therapeutic portion of the procedure remains unchanged.

6.2 Fluoroscopy and total procedure time

In the carotid study, fusion guidance reduced fluoroscopy time from 24 ± 8 to 21 ± 6 minutes and total procedure time from 54 ± 18 to 47 ± 13 minutes (8). During standard EVAR, Stangenberg et al. reported fluoroscopy time of 18.4 ± 6.8 versus 26.8 ± 10.0 minutes and procedure time of 80.4 ± 21.2 versus 110.0 ± 29.1 minutes with fusion versus conventional guidance, respectively (16).

For fenestrated EVAR, 3D fusion CT was associated with substantial reductions in fluoroscopy and, in more complex three- or four-vessel repairs, procedure time fell from approximately 330 ± 100 to 230 ± 50 minutes (17). Meta-analysis of standard and complex EVAR subsequently found that complex EVAR with fusion was associated with mean reductions of

approximately 14 minutes in fluoroscopy and 52 minutes in procedure duration; standard EVAR showed a smaller but significant reduction in procedure time (18).

6.3 Radiation exposure

Radiation outcomes are more heterogeneous than time or contrast outcomes. In carotid stenting, fusion guidance was associated with approximately 31% lower radiation exposure (207 ± 23 versus 300 ± 26 mGy) (8). In standard EVAR, Stangenberg et al. reported lower air kerma with fusion (1067 ± 470 versus 1768 ± 696 mGy) (16). In fenestrated EVAR, significant reductions in radiation exposure were reported across two-vessel and more complex repairs after implementation of 3D fusion CT (17).

Conversely, some comparative studies have found similar DAP despite major reductions in contrast volume, and meta-analytic estimates for radiation have shown heterogeneity (18,19). This is not contradictory: a roadmap may reduce DSA acquisitions but introduce registration imaging, cone-beam CT or additional fluoroscopy. The final dose therefore reflects the entire imaging chain, not the presence or absence of a roadmap label.

6.4 Contrast volume

Reduction in iodinated contrast is among the most reproducible benefits of fusion roadmapping. In standard EVAR, contrast volume fell from 77.3 ± 23.0 to 37.4 ± 21.3 mL with fusion guidance (16). In complex aortic repair, fusion-based roadmapping has been associated with marked reductions in contrast volume, and systematic review/meta-analysis estimated reductions of approximately 40 mL in standard repairs and 71 mL in complex repairs (20). A later meta-analysis estimated a reduction of approximately 79 mL in complex EVAR (18). These findings are clinically relevant because contrast reduction may be valuable in patients with impaired renal function, although lower contrast use should not be equated automatically with improved renal outcomes unless those outcomes are specifically measured.

6.5 Patient time on table/in-room time and length of stay

Evidence for patient time on the angiography table or total in-room time is notably thinner than evidence for procedure and fluoroscopy time. The carotid fusion study found no significant difference in total in-room time despite faster cannulation and shorter procedure time (8). This distinction matters because room occupancy includes anesthesia, positioning, sterile preparation, vascular access, equipment preparation, hemostasis and recovery-related workflow that roadmapping may not influence.

Similarly, recent pooled aorto-iliac evidence demonstrates reductions in procedure time,

fluoroscopy time, contrast and radiation metrics but no clear difference in length of stay or major adverse outcomes (21). Thus, claims that roadmapping shortens hospitalization or overall room occupancy should be made cautiously.

7. ILLUSTRATIVE ANGIOGRAPHIC IMAGES

The following images are provided as anonymized illustrative examples of selective angiography and the vascular information that can be retained for roadmap-guided navigation. Image processing was limited to cropping, grayscale conversion and global contrast optimization; no vascular structures were generated, removed or altered.

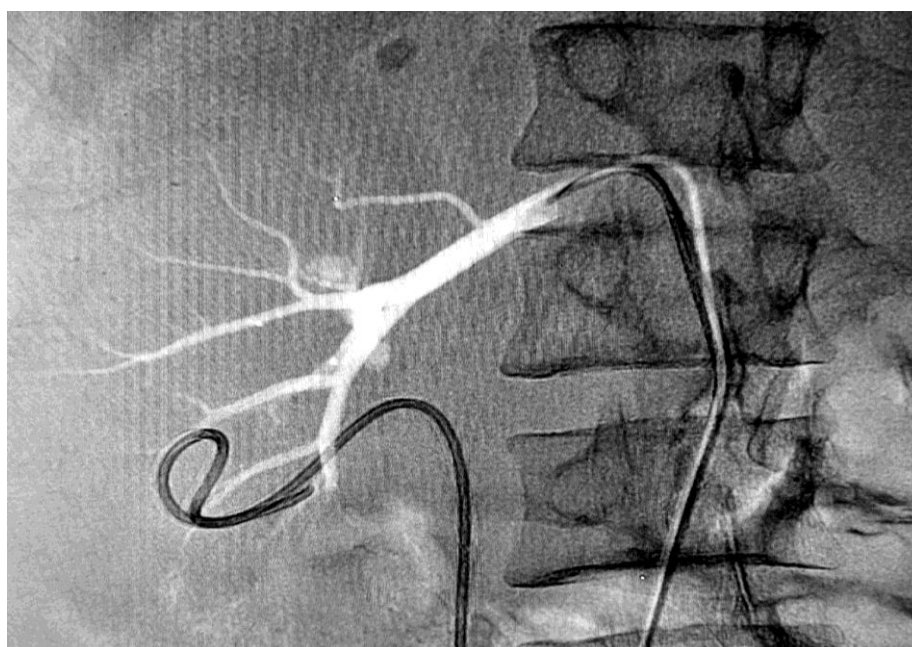


Figure 1A. Selective contrast angiography demonstrating branching vascular anatomy with the catheter positioned at the target arterial territory.

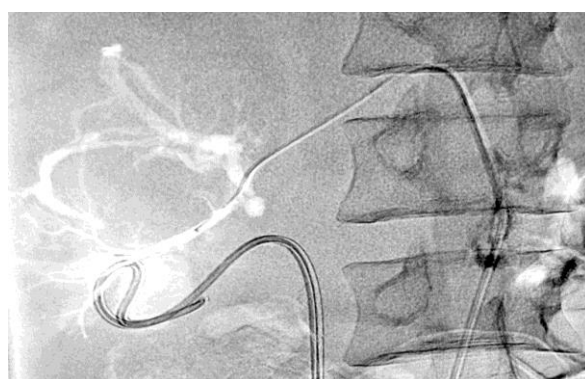


Figure 1B. Contrast-defined target arterial anatomy on an angiographic display; such an acquisition can provide the vascular reference used for subsequent roadmap navigation.



Figure 1C. Selective angiographic opacification with catheter/device visualization, illustrating the spatial information that can be retained during roadmap-assisted navigation.

8. DISCUSSION

The available evidence supports roadmapping as an information-reuse strategy that can improve procedural efficiency, but the magnitude of benefit is strongly context dependent. The central physical advantage is simple: once the vascular pathway has been demonstrated, a stored 2D roadmap or registered 3D model can preserve that anatomical information while the operator advances a radiopaque device. The clinical consequence is potentially fewer repeated localization angiograms and faster target-vessel selection.

The strongest direct evidence for navigation efficiency comes from outcomes such as cannulation and wiring time. The approximately 10-minute reduction in common carotid cannulation reported with 3D fusion (8) and the large reduction in aorto-iliac CTO wiring time (9) are more specific to the proposed mechanism than a change in total procedure time. Total procedure duration contains many components—access, device preparation, treatment, completion imaging and hemostasis—that may not respond to better vascular localization. This explains why some studies demonstrate clear navigational gains without proportional changes in room occupancy.

Radiation findings require equally careful interpretation. It is tempting to assume that a

roadmap is a low-dose alternative to DSA, but this is only conditionally true. Roadmap creation requires radiation, and 3D fusion may require cone-beam CT or rotational acquisitions. Dose savings occur when the stored map prevents enough repeated high-dose imaging to outweigh the acquisition and maintenance cost of the roadmap. This balance varies with procedural complexity, patient size, pulse/frame rate and operator practice. The appropriate endpoint is therefore cumulative procedural dose—preferably Ka,r and PKA—rather than fluoroscopy time alone (4–6).

The relationship between image quality and dose also prevents indiscriminate dose reduction. Subtraction combines noise from the mask and contrast frames, and excessive reduction in exposure can impair visualization of small vessels. Nevertheless, modern dose-optimization studies demonstrate that substantial reductions in DSA exposure can sometimes be achieved without a detectable loss of clinically relevant vascular image quality (22). Roadmap protocols should therefore be optimized rather than simply minimized.

Contrast reduction is one of the most consistent findings across fusion studies. The ability to navigate using a pre-existing vascular model can reduce the number of contrast injections required merely to re-establish orientation. This

is especially attractive in complex aortic intervention, where multiple branch vessels must be selected. However, contrast reduction is a process outcome; claims regarding prevention of contrast-associated acute kidney injury require dedicated clinical outcome data and should not be inferred solely from lower contrast volume.

Conventional 2D roadmapping and 3D fusion should also not be conflated. A 2D roadmap is projection dependent and vulnerable to patient or table motion. Three-dimensional fusion can provide multi-angle guidance but introduces registration error and can become inaccurate when stiff devices deform the vasculature. The operator must recognize misregistration and confirm critical anatomy when necessary. Fusion therefore supplements, rather than replaces, angiographic judgment.

From a workflow perspective, the evidence suggests that the greatest benefit is likely in procedures with difficult target-vessel localization, tortuous anatomy, multiple branch cannulations or repeated working projections. In straightforward anatomy, the time required to create and register a sophisticated roadmap may offset some of the gain. This likely contributes to heterogeneity between studies and reinforces the need to report procedure complexity when comparing roadmap and non-roadmap cohorts. A further limitation of the literature is that most comparative studies are observational and many evaluate image-fusion systems rather than conventional 2D roadmapping. Operator experience, equipment generation, protocol changes and learning curves can confound apparent improvements. Meta-analyses therefore combine heterogeneous technologies and procedural populations (18,20,21). Randomized evidence remains limited. Future studies should prospectively define cannulation time, number of localization angiograms, fluoroscopy time, DSA acquisition count, Ka,r, PKA, contrast volume, total procedure time and total in-room/table time. Reporting these components separately would clarify exactly where roadmapping produces benefit.

9. PRACTICAL IMPLICATIONS

A rational roadmap strategy is to acquire the minimum image quality required to define the target vascular pathway, use the lowest clinically

adequate pulse/frame rate, collimate tightly, avoid unnecessary magnification, maintain favorable detector geometry, and reuse the stored map for as long as registration remains trustworthy. Re-acquisition should be driven by loss of registration or a genuine need for updated vascular information rather than routine repetition. These principles align roadmapping with the broader ALARA approach to fluoroscopically guided intervention (4,5,14,15).

10. LIMITATIONS OF THIS NARRATIVE REVIEW

This review is narrative rather than systematic and does not provide a pooled effect estimate. The literature includes different vascular territories, imaging platforms, definitions of radiation dose and procedural complexity. Several influential studies are retrospective, and technological improvements over time can favor later fusion-guided cohorts. Conventional 2D roadmap evidence is less extensive than the literature on 3D fusion imaging. Accordingly, quantitative results should be interpreted within the specific procedure and technology studied.

11. CONCLUSION

Angiographic roadmapping converts transient contrast information into a persistent navigational reference. Its physics is rooted in X-ray attenuation, logarithmic subtraction and digital image combination; its clinical value derives from reducing repeated anatomical localization during catheter and guidewire navigation. Comparative evidence indicates that roadmap/fusion guidance can shorten target-vessel cannulation or wiring, reduce fluoroscopy and procedure time in selected interventions, and consistently reduce contrast use. Radiation reduction is achievable but not automatic because roadmap and registration acquisitions themselves carry dose. Evidence for shorter total in-room/table time or hospital stay is substantially less consistent. Roadmapping should therefore be implemented as an optimized, procedure-specific navigation strategy rather than viewed as an inherently low-dose imaging mode.

12. ETHICAL APPROVAL / IRB STATEMENT

Ethical approval and institutional review board (IRB)/ethics review committee approval were not applicable because this work is a narrative review of previously published literature and involved no prospective recruitment, intervention, or collection of identifiable patient data. The illustrative angiographic images supplied for this review were anonymized before manuscript preparation. Authors should confirm compliance with their institution's and the target journal's policy governing publication of clinical images before submission.

13. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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15. AUTHOR CONTRIBUTIONS

Author 1: Conceptualization, Methodology, Investigation, Data Curation, Writing – Original Draft.

Author 2: Methodology, Formal Analysis, Writing – Review & Editing.

Author 3 and 4: Validation, Visualization, Writing – Review & Editing.

Author 5 and 6: Supervision, Project Administration, Writing – Review & Editing.

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