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Editorial

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# Advancing Explainable AI in Tandem with Precision Medicine and Theranostics: Catalyzing the Next Revolution through Digital Twins

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## Editorial

The literature on artificial intelligence in medical image processing, think convolutional neural networks, transformers, and generative models, is exploding with complex algorithms for segmentation, classification, and reconstruction [1-4]. Yet, this rush toward ever-sophisticated black-box systems misses a critical shift: explainable artificial intelligence (XAI). By decoding model decisions through techniques like SHAP, LIME, or attention visualization, XAI enhances clinical trust, mitigates diagnostic biases, and aligns with regulatory demands. Without interpretability, opaque models risk misdiagnosis and ethical pitfalls, as seen in high-profile failures like the International Business Machines (IBM) Watson for Oncology system's inaccurate recommendations [5]. The future hinges on transparent systems that doctors and patients can trust [6-8]. This emphasis on transparency paves the way for integrating XAI with precision medicine, where tailored approaches demand not just accuracy but verifiable insights. Precision medicine is a game-changer by tailoring diagnostics and treatments to each patient's unique biology. In medical imaging, it elevates scans from broad diagnostics to personalized insights, driving better outcomes and fewer errors. By aligning care with individual profiles, it boosts efficiency, enhances patient trust, and cuts healthcare costs. The value lies in its precision in matching therapies to specific needs, making medicine more effective and humane. Theranostics amplifies this by merging imaging with targeted therapies, such as radiolabeled agents that both detect and treat cancers, ensuring interventions are not only precise but also immediately actionable [9-12].

To fully realize these personalized benefits in imaging, however, explainable AI is stepping up in medical imaging, spotlighting techniques like LIME for local interpretability, SHAP for feature attribution, and Grad-CAM for visualizing decision heatmaps in CNNs. Right now, the focus is on demystifying black-box models, uncovering why an algorithm flags a lesion or predicts metastasis, so clinicians can validate outputs in real-time workflows. The benefits are substantial: it slashes diagnostic errors by exposing biases, such as overlooked subtle imaging artifacts, and speeds up adoption by letting doctors trace reasoning paths. Over conventional opaque AI, XAI delivers trust (essential for high-stakes decisions), regulatory approval, and reduced liability risks, while empowering collaborative care. Ultimately, it's the bridge to reliable, human-aligned tools that truly advance imaging precision **[7,13-15]**. Imagine a digital twin, not a sci-fi gimmick, but a virtual replica of your body encoded in data, simulating every heartbeat, gene variant, and historical scan detail. It's a dynamic model that clinicians can probe, simulate under stress, and use to predict outcomes: Will this chemotherapy reduce the tumor size in the coming weeks, or lead to unforeseen mutations? This represents precision medicine amplified, offering benefits such as minimizing trial-and-error in treatments, preempting health crises, and empowering patients with greater agency over their care. Yet, the key enabler is explainable AI, which renders these twins trustworthy. Currently, XAI provides insights into model internals, revealing why a pixel indicates risk or a biomarker alters a prognosis, directly linking data to individual biology. For fully realized digital twins, however, we must advance beyond standard tools like SHAP to incorporate causal inference, real-time simulations, and integrated models that transparently combine imaging, genomics, and lifestyle factors. This requires developing advanced, dedicated XAI frameworks that adapt over time, articulate predictions clearly, and foster robust trust, enabling clinicians to rely on them confidently. The potential payoff is transformative: a shift from reactive to predictive, personalized medicine that is highly reliable. Of course, achieving this demands addressing challenges like data privacy under regulations such as GDPR and HIPAA, as well as ensuring computational scalability for real-time applications **[16-19]**.

For the digital twin in precision medicine, XAI cannot remain off-the-shelf, it must be purpose-built, functioning like an adaptive system. Consider layers that not only highlight pixels but also trace causality, such as how a specific gene variant under physiological stress might alter heart rhythm in the near future. Though sophisticated, it must be dynamic enough to rerun predictive scenarios intraoperatively if blood pressure spikes, providing explanations in accessible language for the surgeon's immediate use. Being dedicated involves linking every heatmap to the patient's unique history, not just generic risk scores, but personalized insights like rerouting medications based on a familial aneurysm detected in prior scans. Crucially, trust will not emerge from isolated experts in single institutions; it requires global data pooling, with centers contributing de-identified datasets to a centralized repository, enabling XAI to learn from millions rather than thousands. This approach overcomes siloed limitations, transforming the digital twin from speculative to rigorously validated, explainable, and deployable at the bedside.

In the end, a precise, personalized digital twin, grounded in explainable AI, might just catalyze medicine's next revolution. All our data gathering, our quiet collaborations, and the algorithms humming in the background could converge there: not scattered sparks, but a unified vision that clinicians, developers, and patients hold in view, guiding every decision toward transparent, transformative care.

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