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Perspective

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Embracing a new era of echocardiography-guided percutaneous and non-fluoroscopical procedure for structure heart disease

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Abstract: The advancement of catheter-based interventional techniques represents a significant evolution in cardiovascular medicine. However, traditional methods that rely on fluoroscopic guidance present considerable limitations including radiation exposure and contrast agent-related risks and the heavy load-caused lead suits. In response, zero or low X-ray emerge, including percutaneous and non-fluoroscopical (PAN) procedure coming as a transformative solution, particularly in treating congenital heart disease, valvular disease, and arrhythmias. These methods minimize the risk of iatrogenic injuries associated with radiative procedures. Innovative PAN procedures and methodologies have been developed to enhance imaging, transcatheter interventions, safety, and accuracy, overcoming previous limitations. By eliminating radiation and expanding accessibility, PAN procedures offer a safe, effective, and economically viable alternative to traditional methods, ushering in a new era of minimally invasive cardiovascular treatment.

Keywords: echocardiography-guided intervention; percutaneous intervention; heart disease; percutaneous and non-fluoroscopical (PAN)

Catheter-based interventions represent a major advancement in cardiovascular medicine, a significant departure from earlier empirically based practices. Progress in understanding human anatomy facilitated a shift toward more observable techniques, as seen in ancient medical practices across various cultures [1, 2].

Medical knowledge, initially transmitted orally and through manuscripts like Galen's and Vesalius's works, progressed slowly [3, 4]. Surgery, for over two millennia, relied on a 'cut open to find' approach until advancements like Röntgen's 1895 discovery of X-rays revolutionized diagnostics and treatment [5]. Forssmann's 1929 self-catheterization, guided by X-rays, marked the genesis of catheter-based interventions, which have since rapidly advanced, surpassing traditional surgery in various fields, including congenital heart disease, coronary artery disease, and neurointerventions.

Werner Forssmann's 1929 self-catheterization, guided by X-rays, marked the birth of catheter-based interventions [6].

Since then, catheter-based interventions have rapidly advanced, surpassing traditional surgery in treating congenital heart disease, coronary artery disease, and

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neurological conditions. This technological transformation has led to interventional procedures largely replacing traditional vascular surgery.

Following Röntgen's discovery of X-rays, interventional therapy, based on 'seeing without cutting', revolutionized treatment for conditions like congenital heart disease, valvular disease, and coronary artery disease. This minimally invasive approach spurred innovation in medical devices (valves, stents, balloons) and imaging technologies (DSA, CT). Advancements in materials science and manufacturing further supported the growth of radiological interventional techniques.

Radiation-based techniques, however, present significant challenges. They can cause iatrogenic organ damage and have limited applicability in certain populations. Contrast agent exposure carries risks, including contrast-induced nephropathy with a mortality rate as high as 20 %, and is unsuitable for patients with allergies, pregnancy, or liver/kidney dysfunction. Interventional procedures often expose both patients and medical staff to excessive radiation, requiring the latter to wear heavy lead aprons that impede performance and safety. Furthermore, the two-dimensional nature of radiation imaging limits precision by lacking the depth perception necessary for accurate guidance.

Building upon the Curie brothers' 1880 work on the piezoelectric effect, echocardiography, developed as a diagnostic tool by the Dussik brothers in 1941, offers significant potential for medical imaging [7, 8]. While echocardiography has revolutionized diagnostics, its application in interventional procedures presents unique challenges. The heart's pulsatile nature means that guidewires and catheters move with the heartbeat and blood flow, making precise positioning difficult. This necessitates overcoming the significant challenge of using echocardiography for detection, positioning, and orientation, while acknowledging its limitations as a standalone guidance modality.

Just as air can support a paper airplane but an engine is needed to lift a metal airplane, echocardiography requires technological advancements to overcome its current limitations and enable effective guidance for cardiac interventions.

Guided by this idea, we have an established echo-based system, together with a series of instruments or pre-specified procedures, and this new concept has improved echocardiography imaging capabilities, solving the problem of 'better seeing' [9].

We developed an echo-guided delivery system with a three-dimensional curvature that conforms to cardiac structures, allowing for three-dimensional rotation. This transforms passive single-plane scanning into active three-dimensional detection, increasing the probability of echocardiography detection devices by five times.

We invented an echocardiography-guided catheter with a unique 'large cavity and thin edge' design, which creates multiple interfaces of 'metal-liquid-polyurethane'. The continuous reflections across interfaces with different densities can boost echocardiography decibel levels by 20–30 % [7, 9].

We also invented an echocardiography-guided guidewire with a spindle-shaped head that can expand and contract. By changing its volume, it enhances echocardiography detection capability. When used in conjunction with the 'effective cross-sectional method', it has been shown in randomized controlled clinical studies to improve the surgery success rate of beginners from 69 % to 100 % [7, 9].

We introduced the 'key anatomical structure detection method'. A method used to utilize the relatively small and fixed spaces of cardiovascular key structures (e.g., the inferior vena cava entrance or aortic isthmus) where devices remain stationary and unaffected by blood flow. Echocardiography is employed to establish fixed imaging planes at these crucial structures, enabling easy detection of device tips and trajectories as they approach. This method effectively resolves the challenge of echocardiography's inability to locate devices within the heart. This method effectively resolves the challenge of echocardiography's inability to locate devices within the heart, increasing the echocardiography positioning success rate from 50 % to over 98 % [7, 9].

We also developed a 'working length marking method' for catheters and delivery systems to precisely control insertion depth. This reduces heart and blood vessel damage from excessive insertion, decreasing complication rates from 6.5 % to less than 0.2 % by preventing excessively deep insertion of the hard sheath [7].

What's more, the 'effective echo view method' utilizes echocardiography to display the longitudinal course of devices (e.g., catheters, guidewires) over a significant length (>1 cm), facilitating precise localization and orientation of their distal ends [7].

Echocardiography-guided interventional techniques are radiation-free and incisionless, enhancing patient and healthcare worker safety and expanding treatment options to include more critically ill patients [10, 11]. The percutaneous and non-fluoroscopical(PAN) procedure's independence from large equipment, radiation shielding, and dedicated catheterization labs allows for its performance in outpatient and community settings, reducing infrastructure costs and improving healthcare access.

As part of a UN global sustainable development initiative, the PAN procedure is expanding access to cardiac intervention in underserved communities. A global training program has been established, educating trainees from over 30 countries and regions to improve global healthcare quality. Echocardiography's limitations include insufficient resolution for visualizing fine structures like coronary plaques and the conduction system, necessitating millimeter or micrometer-level imaging for precise treatment. Emerging technologies, such as radar, high-speed MRI, intravascular endoscopy, and magnetic navigation mapping, promise to significantly advance medical imaging and treatment.

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References

1. Collado-Vázquez S, Carrillo JM. Cranial trepanation in the Egyptian. Neurologia 2014;29:433–40.
2. Yalamanchili H, Sclafani AP, Schaefer SD, Presti P. The path of nasal reconstruction: from ancient India to the present. Facial Plast Surg 2008;24:3–10.
3. Kornu K. Enchanted nature, dissected nature: the case of Galen's anatomical theology. Theor Med Bioeth 2018;39:453–71.
4. Russell GA. Vesalius and the emergence of veridical representation in Renaissance anatomy. Prog Brain Res 2013;203:3–32.
5. HeissForssmann HWW, Hurst JW. A German problem with the nobel prize. Clin Cardiol 1992;15:547–9.
6. Saffarzadeh AG, Canavan M, Resio BJ, Walters SL, Flores KM, Decker RH, et al. Optimal radiation dose for stage III lung cancer-should "definitive" radiation doses Be used in the preoperative setting? JTO Clin Res Rep 2021;2. https://doi.org/10.1016/j.jtocrr.2021.100201.
7. Kong P, Zhao G, Zhang Z, Zhang W, Fan T, Han Y, et al. Novel panna guide wire facilitates percutaneous and nonfluoroscopic procedure for atrial septal defect closure: a randomized controlled trial. Circ Cardiovasc Interv 2020;13:e009281.
8. Singh S, Goyal A. The origin of echocardiography: a tribute to Inge Edler. Tex Heart Inst J 2007;34:431–8.
9. IEEE draft standard for a unified terminology and framework for percutaneous and non-fluoroscopic technology (PAN technology) in cardiovascular diseases. IEEE P3182/D10, Feb 2024. 2024:1–26.
10. Pan XB, Ouyang WB, Wang SZ, Liu Y, Zhang DW, Zhang FW, et al. Transthoracic echocardiography-guided percutaneous patent ductus arteriosus occlusion: a new strategy for interventional treatment. Echocardiography 2016;33:1040–5.
11. Siagian SN, Prakoso R, Putra BE, Kurniawati Y, Lelya O, Sembiring AA, et al. Echocardiography-guided percutaneous patent ductus arteriosus closure: 1-year single center experience in Indonesia. Front Cardiovasc Med 2022;9. https://doi.org/10.3389/fcvm.2022.885140.