

Calcified plaque imaging and detection in ex-vivo porcine heart arteries using a scalable, lead-free intravascular ultrasound array

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Abstract

Cardiovascular diseases are the leading cause of death worldwide, causing 17.9 million fatalities annually and posing social and economic burden. In Europe alone, they impose a €210 billion expense. Atherosclerosis, the accumulation of fats and other substances within arterial walls, leads to arterial narrowing, blocking blood flow. Percutaneous coronary interventions (PCI) are commonly used to restore arterial patency and optimise blood flow in coronary circulation. Intravascular ultrasound (IVUS) uses a catheter-mounted transducer to image vessel walls and atherosclerotic plaque, guiding PCI with notable advantages, including a 50% reduction in post-procedure cardiovascular mortality. Commercial IVUS catheters employ lead-based transducers, representing health and environmental risks. Transitioning to lead-free alternatives is crucial and timely to support global initiatives including the Restriction of Hazardous Substances (RoHS) regulation to advance environmentally sustainable piezoelectric technologies. Despite progress in understanding the piezoelectric properties of lead-free materials, scaling up their production remains challenging. A scalable, RoHS-compliant array transducer is presented. Coded excitation was employed to compensate the lower piezoelectric coefficient of the array relative to its lead-based counterparts, and demonstrate improved imaging and detection of calcified plaques in *ex-vivo* porcine heart arteries.

The 32-element array (163 μm -pitch, 3.82 mm-elevation, 5 French gauge) was characterised via electrical impedance and pulse-echo measurements. Coded excitation was used to address its signal-to-noise ratio challenge. The impedance magnitude showed uniformly damped responses, with the phase spectrum indicating resonance around 21 MHz. Pulse-echo analysis revealed a peak frequency at 19.22 ± 2.2 MHz, and a 66.80 % bandwidth (-6 dB). Comparative analysis including chirp, Barker and Golay excitations imaged the arterial wall, and B-scans across three samples detected calcified plaques. Subsequent investigations explored detection of dense fibrous plaques in arteries (down to approximately 8 mm diameter) using chirp. These findings highlight lead-free transducers as a sustainable, high-performance candidate for next-generation IVUS systems.