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Tenergy transmission and beam-spot optimization of a multilayer-coupled composite applicator for radial extracorporeal shock wave therapy (r-ESWT)

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Introduction
Background Energy delivered by radial extracorporeal shock-wave therapy (r-ESWT) is curtailed by the ≈80 % reflection that occurs when a Ti-6Al-4V applicator (27 MRayl) meets soft tissue (1.5 MRayl).

Material & Methods
A two-layer applicator was developed in which a tungsten-filled epoxy layer (6 MRayl) and a medical-grade silicone layer (1.35 MRayl) bridge the impedance gap. A 3-D explicit finite-element model (LS-DYNA) coupled to an NSGA-II optimiser varied epoxy thickness (1.2–2.0 mm), silicone thickness (0.8–1.3 mm) and face curvature (R 25–40 mm) to maximise transmitted energy (η), minimise beam non-uniformity (UI) and limit surface heating (ΔT_{max}). Ten prototypes with the optimal geometry (epoxy 1.6 mm, silicone 1.0 mm, R = 32 mm) were built by vacuum casting and spin-coating. Pressure fields were mapped in degassed water with a 28 µm PVDF membrane on a 1 mm grid at depths of 10, 20 and 30 mm; surface temperature rise was captured by high-speed infrared imaging. A commercial single-layer Ti head served as control.

Results
The two-layer head more than doubled transmitted energy ($\eta = 0.64 \pm 0.03$ vs 0.30 ± 0.02; $p < 0.001$), increased peak positive pressure by 28 % (4.07 ± 0.11 MPa) and narrowed the −6 dB radial beam width from 18.0 to 13.5 mm (–24 %). Surface temperature rise after 50 pulses fell from 2.9 ± 0.3 °C to 1.1 ± 0.2 °C. All experimental values deviated <10 % from simulation. No delamination or acoustic drift was seen after 10^5 fatigue cycles.

Discussion
A cost-effective, two-layer impedance-matched, convex applicator markedly improves energy delivery and beam uniformity in r-ESWT while reducing superficial heating. The design uses low-temperature casting and is readily retrofittable to existing devices, providing an immediately translatable route toward deeper, more comfortable shock-wave therapy.