Comparative Impact Resistance of Titanium Mesh (Ti), Polymethyl Methacrylate (PMMA) and Polyether Ether Ketone (PEEK) in an in vitro Cranioplasty Model.

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Disclosure/Financial Support: Supported by AO Foundation grant S-12-78S (to Dr. Oleh Antonyshyn). None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

PURPOSE: To determine in vitro biomechanical properties (impact resistance and shape retention) of common cranioplasty materials.

METHODOLOGY: A virtual skull model with two topographically distinct defects was created. Defects (8x6cm) were designed to represent one highly contoured site (frontoorbital - FO) and one relatively flat site (temporoparietal - TP). Three cranioplasty materials (Ti, PMMA and PEEK) were used to manufacture custom skull-specific implants for rigid fixation to the two defects on the skull model. Impact testing used a falling weight design with increasing kinetic energies (KE), as per the American Society of Testing and Materials. Known impact forces associated with common etiologies of blunt head trauma were referenced to define input KE for increasing levels of impact. Implants were successively tested at 0.5, 1.0, 3.0 and 5.0 joules of energy. Post impact inspection defined failure as implant fracture, >3mm deformation or fixation failure. A load cell measured impact force while a high-speed camera determined impact duration. Group outcomes were measured per site as the average impact force and mechanism of failure.

RESULTS: Initial impact testing (0.5 J) resulted in failure of all Ti implants (>3mm deformation) at both defect sites. PMMA and PEEK implants were unchanged. Impact force was significantly different in all groups for TP defects (Ti = 121.7 N, PEEK = 676.7 N, PMMA = 872.3 N) and was significantly less for Ti (154.7 N) when compared with PEEK (954.5 N) and PMMA (932.8 N) for FO defects. Completion of FO defect testing (PEEK, PMMA) yielded no failures and had no significant differences in force profiles at 1.0 J (1440.5 N, 1371.8 N), 3.0 J (2613.1 N, 2492.5 N) or 5.0 J (3126.1 N, 3163.3 N). Completion of TP defect testing (PEEK, PMMA) yielded significant differences in force profiles at 1.0 J (1022.9 N, 1297.0 N). At 3.0 J, all PMMA implants fractured while PEEK tolerated impact with an average force of 1760.4N. At 5.0J, PEEK failed secondary to fixation failure only.

CONCLUSIONS: Ti failed at energies calculated to reproduce the force of a soccer head ball.[1] PMMA and PEEK were significantly stronger, with FO defects experiencing forces similar to a professional boxer punch[2] or impact into a rigid steering hub at 31mph.[3] These findings will guide implant material selection and patient safety.

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