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Femtosecond Laser Micro-Patterning of Toughened Zirconia Implant Surfaces

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Objectives To evaluate phase composition, microstructure and surface properties of yttria- and ceria-stabilized zirconia exposed to three femtosecond laser-textured micro-patterns.

Methods Commercial 3mol% yttria-stabilized zirconia (3Y-TZP, Tosoh), containing 0.25wt% Al_2O_3, and lab-made 10mol% ceria-stabilized zirconia (Ce-TZP, Daiichi), containing 0.25wt% Al_2O_3 doped with 0.2mol% CaO, were studied. Zirconia powders were cold isostatically pressed to disks, pressureless sintered (3Y-TZP at 1350°C, Ce-TZP at 1250°C, 2h) and polished (control). Each zirconia grade was conventionally sandblasted and etched, or experimentally treated using a femtosecond laser (Carbide, CB3-20W) to obtain the following surface patterns: (1) dots, (2) lines, and (3) grid. Phase composition was characterized using X-ray diffraction (XRD); surface roughness (Sa) was measured using optical confocal microscopy and microstructure was analyzed using scanning electron microscopy (SEM). Surface wettability (hydrophilicity) was measured using a static sessile-drop test. Statistics involved Kruskal-Wallis and Welch ANOVA with post-hoc Bonferroni tests (α=0.05).

Results Rietveld refinement revealed increased monoclinic phase for sandblasted and etched 3Y-TZP and Ce-TZP (16.8wt% and 40.7wt%, respectively), compared to polished and laser-patterned surfaces (0-2.5wt%). Rhombohedral phase was only detected for sandblasted and etched 3Y-TZP (29.6wt%). Sa values of laser-treated surfaces varied between 0.51 and 1.6 µm. SEM revealed regular implant surfaces after laser micro-patterning, while sandblasting and etching produced random surface topographies in both zirconia grades. Laser micro-patterning led to formation of surface cracks in both types of zirconia. Sandblasting and etching increased hydrophilicity ($\theta \approx 50°$), compared to polished surfaces ($\theta \approx 60°$). However, all laser treatments made zirconia surfaces hydrophobic ($\theta > 90°$), except for Ce-TZP micro-patterned with dots that exhibited a lower contact angle ($\theta \approx 77°$).

Conclusions Regardless of zirconia composition, femtosecond laser micro-patterning resulted in more hydrophobic zirconia surfaces without causing significant phase transformations that are expected using conventional implant-surface modifications. Optimization of laser micro-patterning is however needed to avoid cracks at zirconia surfaces.