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Degradation kinetics of dental and medical Zirconia in steam sterilisation and in vivo conditions

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Yttria stabilized Zirconia (Y-TZP) ceramics are common materials for dental and orthopedic implants and also candidates for medical devices such as scalpel blades, which need sterilization for multiple use. It is well known that Y-TZP is prone to undergo a surficial degradation, where the phase transformation of the tetragonal to the monoclinic modification is detrimental to the properties of the material, even though this transformation as a dispersed phenomenon in the interior is the reason for the high fracture toughness of such ceramics. The surface process is commonly attributed to the ingress of water constituents in vacancies, but it is not clear, if the process proceeds by diffusion or reaction control, how deep it can penetrate into the material at all and which kinetic equation is valid under steam (i.e. hydrothermal) conditions or in the case of application in the body.
We have studied the degradation behavior in an autoclave at 134°C and in hydrous storage at low temperature. The extend of degradation in form of the amount of transformed Zirconia after the treatments and its depth level was followed by surface XRD and Raman spectroscopy and through the analysis of FIB milled sections by SEM and EBSD. We will show that the often accepted Mehl-Avrami-Johnson law modeling a nucleation, growth and saturation process for the development and the transformation speed as derived from surface XRD data is misleading. The true kinetics as determined in the sectioning studies will be shown to clearly consist of a simple linear progression of the layer thickness of a largely transformed Zirconia with time. Surface-XRD distorts the quantification with depths of such a layer-on-layer situation because of the exponential form of the signal absorption with penetration.
With this knowledge we discuss, how the surface XRD data can nonetheless be used to infer true degradation kinetics and how the low temperature experiments relate to the hydrothermal ones. The consequences for the application of Zirconia bioceramics will also be discussed.