Thermoluminescence study on materials used in restorative dentistry for personal dosimetry applications

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Introduction

In recent years, the Retrospective Accidental Dosimetry has been developed. The main reasons that led to this is the possible risks of unexpected radiation events such as nuclear accidents, radiation leakages or nuclear waste, but also accidents in case of radiation therapy. In these cases it is necessary to determine the absorbed dose as fast as possible in order to start procedures that can limit the damages. The aim of the present study, which is included in the area of ionizing radiation, is of a dual nature. It aims on establishing the materials used in restorative dentistry as objects of personal accidental dosimetry, but also to establish luminescence techniques as innovative methods for the discrimination between materials with different stabilizers. The study is performed on monolithic zirconia, but the samples differ in the amount of stabilizer in their synthesis and are from different brands. Thermoluminescence (TL) is a basic application tool in radiation dosimetry and was used for the dosimetric study.

Materials and Methods

All the samples are monolithic zirconia, but they differ in the amount of stabilizer in their synthesis, which is used to maintain high toughness. Moreover, were studied samples with the same amount of stabilizer but of different commercial brands. Following table presents the under study samples:

Sample A	Zirconia+3%Yttria, Brand A
Sample B	Zirconia+3%Yttria, Brand B
Sample C	Zirconia+3%Yttria, Brand C
Sample D	Zirconia+5%Yttria, Brand D

X-ray diffraction analysis (XRD) was performed to determine any structural changes. The measurements were utilized with a two-cycle Rigaku Ultima+ diffractometer -operating at 40 kV/30.

TL measurements were carried out using Harshaw Model 3500 TLD-Reader equipped with a $^{90}Sr/^{90}Y$ beta particle source, delivering a nominal dose rate of 0.56 Gy/min. All measurements were performed in a nitrogen atmosphere with a low constant heating rate of 2 °C/s.

- 1st Protocol (Successive):

- Zeroing of any signal of the sample by heating up to 350 °C
- Irradiating the sample with D=11.2 Gy and recording TL signal up to 350 °C
- Repeat last step for 9 more times

- 2nd Protocol (Single Aliguot Regenerative dose):

- Irradiating the sample with "random" dose 7.28 Gy and recording TL signal up to 350 °C
- Irradiating the sample with TD (test dose) 2.8 Gy and recording TL signal up to 350 °C
- Irradiating the sample with D_i(D_i=1.12, 2.24, 4.48, 8.96, 17.92, 7.28 Gy) and recording TL signal up to 350 °C (L_i)
- Irradiating the sample with TD (test dose) 2.8 Gy and recording TL signal up to 350 °C (T_i)
- Repeat two last steps for new D_i

The glow curves were analyzed through a deconvolution method of analysis, using the General Order of Kinetic (GOK) Model. Microsoft Excel along with the Solver add-on feature was utilized for the deconvolution.

$$I(T) = I_m \cdot b^{\frac{b}{b-1}} \cdot \left(\frac{E}{kT}\cdot\frac{T-T_m}{T_m}\right)\cdot\left[(b-1)\cdot(1-\Delta)\cdot\frac{T^2}{T_m^2}\left(\frac{E}{kT}\cdot\frac{T-T_m}{T_m}\right)+Z_m\right]^{-\frac{b}{b-1}}$$

Δ = 2kT, Zm= 1+(b−1)·Δm, I, I_m: TL intensity, maximum Intensity, b: kinetic order of TL process, E(eV): activation energy, T , T_m(K): Temperature, Maximum Temperature, k(eV/K): Boltzmann constant

Results

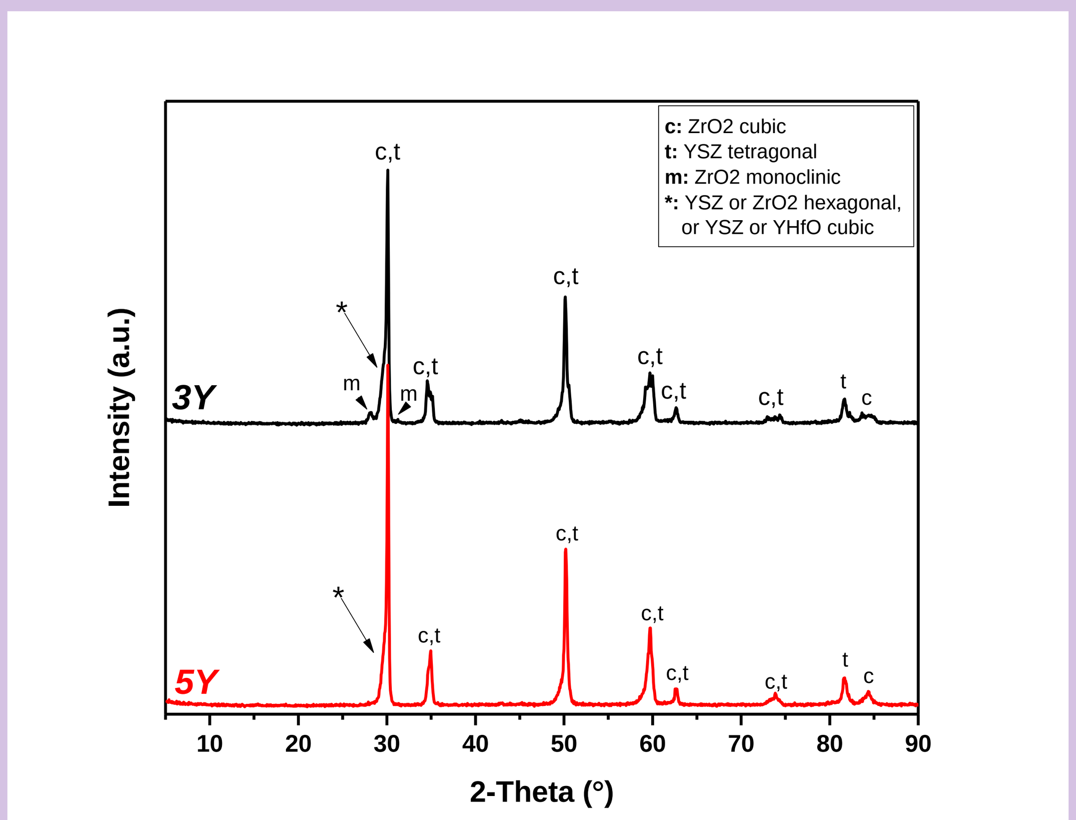

Figure 1: XRD patterns of Sample A (up) and Sample D (down).

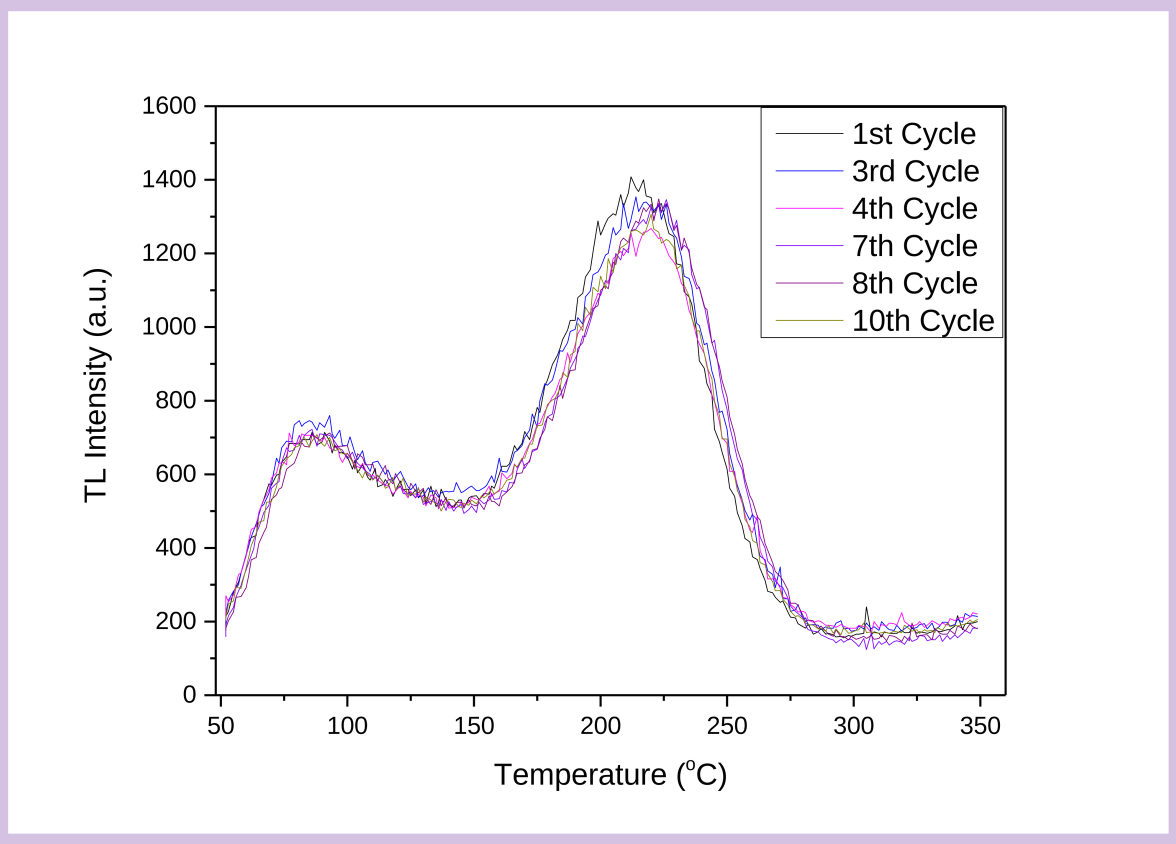

Figure 2: TL glow curves of Sample A after 10 successive cycles of irradiation-measurement

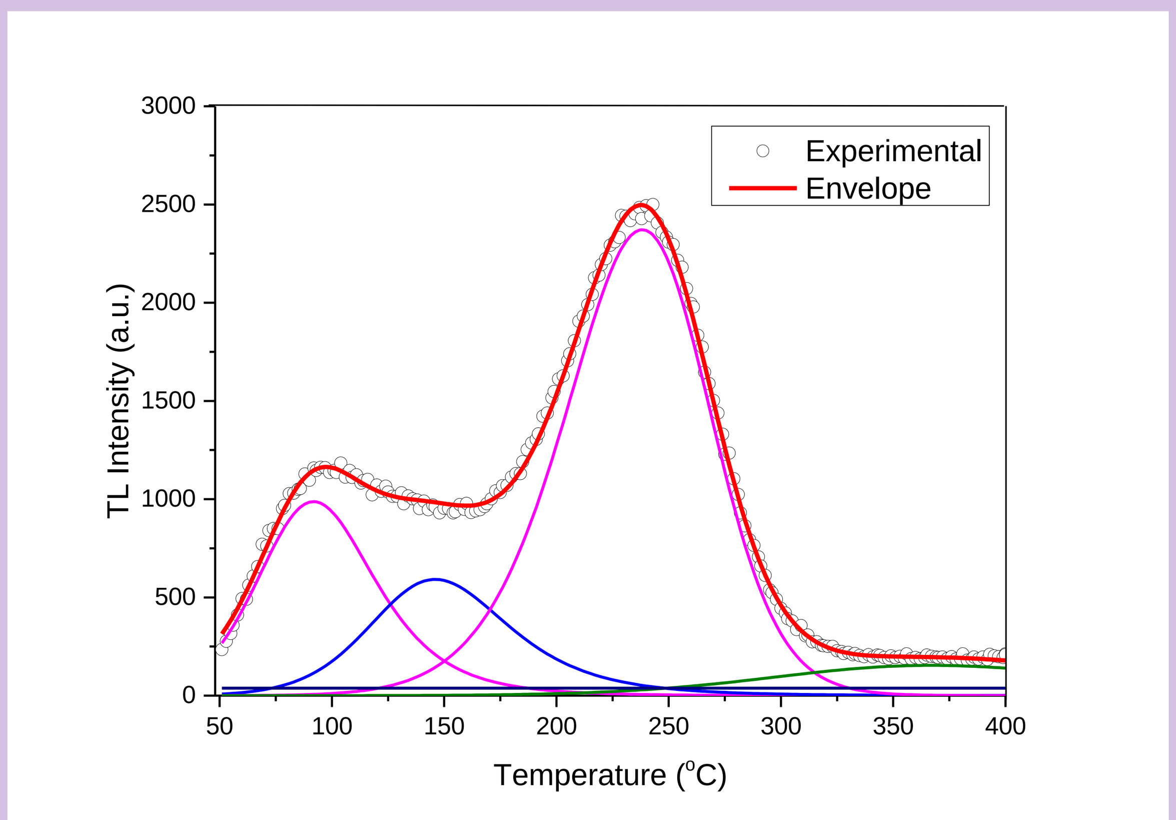

Figure 3: Representative glow curve-fitting analysis using the GOK model, for an artificial irradiation dose of 17.92Gy for Sample A.

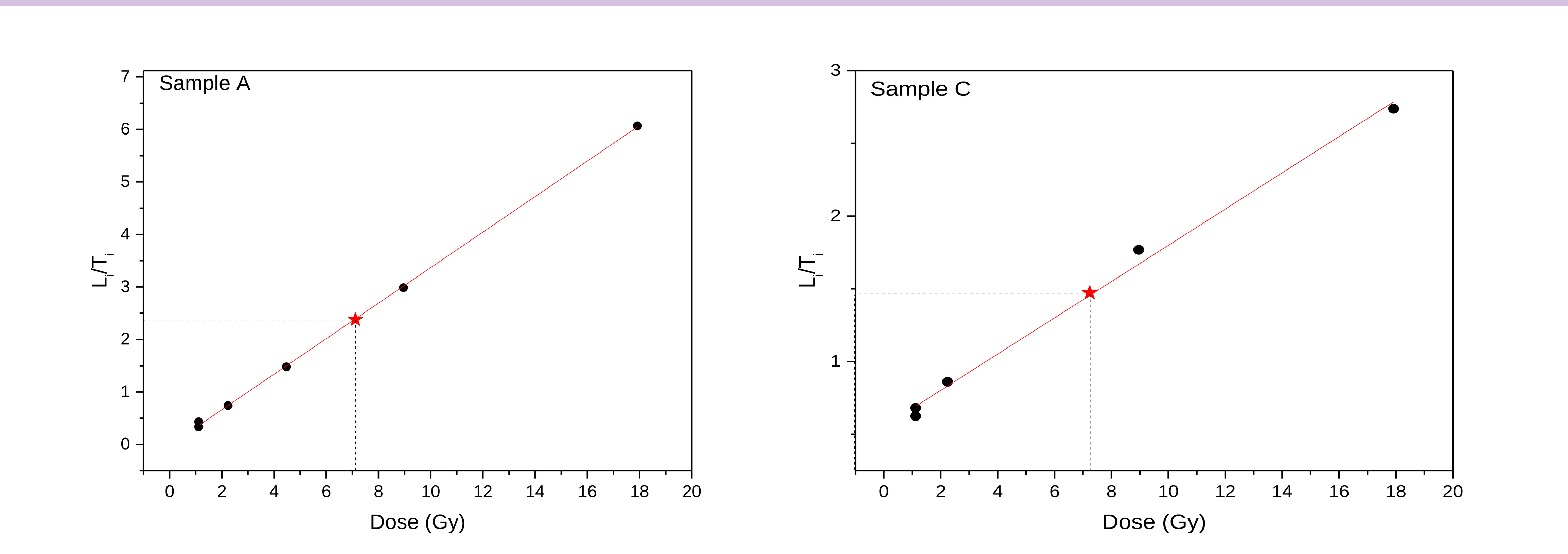

Figure 4: Corrected luminescence signal (Li/Ti) as a function of the Di for two of the samples. The recycling ratio is equal to 0.95±0.05 for Sample A and 0,93±0.07 for Sample C. The calculated ratio of the recovery dose test is ≈ 0.98 in both cases.

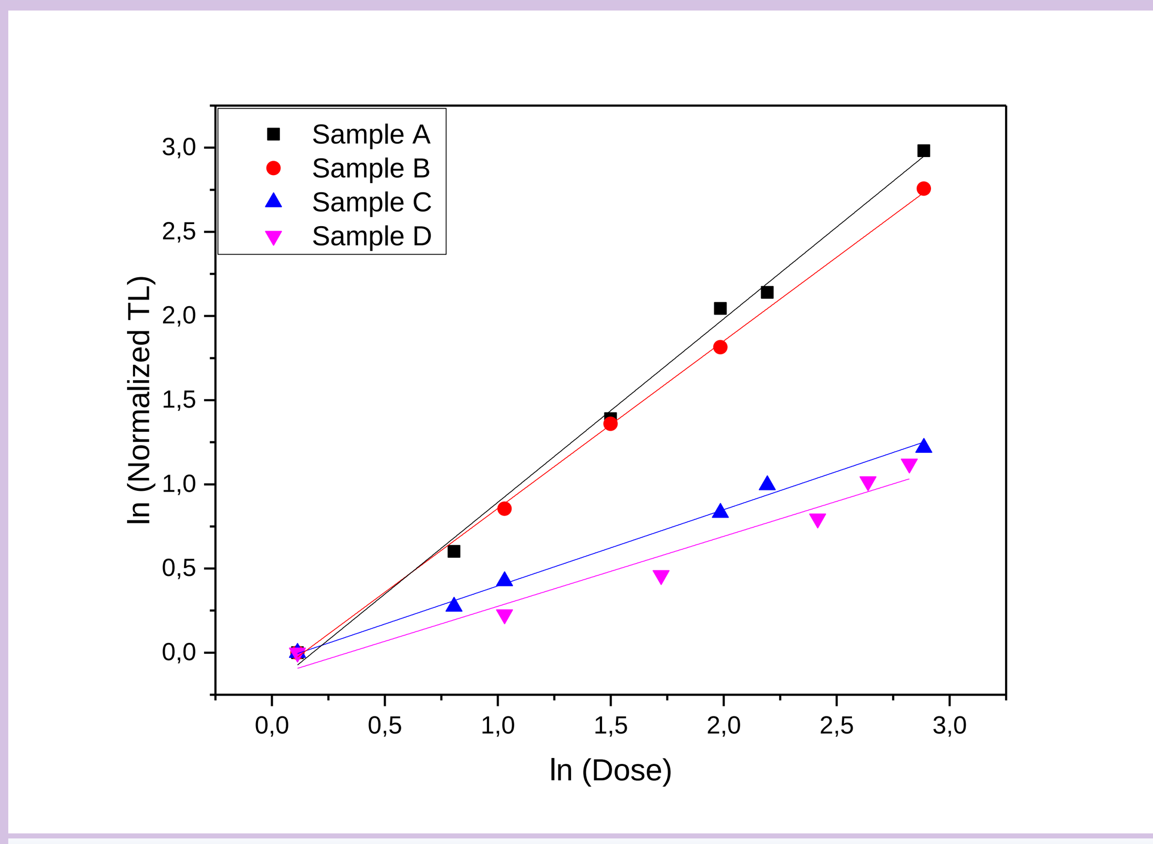

Figure 5: Dose response. All samples present linear dependence over the dose.

Conclusions

- The XRD patterns of the samples with different Yttria content shows that the 3Y presents cubic and monoclinic zirconia content, together with a tetragonal phase that is attributed to yttria stabilized zirconia. The sample with the higher yttria content also presents cubic zirconia and tetragonal yttrium stabilized zirconia, but the phase of monoclinic zirconia is totally absent apart from that, in this case, cubic seems to be the dominant phase.
- None of the samples gets sensitized after successive cycles of irradiation-TL measurement. So the SAR protocol can be applied. This property is necessary for a dosimeter since it could be used more than once.
- There is a linear dependence over dose, but the samples presents different patterns. The difference should be further studied. The linear response to the doses is the most important property for a potential dosimeter.
- Both the recycling ratio and the estimated recovery dose shows that the samples are suitable candidates as personal accidental dosimeters.

References

- I.K. Sfampa *et al.*, Appl. Radiat. Isot. **157**, 109024 (2020).
- I.K. Sfampa *et al.*, Radiat. Meas. **125**, 7 (2019).