The common surgical face mask as emergency dosimeter

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Abstract:
Exposures of individuals to doses of radiation in the order of Grays warrant a rapid medical response that ought to be well directed to the patients most in need in order to maximize the chances for survival. In some conceivable emergency situations, such as nuclear detonations or large releases of radioactive materials, we may expect a large amount of subjects without conventional dosimeters to be exposed, and medical triage to optimize the available medical resources to become necessary. Fortuitous dosimeters, i.e. materials that an average person is likely to have on them in case of exposure, such as a smartphone, are thus of interest to be characterized in their properties as dosimeter to aid in the rapid estimation of exposure and its severity - also to separate the worried-well from urgent medical cases. Calcite is a naturally occurring mineral that is ubiquitous in everyday materials and has a thermoluminescent response to ionising radiation. Modern polymer-fiber materials incidentally use precipitated CaCO3 from calcite as a so-called filler to improve material properties, such as water resistance, comfort, or thermal insulation. Due to the ongoing SARS-CoV-2 pandemic, many countries mandate the regular use of common surgical face masks, which contain CaCO3 filler powder. In this work we discuss how standard commercially available face masks thus exhibit a thermoluminescent response that is proportional to dose, thus presenting itself as potential fortuitous emergency dosimeter. With the herein used detection setup, the minimum detectable dose was found to be of the order of 1 Gy. This is just below the recommended limits of 2 Gy for emergency triage and thus may prove a supplementary dose assessment method in critical scenarios. We discuss the limitations of our study provide an outlook on how the materials and methods can be improved.

1 INTRODUCTION

In the hours following a large-scale radiological event, such as a nuclear detonation (e.g., Hiroshima) or the meltdown of a nuclear power plant (e.g., Chernobyl), the surge of casualties requiring treatment at hospitals in the vicinity of the event will require crisis standard of care [1]. According to urban nuclear detonation models of typical US cities [2], the number of casualties with radiation doses well exceeding 1 Gy can be of the order of 100'00 and can vary by an order of magnitude. In such case, a triage procedure will have to be applied to best redirect medical resources [3] towards those who are most in need and/or most likely to benefit. Triage in radiological emergency events has the added complexity of casualties potentially presenting a combination of symptoms of acute radiation syndrome (ARS), trauma, burns, or psychological distress [4]. Rapid objective individual dose assessment is therefore a key-factor in the preparedness and response to radiological emergencies [5]. While ARS symptoms or white blood cell counts can be informative, the sensitivity, specificity, or speed of the information may not suffice for such a situation [6].

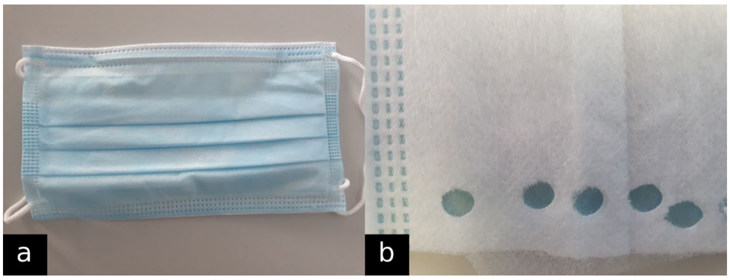

Figure 1. Picture of the face mask used for the dose response study (a). The samples were taken from the mask using a standard hole puncher (b).

Direct dose information from a standard dosimetric material (e.g., BeO, Al_2O_3, LiF) can provide the needed information for triage, yet the affected person will need to have had the material on them during exposure. A luminescence dosimetric material typically refers to a material with a thermoluminescence (TL) and/or optically stimulated luminescence (OSL) response proportional to the received dose of ionizing radiation. This introduces the interest in so called fortuitous dosimeters, commonplace materials that a person is likely to carry, and that could be used for dose assessment in such a scenario. As evaluated by the EU MULTIBIODOSE consortium [6] based on the data of Chernobyl victims, for which no immediate death was recorded below this threshold [7], a dose less than 2 Gy may not warrant immediate medical care and is thus chosen as the recommended triage limit. A fortuitous dosimeter must therefore be able to meet this minimum detectable dose. Besides the detection limit, other criteria that a fortuitous dosimeter must fulfil are: ubiquity among membres of the general public, willingness to be handed over to emergency responders, easiness and rapidity of sampling and dose assessment procedure. Items that have already been quantified to be usable as such in scenarios include, among others, mobile phones [8, 9], ibuprofen [10], or faux-leather bags containing mineral filler [11, 12], using both TL or OSL methods to read out dose information.

Common surgical face masks based on non-woven polymer fabrics contain mineral fillers to improve characteristics such as breathability, water resistance, or overall ergonomy [13]. The filler is hereby often based on precipitated calcium carbonate (PCC), which can be extracted from natural calcite - a known TL material [14]. Due to the ongoing SARS-CoV-2 pandemic, many countries mandate the regular use of common surgical face masks [15]. We therefore identified both the fortuitous availability and dosimetric potential of the surgical face mask for emergency dosimetry.

The objective of this paper is to assess whether common face masks can be used as emergency dosimeters. We show the TL signal in response to ionising radiation doses of a commercially available face mask and compare it to calcite. We then present which doses can be reasonably detected, and present a simple measurement protocol enabling dose assessment in the range from around 1 Gy to 20 Gy.

2 MATERIALS AND METHODS

For the tests using a commercially available material, we used Zoey Medical disposable face masks [16] (see Figure 1). The samples were cut out using a standard paper hole-puncher (diameter of 6±0.5 mm) and placed in stainless steel measurement cups. For irradiation and subsequent TL readout we used a Risø TL/OSL-DA-20 reader [17]. With a built-in $^{90}Sr/^{90}Y$ source for β irradiations, the system allows for subsequent read-outs using TL. In this work the light was acquired in a photomultiplier tube (PMT; type ET Enterprises PMD9107Q-AP- TTL) with no additional filters aside from the in-built silica windows. Note that the main emission line of calcite is 630 nm [18, 19], while the PMT used in this work has a quantum efficiency of less than 10 % at 600 nm.

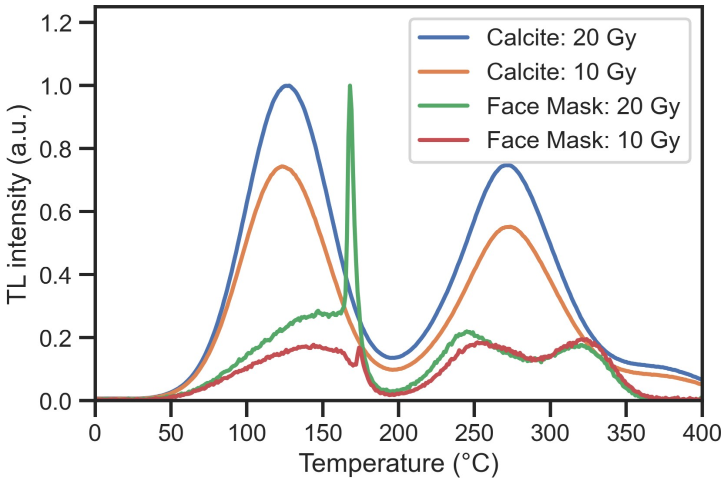

Figure 2. TL response of a calcite sample compared to a face mask sample after a 10 Gy and 20 Gy β irradiation, normalized to the respective maximum value at 20 Gy for illustrative purposes.

3 RESULTS AND DISCUSSION

3.1 TL response of calcite and face mask

In Figure 2, we present the TL spectra up to 400 °C acquired at a heating rate of 1 °C/s after irradiations of around 10 Gy and 20 Gy. Calcite exhibits the well known peak structure [19]: Peak 1 in the region around 120 °C, and Peak in the region around 260 °C. The face mask shows a more complex behaviour. Most strikingly we observe a peak at 160 °C which coincides with the melting temperature of the polymer [20], potentially allowing for a more efficient heating of the filler at this point and thus a signal spike. The Peak 2 region of the face mask also shows a more complex structure, exhibiting two peaks instead of one. The total luminescence is thus likely to stem both from the polymer and the mineral filler.

3.2 Minimum detectable dose of face mask samples

To assess the minimum detectable dose (MDD) of the face mask samples we measured the TL of an unirradidated sampleover the same TL readout range (20 °C to 400 °C at 1 °C/s) and plotted the distribution (see Figure 3). We chose a conservative approximation of a MDD asthe dose whose signal corresponds to the mean plus three times the standard deviation of the background counts σ_B [21]. As is clear from Figure 3, the data is best fitted by a skewed normal distribution. The determined MDD limit still captures more than 98.4% of the data, very closely satisfying our requirement of three sigma (99.7%).

To determine the MDD of the face mask samples we prepared 23 samples that were irradiated with different doses from around 0.04 Gy to 20 Gy. This approach also simulates the practical scenario of attempting a dose recovery of unknown face mask samples. We first observe the TL integrals for different integration intervals, see Figure 3. We find that the region above 200 °C, i.e. the region of calcite's Peak 2, contains a high native signal that yields a high background signal and thus low sensitivity for the given dose. A native signal in this context means a TL signal that is due to the accumulated dose from natural radiation sources (ionising or non-ionising, i.e., electromagnetic radiation). In the region of Peak 1 from 25 °C up to 200 °C we however find a monotonous response with dose.

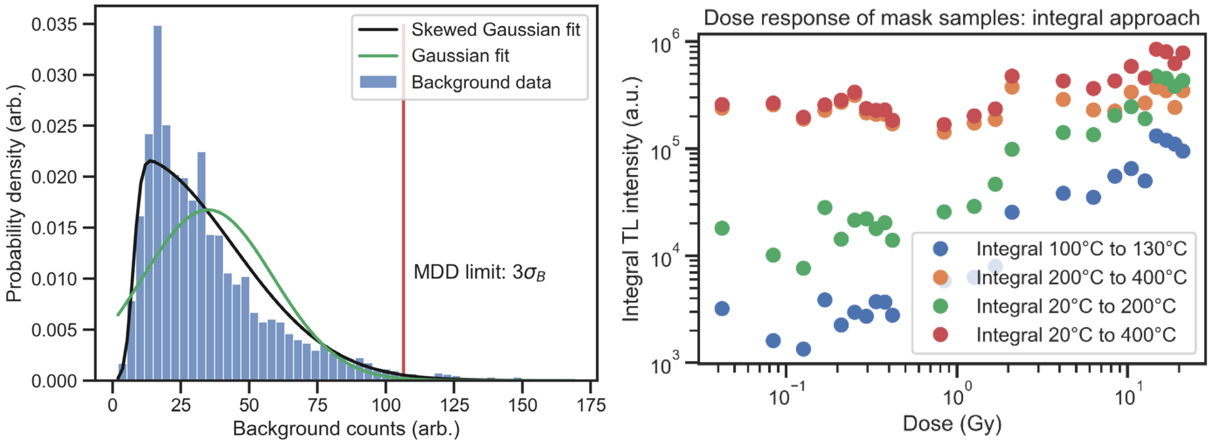

Figure 3. Left: Histogram of the background counts of a TL measurement in the used experimental setup. **Right:** Integral TL curve counts for various integration ranges for individual face mask samples that were given different doses.

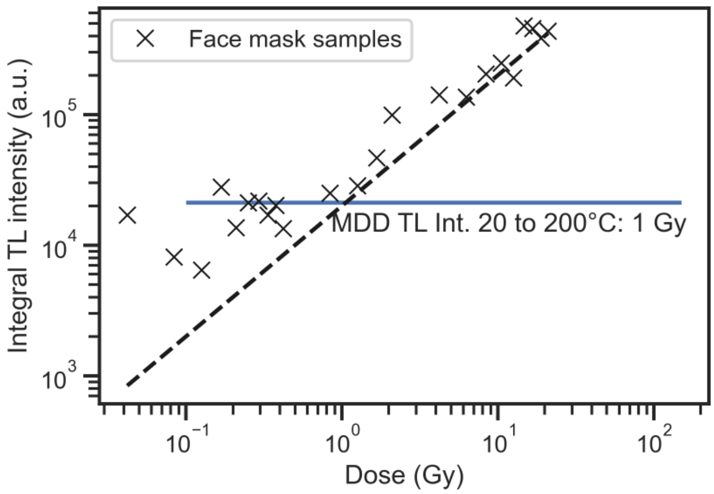

Figure 4. Integral TL from 0°C to 200°C of individual face mask samples that were given different doses. The MDD using the limits determined from background measurements is indicated (continuous blue line), showing that in principle a dose of 1 Gy and higher is detectable. A linear fit (dashed line) is added for visual guidance.

Integrating only over the peak region (100 °C to 130 °C) was not found to improve sensitivity. In Figure 4 we display the final results of the 25 to 200 °C integration interval and display the MDD.

The MDD line corresponds thus to the TL integral at a dose of about 1 Gy. We nonetheless notice some outliers in the data that exceed this limit despite a low dose irradiation. For most of the data a linear fit nonetheless appears to capture the TL integral behavior well. Since severe cases of exposure warranting immediate medical attention typically occur in exposures above 2 Gy [5], we conclude that a fortuitously worn face mask may aid the triage procedure in an emergency situation.

3.3 Limitations and outlook

In this study we encountered several limitations that impact the herein presented results: Firstly, our detection setup was not optimized for a red emitting TL material (see Section 2). Using a red sensitive PMT a potential sensitivity gain of factor 6 or more is conceivable. Secondly, we found that the native signal in the high temperature region of the TL (above 200 °C) was too high to allow for a dose determination (up to the maximum dose we studied, 20 Gy). Annealing of the mineral filler before incorporation into the fiber may alleviate this. This may be of interest for dosimetry as this region of the TL curve has a higher thermal stability (of the order of thousands of years [18]). Thirdly, we were only able to use the low temperature region of the TL curve for dose determination. Calcite has a well known thermal fading in this region with a lifetime of the order of 20 h [22] that limits the dose recovery to the same day at best. A careful characterization of light sensitivity and fading characteristics is thus necessary to increase the accuracy of dose recovery using face masks.

4 CONCLUSION

In this work we demonstrate that commercially available face masks can be used for emergency dosimetry. An ongoing, widespread face mask mandate in many countries due to the SARS-CoV-2 pandemic makes face masks suitable candidates for fortuitous emergency dosimeters due to their large occurrence amongst membres of the general public and radiation response. They can therefore assist medical triage procedures in large scale radiation exposure scenarios. With our detection equipment we found a minimum detectable dose of the order of 1 Gy which is within the recommended limit of 2 Gy. We discuss the limitations of our work regarding the detection setup, fading properties of calcite, and indicate future avenues of investigation.

Acknowledgments

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