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Analytical methodology

Feasibility of measuring zinc in human nails using portable x-ray fluorescence

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ABSTRACT

A variety of adverse health effects have been identified as resulting from zinc deficiency. Zinc supplementation may therefore be indicated for certain individuals or populations. A rapid and straightforward means of assessing zinc status in humans would be of considerable medical benefit. In this study, the feasibility of measuring zinc levels in human fingernails or toenails using a portable x-ray fluorescence technique was assessed. Whole nail models (or phantoms) were constructed from resin, and dosed with various concentrations of zinc. These different concentration "nails" were cut into small slices of 4.4 ± 0.2 mm width. The combination of these various slices into different arrangements allowed the modeling of different time-dependent zinc exposure scenarios. A portable x-ray fluorescence device was tested using an "open beam" configuration having a beam diameter of ~9 mm, and using a "weld mask" configuration with the beam width reduced to 2.9 mm. Minimum detection limits were determined to be 0.15 ± 0.01 ppm for the open beam, and 1.13 ± 0.08 ppm when using the weld mask. By scanning across the length of the model nails, it was demonstrated that differences in zinc levels deposited over time could be detected, and that the weld mask configuration was better suited to resolving spatial changes. The x-ray fluorescence approach was found to be highly sensitive for detecting zinc in nail, and capable of differentiating patterns of zinc uptake over time.

1. Introduction

The ability to test for zinc nutritional status has become an important topic in medical science. Zinc plays a critical biochemical role in the function of enzymes and other biomolecules [1], and zinc deficiency has been linked to a number of adverse health outcomes in humans. Recent estimates have placed the total number of people worldwide having zinc deficiency at 1–2 billion [2,3]. Severe zinc deficiency can lead to deleterious effects for a variety of systems in the body, including the immune, central nervous, skeletal, gastrointestinal, reproductive, and epidermal [4]. Specific effects in cases of severe zinc deficiency can include impaired immunity, skin lesions, diarrhea, and death. More common is moderate zinc deficiency, which has been associated with growth retardation, immune effects, and lethargy. Although not nearly as widespread as zinc deficiency, excess levels of zinc can also be problematic for human health [5].

Zinc supplementation may be indicated for certain individuals or populations. On a global scale, efforts to counter zinc deficiency have been inhibited by the lack of a straightforward, reliable diagnostic test of zinc status. Currently, the most common approach for assessing the zinc status of an individual is a measurement of serum or plasma zinc concentration [4,6] through, for example, inductively coupled plasma mass spectrometry (ICP-MS). This approach, however, presents problems as zinc levels will fluctuate over the course of a day and are influenced by the relative timing of testing and meals [6]. In addition, a serum or plasma concentration test can present practical difficulties as it requires a complex procedure involving a blood draw, blood processing, and subsequent analysis (usually at a distant lab). This is expensive and introduces a significant time delay between the sampling and availability of the result. For all of these reasons, it would be beneficial to develop an alternative diagnostic test with a new biomarker of zinc nutritional status.

Recently, it has been proposed that the assessment of zinc in human nail using laser-induced breakdown spectroscopy (LIBS) could provide an alternative diagnostic test [7]. Using a calibrated LIBS approach, zinc concentration in the nails of five subjects were correctly identified to within an average of 7 parts per million (ppm), when assessed by a comparison of LIBS results with those from speciated isotope dilution mass spectrometry [7]. The average standard deviation from the LIBS trials was 14 ppm, which corresponded with an average fractional

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uncertainty of 12%. While LIBS appears to be encouraging as a minimally invasive and portable method of assessing zinc nutritional status, its precision of measurement may be somewhat lacking.

As another possibility for an alternative to the serum or plasma test, the current paper considers the feasibility of measuring zinc in human nails using a portable x-ray fluorescence technique (XRF). It has previously been demonstrated that zinc concentration in nail serves as an appropriate indicator of zinc nutritional status [8]. As part of that particular study, two subjects with standard levels of dietary zinc had their intakes elevated in a well-controlled fashion through zinc supplementation and changes in diet. Zinc concentrations in nail showed a clear increase at the spatial locations corresponding to the timing of the increased zinc intake. Additionally, a larger group of 29 individuals scored for phytate/zinc ratio (based on self-reported diet) showed a strong inverse correlation between their phytate/zinc dietary score and measured zinc concentration in nail clippings. Zinc concentrations in human nail were again assessed in that study through LIBS [8]. The current study proposes a different approach to nail measurement, using XRF to assess zinc concentration at various locations within intact human nail, modeled here using a solid resin. Although portable XRF has previously been examined for its potential to detect zinc in nail clippings [9], this is the first study to consider its ability to track zinc spatially across the length of an intact nail.

2. Methods

In order to investigate the spatial resolution of our portable XRF system, a collection of model human nails (or phantoms) were fabricated. This was done using a commercial polyester resin and solidifying agent (Bondo Corp.; Atlanta, GA) that were used to simulate human nail. Phantoms of four different zinc concentrations (0, 10, 20, and 30 ppm) were initially created by adding appropriate amounts of zinc atomic absorption spectrometry standard solution (Sigma-Aldrich; Oakville, ON) to the resin. The mixtures of zinc, resin, and solidifying agent were poured into circular molds with a diameter of 39 mm. The phantoms were allowed to dry until completely solid. The samples were then removed from the molds and measured to have, on average, a thickness of 3.2 ± 0.1 mm.

All measurements were made using an Olympus Innov-X Delta Premium DP-2000 (Innov-X Technologies Canada; Vancouver, BC) portable XRF system, having a tube voltage of 40 kV and current of 100 μA. This system has a rhodium target x-ray tube, and a beam diameter of approximately 9 mm at the location of the sample. For stability and reproducibility, the system was operated in a tabletop stand mode (Fig. 1). The x-ray beam originates directly underneath a Prolene window (thickness of approximately 6 μm), through which the x-rays travel to strike the sample. A silicon drift detector (SDD), with an area of 30 mm^2 collimated to an effective area of approximately 20 mm^2, is also located underneath the sample and detects emitted characteristic x-rays and scattered photons at various energies. For all experiments performed, two distinct beam configurations were used. The first used the default “open beam” configuration producing a beam diameter of ~9 mm on the sample, as noted above. The appearance of the open beam configuration at the location where samples are placed is shown in Fig. 2. The second configuration used a commercially available “weld mask” (Innov-X Technologies Canada; Vancouver, BC) to restrict the beam size to a width of 2.9 mm. The appearance of the weld mask configuration is illustrated by Fig. 3.

Fig. 2. The open beam configuration showing the location where samples are placed.

Using a band saw, each of the original phantoms was sliced into pieces of, on average, 4.4 ± 0.2 mm width. Individual pieces were then belt sanded for smoothness and consistency of shape, and wiped clean to remove any particles. The individual pieces could then be rearranged into a variety of six-piece configurations in order to simulate nails with different profiles of zinc uptake. Pieces were simply placed side by side against each other, with no adhesive material used to join

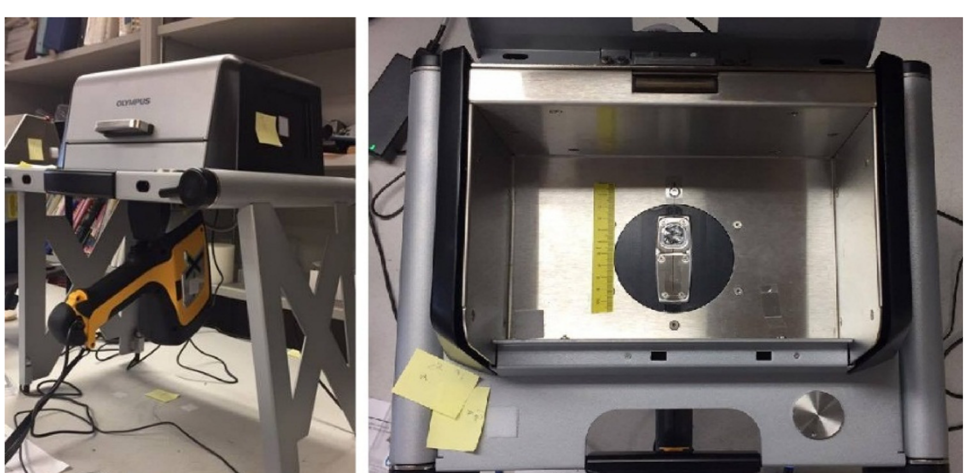

Fig. 1. The Olympus Innov-X Delta Premium DP-2000, operated in tabletop stand mode.