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Time Domain Broadband Characterization of Human Cadaver Bone (500 -1100nm)

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Abstract: We present optical characterization (500-1100nm) of fresh human bone. We observe the presence of various biomarkers like met-Hb, Hb, lipids, collagen and further discuss the optical properties of cortical bone, trabecular bone, and bone marrow. © 2024 The Author(s)

1.Introduction

Osteoporosis is a widespread bone disease characterized by decrease in bone density leading to fragility fractures. It accounts for 200 million women in global level with over 8.9 million fractures annually [1]. Current gold standard tool, Dual Energy X-ray Absorptiometry (DEXA) diagnosis osteoporosis by measuring bone mineral concentration. However, DEXA falls short in assessing bone microarchitecture and characterizing crucial biological elements, for example collagen - a key component of connecting tissue in bone - restricting DEXA's capacity to evaluate overall bone strength. This raises a need to develop diagnostic techniques which can complement the existing DEXA to assess comprehensive bone health to diagnose Osteoporosis.

Diffuse optical techniques have proven to be an important tool for *in vivo* diagnostics due to its high penetration depth and non-invasive nature. To diagnose osteoporosis or to understand the overall bone strength, the need to understand optical nature of bone is immense. Preliminary *in vivo* studies on bone were done in the past by Pifferi et al.,[2] and Konugolu Venkata Sekar et al., [3] however, optical properties of a fresh human bone were not established in the literature so far.

We present for the first time broadband optical characterization of cadaver human bone in 500-1100nm wavelength range. Cadaveric bone samples were obtained with approval from the Clinical Research Ethics Committee of the Cork Teaching Hospitals (CREC) at University College Cork (Reference number: ECM 4 (r) 05/04/2022 & ECM 5 (8) 05/04/2022). We observe the presence of various biomarkers such as met-Hb, de-Oxy Hb, lipids, collagen. We further discuss the optical properties of three main components of bone namely, cortical bone, trabecular bone, and bone marrow.

2. Material and methods

Photon Time of Flight (pToF) technique uses a broadband supercontinuum fiber laser as source. The source used here (Fianium SC450, UK) is a pulsed white light with spectral range from 450-2400nm with 100ps pulse width and 20MHz repetition rate. The beam is dispersed by a rotatable Pellin-Broca prism and the desired wavelength is coupled into a graded index fiber (0.1NA, 25um, 2m) to irradiate the sample. Scattered photons are collected by the single photon detector (mpd SPAD) and the pToF curves were recorded through laser-synced Time Correlated Single Photon Counting (TCSPC) system. Complete details of the setup can be found elsewhere [4].

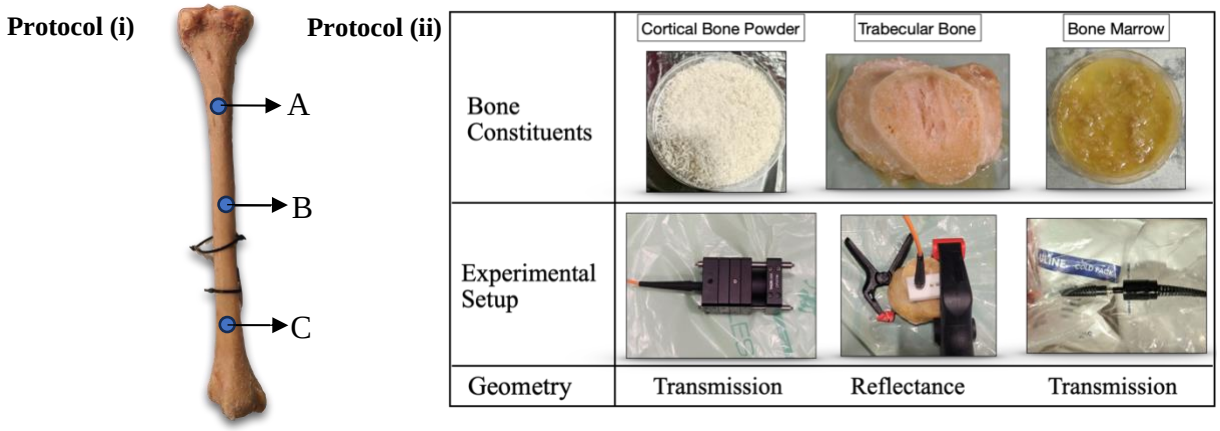
Absorption and scattering coefficients were extracted at each wavelength by fitting the recorded pToF curves to the solution of diffusion equation for an infinite slab model. The obtained scattering spectrum was fit to empirical power law derived from Mie theory. Complete details of data analysis can be found elsewhere [3].

Experimental arrangements (See Fig.1)

Protocol (i) pToF measurements recorded at locations A, B, C of human bone.

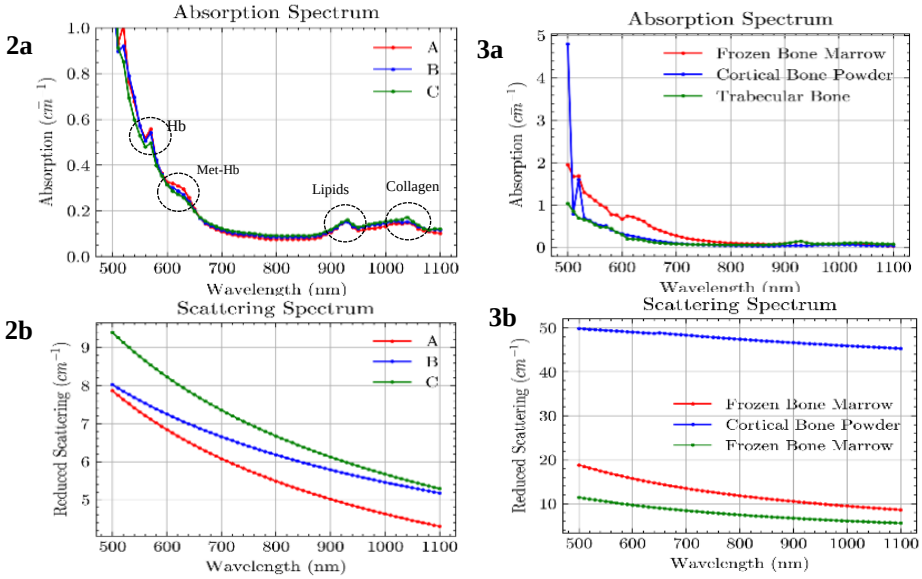
Protocol (ii) pToF measurements recorded for cortical bone powder (CBP), trabecular bone (TB), and frozen bone marrow (BM).

Fig.1



3. Results

The absorption peaks at 550nm indicates the presence of Hb content of bone. The absorption peaks in 920-980 nm region and 1020-1050 nm region can be helpful to quantify lipids and collagen contents of the bone respectively. The absorption spectrum of three main constituents of bone (Fig.4a) reveals that the trabecular bone contributes to lipid content in the bone. Both CBP and BM were found to follow same trend of absorption decay with wavelength.



Absorption and Scattering spectrum of
(i)Bone at locations A, B & C *Fig2(a,b).*
(ii) CBP, TB and BM *Fig3(a,b).*

4. Conclusion

For the first time, we report the optical characterization of cadaver human bone in 500-1100nm wavelength range indicating the presence of biomarkers like Hb, met-Hb, lipids, collagen etc., Furthermore, the optical characterization of cortical bone, trabecular bone and bone marrow gave insights into the optical properties of bone constituents that are responsible for certain biomarkers in the bone. This work aids to understand the biological components present in the bone which can help in assessing comprehensive bone health to diagnose Osteoporosis.

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