European Partnership on Metrology
Call 2025 – Health, Integrated European Metrology, Regulation and Research Potential

Selected Research Topic number: **SRT-h01**
Version: 1.0

Title: Optical characterisation of solid tissue-mimicking phantoms

Abstract

Optical techniques are pervasive in the medical sector, ranging from low-cost monitoring devices to life-critical techniques applied during surgery. Establishing tissue-mimicking phantoms with known optical properties and long-term stability is key to enabling the comparison of biomedical devices from different vendors and institutions, to support the development of standards, and assist the clinical translation of new technologies. Coordination among metrological and research institutes is needed to identify and overcome the limitations preventing the optical characterisation of solid phantoms, offering a long-sought solution to the costs, ethical concerns, and limited accessibility associated with the current *in vivo* testing paradigm.

Keywords

Tissue-mimicking phantom, Light scattering, Time-domain spectroscopy, Oximetry, Diffuse optics, Near infrared spectroscopy, Monte Carlo simulations

Background to the Metrological Challenges

The market for biomedical optical tools achieved a revenue valuation of $128 billion USD/year in 2023, with a global market estimation for pulse oximeters alone expected to reach $5.4 billion by 2033. These tools use diffuse optics, deploying low-power, non-ionising and inherently non-invasive near infrared light, and offer a powerful and cost-effective tool for clinical and homecare diagnostics. By measuring the spatial, angular, or temporal distributions of light scattered from a turbid medium, information can be extracted relative to its absorption and scattering properties that can reveal structural and chemical composition in terms of water, lipid or collagen content, concentration of oxy- and deoxy-haemoglobin, cytochrome c-oxidase, etc. This makes diffuse optics a prominent non-invasive and possibly non-contact clinical application of Near-Infrared Spectroscopy (NIRS) for real-time monitoring of blood oxygen saturation in cerebral oximetry for neonatal, paediatric and adult surgical procedures, for detecting brain injury after cardiac arrest, as well as breast cancer tumour diagnostics and for use in remote homecare.

Increasing the use of biomedical optical tools requires the development of an SI traceability chain from NMI to the medical devices employed in clinical settings. Research is needed to reduce the inconsistency in saturation measurements from different optical instruments and the lack of clinician consensus on the reliability of these devices when used on patients of differing skin pigmentations. EURAMET's TC-PR Orientation Page 2025 Health highlights this effect and the need it generates to develop correction models to account for irradiation "through translucent media, such as the skin". Several commercial devices use multiple wavelengths to mitigate skin pigmentation sensitivity, but oximeters continue to exhibit a decrease in saturation level with simulated melanin content, which is particularly marked at lower saturation levels. The ISO 80601 family of standards (e.g., ISO 80601-2-85 on cerebral oximetry, IEC 80601-2-71 on functional NIRS) regulate only basic safety aspects, without covering a comprehensive performance assessment of these instruments. Controlled parametric investigations in optical oximetry that avoid the variability and concerns of in vivo studies, based on tissue-simulating phantoms with known optical properties are required to address these issues. Phantom-based testing would provide a powerful approach to evaluate and compare oximeters, free from these limitations, carrying no risks for humans, and enabling the routine control of diffuse optics equipment.

Additionally, long-term (>1 y) stability and tunability of the optical properties of phantom materials across the full biological relevant range are also not fulfilled by typical water-based phantom formulations, posing the

EURAMET MSU,
Email: part.msu@euramet.org
Metpart.eu

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need for alternatives with high stability and small intra- and inter-batch variability. Due to these challenges, proposals to abandon *in vivo* testing are met with clinical resistance, hindering the establishment of a phantom-based approach. Coordination among metrology institutes is needed to overcome current limitations and obtain a first set of solid tissue-mimicking samples with known optical properties. A set of common standards generated from “approved phantoms" would provide a transferal of calibrations from NMI to clinical locations, allowing direct comparison between systems. Besides oximetry, tissue-mimicking phantoms with well-defined absorption and scattering coefficients are generally needed for the development, calibration and comparison of all medical devices relying on the absolute determination of optical properties of tissues.

To date, three main protocols for performance evaluation of diffuse optics devices (MEDPHOT, BIP, and nEUROPt) were elaborated in collaborative European projects and implemented on three kits of tissue phantoms. These studies exposed a significant accuracy problem affecting solid phantoms. While liquid phantom optical properties exhibit excellent agreement between different techniques and laboratories, this is not the case for solid matrices, where accurate optical characterisation is not straightforward to obtain neither a priori—from the nominal properties and concentration of raw materials—nor a posteriori—from a direct measurement on diffusive phantoms. The European metrology research community is addressing the characterisation of translucent materials in recent and ongoing EURAMET projects (e.g., measurement of the Bidirectional Scattering–Surface Reflectance Distribution Function (BSSRDF) which can be applied to the direct measurement of the phase function, scattering and absorption coefficients of media akin to tissue-mimicking phantoms developed during the EMPIR project 18SIB03 BxDiff and Metrology Partnership project 23IND14 xDDiff project. Additionally, very recent time-domain techniques have shown potential for reducing systematic biases related to skin pigmentation when applied to multi-layered configurations. Proposals addressing this topic should build on these developments and develop an SI traceable and optically characterised solid tissue-mimicking phantoms suitable for demonstrating compliance with international standards.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The proposal shall focus on the traceable measurement and characterisation of a set of stable and highly reproducible solid tissue-mimicking phantoms by determining their optical properties with SI-traceability, to improve the performance assessment of optical medical devices and support the transition away from in vivo testing and calibration.

The specific objectives are

1. To characterise a set of solid tissue-mimicking phantoms using established protocols (e.g., MEDPHOT) by independently varying scattering and absorption properties for biologically relevant values (i.e., the 0-0.2 cm^{-1} and 5-15 cm^{-1} ranges). In addition, to characterise these solid phantoms for homogeneity and surface roughness, as well as their long-term stability. Commercially available phantoms and/or phantoms fabricated with different thicknesses are to be included in the characterisation.
2. To characterise the multi-spectral response of identified set of phantoms from Objective 1 at wavelengths within the red and near-infrared therapeutic window, using both time-domain and steady-state bidirectional techniques, with an estimation of the variability and repeatability of the measurements across different positions and durations.
3. To develop a cross-validated methodology for relating the optical response of the selected phantoms from Objective 1 to their optical properties (absorption and scattering coefficients, asymmetry factor of the phase function), leveraging Monte Carlo modelling and diffusion theory, with a target uncertainty below 10 %. Additionally, to determine the linearity and degree of crosstalk between their absorption and scattering coefficients.
4. To develop a procedure for the performance assessment of diffuse optics medical devices that simulates different skin pigmentations based on a two-layered phantom configuration suitable for inclusion into existing standards (e.g., ISO 80601-2-85, IEC 80601-2-71). In addition to write a good practice guide for the performance assessment of existing medical diffuse optics devices based on the performance assessment procedure for use by medical laboratories/practitioners.

5. To facilitate the take up of the results from the regulatory bodies (e.g., FDA, MDCG), technical committees (e.g., ISO/IEC Joint Working Group “Oximeters”, IPASC), industrial community (manufacturers of tissue-mimicking samples and optical medical devices, oximeters), and the scientific community working on diffuse optics.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes, and it is expected that multidisciplinary teams will be required. To enhance the impact of the research, the involvement of the appropriate user community such as medical practitioners, medical (academic) hospitals and industry is strongly recommended, both prior to and during methodology development. Where relevant, proposals are encouraged to build on, or seek collaboration with, existing projects and develop synergies with other relevant European, national or regional initiatives and funding programmes. In particular, links are encouraged with (i) the projects funded under earlier relevant topics of the Horizon Europe programme; or (ii) other relevant European Partnerships.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the [the EMPIR project 18SIB03 BxDiff and Metrology Partnership project 23IND14 xDDiff project and how their proposal will build on those.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.1 M€ and has defined an upper limit of 2.6 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the ’end user’ community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your proposal’s results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability, or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the medical sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of the Metrology Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Timescale

The project should be of up to 3 years duration.