Development of near infrared optical tomography for thyroid cancer diagnosis

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論文題目

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（甲状腺がん診断に向けた近赤外光トモグラフィの開発）

論文要旨

[Introduction]

The incidence of thyroid cancer has been increasing worldwide during the past decades. Thyroid cancer is usually diagnosed by ultrasound imaging and fine-needle aspiration biopsy. However, diagnosis of follicular thyroid carcinoma (FTC), one type of thyroid cancers that can mutate into more aggressive variants, is difficult even after total thyroidectomy. Near infrared optical tomography (NIROT) is a potential approach to diagnosis of FTC because it can measure tumor hypoxia. Since, however, anatomical features of the human neck are complex, image reconstruction of the thyroid is challenging: the thyroid is located in a narrow region between the skin and trachea. In this study, we attempted to get around this issue by extracting the minimum volume of the human neck that is required for the image reconstruction, with the void region of the trachea excluded, and creating a finite element grid. First, we evaluated our image reconstruction algorithm in phantom experiments. And then, conducting time-domain optical measurements of a healthy human neck, we reconstructed the spatial distribution of absorption coefficients and three-dimensional tissue oxygen saturation maps of the whole of the thyroid.

[Method]

This study was approved by the ethical committee of Hamamatsu University School of Medicine (No. 15-082). A multichannel time-domain measurement instrument (TRS-80, Hamamatsu Photonics K.K.) was used to measure the phantom and the human subject. TRS-80 emits the ultrafast pulsed near infrared lights at 760 nm, 800 nm, 830 nm, and detects the transmitted lights through a measuring object that are transferred to the time-correlated single photon counting unit through eight high-speed photomultipliers. The polyurethan-based rectangular phantom (40 × 40 × 70 mm) including a cylindrical absorber with a diameter of 5 mm and a height of 70 mm was used for the evaluation of the algorithm. The subject was a healthy woman who was informed of the aim and procedures of this study. To confirm the tracheal and thyroid positions, a cervical magnetic resonance imaging scan was performed. The magnetic resonance (MR) images were also used to make an optical fiber holder. A total of 15 holes in the holder were arranged at an interval of 1.5 cm and seven source and eight detector fibers were inserted into the holes alternately so that the whole thyroid was illuminated. Forty-nine time-of-flight distributions of photons with the sufficient signal to noise ratio were used for the image reconstruction. Using the MR images, we created the grids with the void region of the trachea excluded. As a comparison, we made another grid by disregarding the presence of the trachea. We obtained the tomographic images of the absorption coefficients by minimizing the least square method with Tikhonov regularization by the nonlinear conjugate gradient method. During the iteration process, the reduced scattering coefficient value was fixed.

[Results]

In the phantom experiment, we confirmed that the high absorption region was successfully reconstructed. Then, we performed the image reconstruction of the human neck and superimposed these images on the MR images. High absorption regions corresponding approximately to the thyroid were reconstructed with the grid with excluding the trachea, although the position slightly shifted to the skin. We calculated tissue oxygen saturation from the absorption coefficient values at the three wavelengths. The tissue oxygen saturation of the thyroid was around 90%, while that in the background tissues, mainly muscles, was around 65%. In contrast, with the grid that disregards the presence of the trachea, the shape of the thyroid was not correctly reconstructed, although the existence of the thyroid may be read from the reconstructed images.

[Discussion]

This is the first study reporting the reconstruction of the spatial distribution of absorption coefficients and tissue oxygen saturation in the human whole thyroid with NIROT. It has been shown that the whole shape of the thyroid can be reconstructed if the grid for the calculations excludes the trachea void region. However, it is expected that reconstructed images will be improved if the reentrant light, which propagates through the trachea, is taken into account. In this study, the thyroid was reconstructed at a position closer to the skin than its actual position. This is attributable to the fact that we did not employ the spatially variant regularization despite decreases in measurement sensitivity along the depth direction. The values of the reconstructed absorption coefficients were much larger than the background values. The quantitative accuracy of the present study is still insufficient because the reduced scattering coefficient was not updated during the iterations. However, tissue oxygen saturation maps indicate that the thyroid is distinguishable from the background tissues. The present study has the three main limitations described above, but it has paved the way to functional optical imaging of the human thyroid.

[Conclusions]

This study presents three-dimensional *in situ* imaging of absorption coefficient and tissue oxygen saturation in the human thyroid by NIROT. The key ingredient is the use of a trachea-tissue boundary grid. It can be expected that NIROT has the potential to visualize the tissue hypoxia of the thyroid cancer.