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Development of a Tailored Thyroid Gland Phantom for Fine-Needle Aspiration Cytology by Three-Dimensional Printing

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BACKGROUND: Fine-needle aspiration cytology (FNAC) is a challenging and risky procedure for inexperienced clinicians to perform because of the proximity of the thyroid to the jugular veins, carotid arteries, and trachea. A phantom model for transfixion practice would help train clinicians in FNAC.

OBJECTIVE: To fabricate a tailored phantom with consideration for authenticity of size, touch, feel, and ultrasonographic (US) characteristics.

METHODS: A three-dimensional (3D) digital model of the human neck was reconstructed from computed tomography data of a subject. This model was used to create 3D-printed templates for various organs that require US visualization. The templates were injected with polymers that provided similar degrees of ultrasound permeability as the corresponding organs. For fabrication of each organ, the respective molds of organs, blood vessels, thyroid gland, and tumor were injected with the material. The fabricated components were then removed from the templates and colored. Individual components were then positioned in the neck mold, and agar gel was poured in. The complete phantom was then removed from the mold. Thereafter, 45 medical doctors and students performed ultrasound-guided FNAC using the phantom, following which they were queried regarding the value of the phantom.

RESULTS: The structure, US characteristics, and elasticity of the phantom were similar to those of the human subject. In the survey, all 45 participants replied that they found the phantom useful for FNAC training, and 30 medical students professed increased interest in thyroid diseases after using the phantom.

CONCLUSIONS: We successfully fabricated a tailored thyroid gland phantom for transfixion practice. As most of the phantom parts are injected in molds fabricated using a 3D printer, they can be easily reproduced once the molds are fabricated. This phantom is expected to serve as an effective and fully tailored training model for practicing thyroid gland transfixion. (J Surg Ed ■:■■■-■■■. © 2017 Published by Elsevier Inc. on behalf of the Association of Program Directors in Surgery)

KEY WORDS: fine-needle aspiration cytology, 3D printing, phantom, ultrasonographic characteristics

COMPETENCY: Medical Knowledge

INTRODUCTION

Ultrasound-guided puncture is currently used for preservation of vessels, drainage, and biopsy; it may be employed for any step of the medical procedure, from diagnosis through treatment. Gaining safe, convenient, and precise access to complicated organ structures requires a high level of technical skill and expertise. Acquisition of such skills is essential for inexperienced doctors, irrespective of the

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pathology and specialization. The most convenient way to acquire skills in ultrasound-guided puncture in any area is by practicing with phantoms, which has led to the development of a wide range of phantoms.[1–3]

Fine-needle aspiration cytology (FNAC) is a necessary procedure for the clinical diagnosis of thyroid gland cancer. Current clinical guidelines recommend FNA for nodules of diameter 1.0 to 1.5 cm as well as for smaller nodules with suspicious ultrasonographic (US) features.[4–6] Training for FNAC for thyroid diseases is essential given that the procedure is technically challenging, particularly for inexperienced residents, because of the proximity of the thyroid to the jugular veins, carotid arteries, and trachea. Recent studies have correlated the increase in diagnostic rate of thyroid gland diseases with increase in training,[7] which further highlights the importance of practicing FNAC with a phantom. Although thyroid neck training phantoms are commercially available, their prohibitive cost is a limitation for repeated training. Therefore, a low-cost, fully tailored phantom is ideal and required for transfixion practice.

Three-dimensional (3D) printing, which is a type of “additive manufacturing”, is now widely used in both academic and commercial institutions. Although 3D printers have been used to create fully tailored phantoms, the types of medically suitable materials that can be printed from a 3D printer are limited. Therefore, we believed that it was necessary to devise a unique approach to create a low-cost, fully tailored, elaborate thyroid gland phantom for transfixion training. The aim of this study was to develop a low-cost thyroid gland phantom using a hybrid of old (traditional mold-based fabrication) and new (direct 3D printing) manufacturing techniques.

MATERIALS AND METHODS

This study was approved by the Ethics Committee of Nagasaki University Hospital (approval no., 16042512). All patients provided written consent for participation.

Materials

The major components that need to be represented in a thyroid gland phantom are the cervical vertebrae, trachea, common carotid arteries, internal jugular veins, thyroid gland, tumor, and surrounding soft tissue. Molds for these components were created using a 3D printer and injected with ultrasound-permeable materials. The 3D-printed molds were composed of a photopolymerizable acrylic resin, and the injected components mainly comprised agar and sodium alginate (Table).

Because blood vessels and the tumor require the fabrication of low, narrow, durable, small structures, a 3% solution of high-strength agar (Ina Agar Karikorikan, Japan; 3 g agar in 100 mL water), which has approximately 5 times the strength/concentration of regular agar, was used for fabricating the phantom.

At the same time, ultrasound luminescence of the thyroid gland is relatively high, and the phantom gland needs to be mechanically strong enough to withstand transfixion. Therefore, sodium alginate, which has the same base material as agar—i.e., algae—was used in combination with agar. The composition of 200 mL gel was as follows: 5 g sodium alginate, 20 mL ethanol, 80 mL saline, 0.1 g tetrasodium pyrophosphate, 0.7 g dicalcium phosphate,

TABLE. Materials and Cost

Organ	Material	Cost
Vertebrae Trachea Outer frame mold Vessel mold Tumor mold Thyroid gland mold	Acrylic light polymerized resin (Velo clear R; 3D printed)	$70 $10 $1500 $30 $10 $40
Vessel Tumor	Agar (Karikorikan R Ina) + saline	$0.1
Thyroid gland	Sodium alginate (KIMICA I-1GR) + ethanol + saline Tetrasodium pyrophosphate Dicalcium phosphate Glucono-δ-lactone + water Agar (Karikorikan R Ina) + water	$1
Surrounding soft tissue	Agar (Yamato R Ina) + ethanol Sodium alginate (WAKO500-600) + ethanol + water	$3

While the vertebrae and the trachea were directly printed using a 3D printer, the remaining parts were poured/injected into 3D-printed molds. Blood vessels and tumor were fabricated with agar, and the thyroid gland was fabricated using a variety of materials. The surrounding soft tissue was fabricated with agar with sodium alginate for regulation of ultrasound luminescence.
3D, three dimensional.