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● *Original Contribution*

MULTIMODAL EVALUATION OF 2-D AND 3-D ULTRASOUND, COMPUTED TOMOGRAPHY AND MAGNETIC RESONANCE IMAGING IN MEASUREMENTS OF THE THYROID VOLUME USING UNIVERSALLY APPLICABLE CROSS-SECTIONAL IMAGING SOFTWARE: A PHANTOM STUDY

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Abstract—A precise estimate of thyroid volume is necessary for making adequate therapeutic decisions and planning, as well as for monitoring therapy response. The goal of this study was to compare the precision of different volumetry methods. Thyroid-shaped phantoms were subjected to volumetry via 2-D and 3-D ultrasonography (US), computed tomography (CT) and magnetic resonance imaging (MRI). The 3-D US scans were performed using sensor navigation and mechanical sweeping methods. Volumetry calculation ensued with the conventional ellipsoid model and the manual tracing method. The study confirmed the superiority of manual tracing with CT and MRI volumetry of the thyroid, but extended this knowledge also to the superiority of the 3-D US method, regardless of whether sensor navigation or mechanical sweeping is used. A novel aspect was successful use of the same universally applicable cross-imaging software for all modalities. (E-mail: martin.freesmeyer@med.uni-jena.de)

Key Words: **Thyroid, Thyroid volume, Ultrasonography, Computed tomography, Magnetic resonance imaging, Three-dimensional, Volumetry.**

INTRODUCTION

Pathological changes of the thyroid gland are frequent and dependent mostly on the local iodine supply and the prevalence of goiter. In Germany, the average prevalence of goiter is 35.9% (Volzke et al. 2003). An exact determination of the thyroid volume and its pathological changes is clinically relevant because therapeutic decisions and monitoring of therapy response are based largely on the thyroid volume (Reinartz et al. 2002; van Isselt et al. 2003).

The primary method for imaging the thyroid is conventional 2-D B-mode ultrasonography (2-D US) (Lucas 2000; Ying et al. 2008). This method is simple, readily available, inexpensive and free from radiation exposure (Reinartz et al. 2002) and has been validated in epidemiological studies (Knudsen et al. 1999; Vitti et al. 1994). Conventional 2-D US is based on separate measurements of the two gland lobes. The simplified mathematical model for volumetric calculations assumes that each lobe represents a rotational ellipsoid (Brunn et al. 1981). In the ellipsoid model, the volume of each lobe is calculated with the formula $length_{max} \times width_{max} \times depth_{max} \times f$, and the two volumes are added. Different values have been recommended for the correction factor f (Brunn et al. 1981; Knudsen et al. 1999; Reinartz et al. 2002; Ying et al. 2008), but usually 0.5 is applied in clinical routine. Application of the ellipsoid model, however, is associated with relatively high intra- and inter-observer variability (Ozgen et al. 1999; Rago et al. 2006). On one hand, this is inherent to the tendency of the mathematical model to generate deviations (Ozgen et al. 1999), and on the other hand, a nodular goiter can cause lobe deformities and/or thickening of the isthmus, leading to significant imprecision in 2-D US volumetry (Rago et al. 2006).

Three-dimensional sonography was developed in the late nineties (Tong et al. 1998). In this case, however, volume assessment is possible only with a dedicated workstation equipped with special software (Andermann et al. 2007; Kot et al. 2009). Recently, it became possible to generate universally compatible data in DICOM (Digital

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Imaging and Communications in Medicine) format that can be subjected to volumetry calculation via a multimodal workstation (Freesmeyer et al. 2012). The advantages of 3-D US in comparison with 2-D US include higher precision (Schlogl et al. 2001) and clearly reduced intra- and inter-observer variability (Lyshchik et al. 2004; Ng et al. 2004).

As an alternative to the ellipsoid model, for 3-D data the organ volume in parallel planes can be delimited from the adjacent tissues via the manual tracing method. This method is less vulnerable to intra- and inter-operator errors and is considered by some authors as the gold standard (Andermann et al. 2007; Reinartz et al. 2002; van Isselt et al. 2003).

The results of a literature search focused on different scanning and volumetry methods via 3-D US are summarized in Table 1. Except for the article by Kot et al. (2009), however, all studies employed only one 3-D US method, mostly sensor navigated 3-D US.

The aim of the present phantom study was to compare the volumetric precision of the ellipsoid model and the manual tracing method. Several techniques were used for this purpose: 2-D US, two different 3-D US methods (sensor navigation [3-D sn-US] and mechanical sweeping [3-D ms-US]), computed tomography (CT) and magnetic resonance imaging (MRI). Two specific aspects were investigated: (i) the influence of phantom shape; (ii) the relative performance of 3-D sn-US and 3-D ms-US. Deformable phantoms compatible with this multimodal approach were developed and scanned, and the data evaluated with a workstation equipped with standard cross-sectional imaging software.

METHODS

Phantoms

Eighteen phantoms with a shape resembling the thyroid gland were developed in 18 pre-defined volumes (10, 15, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180 and 200 mL) meant to reproduce the range of thyroid volumes typically seen in patients before therapeutic interventions. The basic constructs were commercially available, heart-shaped latex balloons in three original volumes. To maintain the constructs in a water bed, four little pieces of plastic (approximately 2×3 mm) were inserted into the phantoms and then ligated with thread from the outside, creating four poles (Fig. 1). The unladen weight (tare) of each empty phantom was measured using a precision scale.

The balloons were filled with a mixture of water and MRI contrast medium (Omniscan, 0.5 mmol/mL; GE Healthcare, Oslo, Norway). The water was pre-boiled to minimize the formation of air bubbles via outgassing of dissolved particles. A previously measured dilution ratio of 1:99 (contrast medium:water) was used, on the one hand with the goal of reproducing density values basically equivalent to those of soft tissue for the purpose of CT imaging, and on the other hand to permit adequate imaging by MRI. The density measurements of the filling mix in comparison to water provided a negligible variability of 0.0015 g/mL; thus, a simplified assumption was made that 1 g of phantom content corresponded to 1 mL of volume. The net volumes derived from the weight measurements represented the reference standard for the assessment of the volumetric accuracy of the different methods (see also below). A tubing system with two three-way stopcocks was used to prevent the entry of air into the phantoms; that is, one stopcock was used to introduce the contrast mixture, and the other, to let out any air bubbles. The phantoms were weighed again at the end of the experiments (gross weight), and subtraction of the previously measured tare provided their net weight and volume.

To reproduce the shapes of the lobes and the typically narrow isthmus of a healthy thyroid, the phantoms were tied as illustrated in Figure 1a. For measurements, the phantoms were placed into a double-walled plastic container (Fig. 1). The four poles of the lobes were fixed with thread to the inner wall of the plastic container, which had been prepared with holes for the insertion and ligation of the thread. The phantoms were then pulled at approximately 2 cm above the bottom of the container, and the latter was filled with water until the phantoms were fully immersed (Fig. 1). After completion of the first measurement cycle with normally shaped phantoms, a second cycle was performed with deformed lobes (a model of nodular goiter) (see Fig. 1b for details). In a third cycle, all ties were removed and the model of thickened isthmus was investigated (see details in Fig. 1c). Finally, the phantoms were removed from the container and weighed again to ensure that any leakage occurring during the measurement was detected.

All experiments were carried out within a time frame of 29 d.

Ultrasonography scans

Two different machines were used for US scans. Conventional 2-D US and 3-D sn-US were performed using Logiq E9 (GE Medical Systems, Milwaukee, WI, USA) and a linear probe (ML 6-15) in virtual convex mode, with a frequency of 11 MHz and an image depth of 10 cm. A single focus was placed in the middle of the phantom. In the case of 3-D sn-US, the phantom was placed on a stretcher approximately 20 cm from a magnetic transmitter (see details in Fig. 2a). Two positional sensors fixed to the probe allowed recording of the position and movement of the ultrasound probe in the magnetic field during scanning (Fig. 2a). The equipment