The newly developed three-dimensional (3D) and two-dimensional (2D) thyroid ultrasound are strongly correlated, but 2D overestimates thyroid volume in the presence of nodules

T. Rago¹, W. Bencivelli², M. Scutari¹, C. Di Cosmo¹, C. Rizzo⁴, P. Berti³, P. Miccoli³, A. Pinchera¹, and P. Vitti¹
¹Department of Endocrinology; ²Department of Internal Medicine; ³Department of Surgery; ⁴Department of Chemical Engineering, University of Pisa, Pisa, Italy

ABSTRACT. The newly developed three-dimensional (3D) and two-dimensional (2D) thyroid ultrasound (US) were compared in assessing thyroid volume (TV) in 104 patients: 53 had an isolated thyroid nodule, 32 toxic diffuse goiter, 17 non-toxic multinodular goiter, 1 toxic multinodular goiter and 1 a toxic adenoma. A real-time Technos apparatus (Esaote SpA, Italy) with a 7.5 MHz linear transducer was used. The volume of thyroid lobes by 2D was calculated according to the ellipsoid formula. In the same session, TV by 3D US was calculated using a probe tracking system (in vivo ScanNT Esaote 3.4 MedCom. Darmasdt) and software to reconstruct 3D images, directly giving the lobe volume. There was a very good agreement between 2D and 3D, but in 94/208 lobes with nodular lesions 2D showed a 10% systematic overestimation compared to 3D, the percentage error being higher in lobes with lower volumes. A possible explanation for this result is the inadequacy of the ellipsoid formula in forecasting the correct lobe profile in the presence of nodules. This intrinsic defect of 2D US should be taken into account when evaluating TV in patients with nodular goiter.


INTRODUCTION
Thyroid ultrasonography (US) has proven to be very effective in the diagnostic approach of thyroid diseases (1-11). However, two-dimensional (2D) viewing by conventional US of three-dimensional (3D) anatomy may reduce the precision of this technique and may be partly responsible for the reported variability of thyroid US. In particular, measurement of thyroid volume (TV) calculated using the ellipsoid formula (12) has possible drawbacks. Firstly, the thyroid is only roughly ellipsoidal in shape, secondly each 2D image with its associated lobe diameter to be used for TV calculation represents just a thin slice of the patient’s anatomy obtained at a particular probe location and orientation, which is both subjective and hard to reproduce (13-15). Thus, for a single observer, the choice of significant images and lobe diameters to be used for TV calculation is somewhat arbitrary.

To overcome these difficulties, we used a 3D US method to image the thyroid gland. 3D US has already been applied to other organs and in particular to the prostate (16-18). 2D B-mode images have been elaborated by a computer to reconstruct 3D images that have been used to quantify normal and abnormal prostate volumes (17, 18). Lyschik et al. (19) report that TV in children and adolescents obtained using 3D US has high accuracy with 3.4% intra-observer variability and 96.5% repeatability. The ellipsoid formula used for 2D volume determination is reasonably adequate when measuring the volume of a normal thyroid lobe by 2D (20, 21), but gross deformations of the thyroid may create problems. The aim of this study was to compare 3D US with 2D US for the determination of TV, both in normal and in nodular thyroid lobes. Our data showed that 2D overestimates TV lobe compared to 3D, in lobes with thyroid nodules.
MATERIAL AND METHODS

Patients
The study included 104 patients, 83 females (mean age 37±14, range 13-76 yr) and 21 males (mean age 39±16, range 16-71 yr). Clinical diagnosis were: isolated nodule (no. =53), toxic diffuse goiter (no. =32), non-toxic multinodular goiter (no. =17), toxic multinodular goiter (no. =1), toxic adenoma (no. =1). For the statistical analysis, we considered all thyroid lobes (no. = 208), and then separately the lobes without nodules (no. =114/208) and lobes with nodules (no. =94/208).

2D thyroid US
Conventional thyroid ultrasonography was performed using a real-time Technos apparatus (Esaote SpA, Italy) with a 7.5 MHz linear transducer. The volume of thyroid lobes was calculated according to the ellipsoid formula:

\[ \text{Volume} = \pi \times \text{width} \times \text{length} \times \text{thickness} \times 12 \]

All ultrasound examinations were performed by the same observer (TR).

3D thyroid US
3D US was performed in the same section of 2D US using the real-time Technos apparatus, integrated by a probe tracking system (in vivo ScanNT Esaote 3.4 MedCom, Darmasdi). The examination was performed by scanning each lobe from the top to the bottom. The lobe was thus segmented into a series of cross-sectional 2D image slices. A boundary was selected in each slice and finally a 3D lobe boundary was generated from the whole set of slices. 2D and 3D US were performed in the same session. The 3D lobe volume was calculated by the software after the acquisition of the data and was thus unavailable while performing the exam.

Statistical analysis
Statistical evaluation was performed using linear regression analysis and the Bland and Altman approach (Stat View, version 5.01) (22, 23) with a confidence interval (CI) of 95%.

RESULTS
All thyroid lobes
The linear regression analysis comparing 2D with 3D in 208 lobes shows that the slope is not significantly different from 1: 1.040 (95% CI: 0.993±1.088), and the intercept not significantly different from 0: -0.295 (95% CI: -1.271±0.681), indicating a very high agreement between the two methods (not shown).

Thyroid lobes without nodules
The linear regression slope obtained comparing 2D and 3D volumes of 114/208 thyroid lobes without nodules was very close to 1: 0.98 (95% CI: 0.914±1.05) and the intercept to 0: -0.025 (95% CI: -1.38±1.32), showing that in this subgroup of lobes, the volume measurements by 2D and 3D were almost coincident, the agreement between the two methods being higher than that observed in all thyroid lobes taken together (not shown).

Thyroid lobes with nodules
The slope of the regression line obtained in the 94/208 lobes with nodular lesions was 1.10 (95% CI: 1.04±1.17) and the intercept -0.45 (95% CI: -1.81±0.91). These data indicate a 10% systematic overestimation of 2D compared to 3D (Fig. 1). Thus, unlike that described above for all thyroid lobes taken together and for lobes without nodules, in this subgroup of lobes, a significant difference between 2D and 3D was observed. The Bland and Altman analysis (21, 24) of the data showed a large dispersion of the differences between the two methods. The absolute value of this difference was greater with increasing TV (Fig 2, panel A), while the percentage error was higher for lobes with lower volumes (Fig. 2, panel B).

DISCUSSION
US has proven to be very effective in the diagnostic approach of thyroid diseases (1-11). Besides the description of the thyroid echostructure, the measurement of TV by US may be useful in the follow-up of patients with thyroid diseases. A more important application of TV measurement by US has been the assessment of the effects of iodine deficiency (25, 26). Indeed, several studies have clearly shown that thyroid US is much more accurate than palpation for the definition of small goiters in children (27-29). For this reason, TV measured by

![Fig. 1 - Linear regression analysis of volume (ml) measurements of thyroid lobes with nodules (no. =94) obtained using two-dimensional (2D) and three-dimensional (3D). The regression slope (continuous line) was 1.10 (95% CI : 1.04±1.17) and the intercept -0.45 (95% CI: -1.81±0.91). This shows a 10% systematic overestimation of 2D with respect to 3D. For comparison is reported the identity line (dotted line).](image)