Variation in thyroid volumes due to differences in the measured length or area of the cross-sectional plane:
A validation study of the ellipsoid approximation method using CT images.

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*Biophysics*

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*CT, Ellipsoid approximation, Graves' disease, Internal radioiodine therapy, Thyroid, Volumetry*
Abstract
Background This study examined the variation in the thyroid volume determined by the ellipsoid approximation method due to differences in the measured length or area of the cross-sectional plane of CT images.

Methods Forty-five patients with Graves' disease were included in this retrospective study. We designated the three-dimensional thyroid volumes extracted manually (VCT) as the reference data and calculated five approximate volumes for comparison: (1) the mean volume of 8100 different thyroid volumes depending on the diameter of the cross-sectional plane at the midpoint of the major axis, (Vellipsoid,mean); (2) the volume using the maximum diameter and its orthogonal diameter, (Vellipsoid,maxlength); (3) the maximum (Vellipsoid,maxvolume) and (4) minimum (Vellipsoid,minvolume) of the 8100 thyroid volumes; and (5) the volume determined with an equivalent circle diameter, (Vellipsoid,Heywood).

Results Thyroid volumes obtained via the ellipsoid approximation method varied depending on the diameter of the cross-sectional plane and included a mean error of approximately 20%, while the concordance correlation coefficient (CCC) differed for each approximate volume. Among these volumes, Vellipsoid,mean and Vellipsoid,Heywood were in good agreement with VCT, according to single regression analyses and the resultant CCC values, with mean errors of 7.0% and 2.5%, respectively.

Conclusion While Vellipsoid,Heywood approximated thyroid volumes with vastly reduced errors, we recommend utilizing three-dimensional thyroid volumetry if measurement accuracy is required.

Full-text
Due to technical limitations, full-text HTML conversion of this manuscript could not be completed. However, the manuscript can be downloaded and accessed as a PDF.

Tables
Table 1. Length of the major axis, $c$, and the angles, $\phi$ and $\rho$, in each patient's thyroid lobe.

|               | Right lobe         |                   | Left lobe          |
|---------------|-------------------|-------------------|-------------------|
| $c_R$ [cm]    | $\phi$ [deg.]     | $\rho$ [deg.]    | $c_L$ [cm]        |
| 6.6±1.2       | -7.65±3.14        | 1.02±5.41         | 6.2±1.2           |
|               |                   |                   | 8.30±3.28         |
Table 2. Thyroid volumes calculated by three-dimensional volumetry ($V_{CT}$) and the ellipsoid approximation method ($V_{\text{ellipsoid,mean}}$, $V_{\text{ellipsoid,maxlength}}$, $V_{\text{ellipsoid,maxvolume}}$, $V_{\text{ellipsoid,minvolume}}$, and $V_{\text{ellipsoid,Heywood}}$).

| $V_{CT}$  | $V_{\text{ellipsoid,mean}}$ | $V_{\text{ellipsoid,maxlength}}$ | $V_{\text{ellipsoid,maxvolume}}$ | $V_{\text{ellipsoid,minvolume}}$ | $V_{el}$ |
|-----------|-----------------------------|----------------------------------|----------------------------------|----------------------------------|---------|
| [cm$^3$]  | [cm$^3$]                    | [cm$^3$]                         | [cm$^3$]                         | [cm$^3$]                         | [cm$^3$]|
| 32.5±14.8 | 30.2±14.1                   | 37.0±18.3                        | 39.1±18.7                        | 25.0±12.3                        |         |

Table 3. Correlation coefficient, CCC, and McBride's scale between $V_{CT}$ and each approximate volume. CCC for assessing the consistency of each relationship was above 0.900 for $V_{\text{ellipsoid,mean}}$ and $V_{\text{ellipsoid,Heywood}}$.

|                      | $V_{\text{ellipsoid,mean}}$ | $V_{\text{ellipsoid,maxlength}}$ | $V_{\text{ellipsoid,maxvolume}}$ | $V_{\text{ellipsoid,minvolume}}$ | $V_{el}$ |
|----------------------|-----------------------------|----------------------------------|----------------------------------|----------------------------------|---------|
| Correlation coefficient* | 0.943                      | 0.939                            | 0.941                            | 0.945                            |         |
| Lin's CCC            | 0.931                      | 0.878                            | 0.841                            | 0.672                            |         |
| McBride's scale      | Moderate                    | Poor                             | Poor                             | Poor                             |         |

* Spearman's rank correlation coefficient

Figures
Figure 1

a) Calculation method for thyroid volumes by the ellipsoid approximation method.

Calculation method for the length of the major axis, \( c \), and the angles, \( \varphi \), and \( \rho \), in each patient's thyroid lobe.
Measurement of arbitrary diameters and their corresponding orthogonal diameters (a and b) on the cross-sectional plane at the midpoint of the major axis. Four approximate volumes (V_{ellipsoid,mean}, V_{ellipsoid,maxlength}, V_{ellipsoid,maxvolume}, and V_{ellipsoid,minvolume}) were obtained from a and b.

Figure 2

\[
V_{\text{ellipsoid}}(\theta_L, \theta_R) = \left( \frac{\pi}{6} \times a_{\theta_L} \times b_{\theta_L} \times c_{\theta_L} \right)_{\text{Left lobe}} + \left( \frac{\pi}{6} \times a_{\theta_R} \times b_{\theta_R} \times c_{\theta_R} \right)_{\text{Right lobe}}
\]

(8100 volumes) (90 volumes) (90 volumes)
Ellipsoid approximation method for thyroid volumes using the equivalent circle diameter (Heywood diameter).

\[ V_{\text{ellipsoid,Heywood}} = \left( \frac{\pi}{6} \times R_L \times R_L \times c_L \right)_{\text{Left lobe}} + \left( \frac{\pi}{6} \times R_R \times R_R \times c_R \right)_{\text{Right lobe}} \]

\[ = \left( \frac{2}{3} \times S_L \times c_L \right)_{\text{Left lobe}} + \left( \frac{2}{3} \times S_R \times c_R \right)_{\text{Right lobe}} \]
Relationship between VCT and the 8100 thyroid volumes obtained by combining a and b of each thyroid lobe [Vellipsoid(θL,θR)]. The upper and lower end of the error bar represents the maximum and the minimum thyroid volume, respectively. The shaded area indicates an area surrounded by the regression lines of Vellipsoid,maxvolume and Vellipsoid,minvolume (Corresponding to Fig. 5c and 5d, respectively). The variation in the approximate volumes tended to increase as the thyroid volume increased.
Figure 5

Relationship between VCT and the five approximate volumes (Vellipsoid,mean, Vellipsoid,maxlength, Vellipsoid,maxvolume, Vellipsoid,minvolume, and Vellipsoid,Heywood). Although there was a strong correlation between VCT and these approximate volumes, the slopes of the regression equation were different for each relationship (0.79–1.20). For this reason, CCC differed for each approximate volume (0.672–0.947).
Figure 6

Error rate between VCT and the five approximate volumes (Eellipsoid,mean, Eellipsoid,maxlength, Eellipsoid,maxvolume, Eellipsoid,minvolume, and Eellipsoid,Heywood). The mean error rate was the highest between Vellipsoid,minvolume and VCT (-23.5%), and the lowest between Vellipsoid,Heywood and VCT (2.5%).