Original Article

Estimation of small thyroid phantom volume by computed tomography

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Abstract

Objective: Although the simple summation-of-areas technique was reported to be useful for estimation of enlarged thyroid volume on computed tomography(CT), its usefulness is unknown for estimation of small thyroid volume. The aim of this study was to examine by using thyroid shaped phantoms whether it is also applicable to estimation of small thyroid volume on conventional and spiral CT.

Methods: Eleven thyroid phantoms made of paper clay, 9 - 126 cc in volume were scanned with 10, 5 and 3 mm slice thickness by conventional and spiral CT and the volume was calculated using the summation-of-areas technique by 3 observers each.

Results: The average overestimations for 10, 5 and 3 mm slice thickness were 10±4%、10±5% and 7±7% in the conventional CT and 11±8%, 8±7% and 7±7% in the spiral CT, respectively. Overestimation was larger in phantoms with 20cc or less (18-25%) than in the phantoms with 26 cc or more (5-8%). Correlations of the CT estimated volume and the actual volume were excellent (r = 0.999) in 10, 5 and 3 mm slice thickness on both conventional and spiral CT scans. Intra- and interobserver coefficients of variation ranged from 3.6% to 7.4%, and 4.5% to 7.4% respectively, indicating that the reproducibility of the technique is high.

Conclusion: These experimental studies suggest that the summation-of-areas technique is applicable to estimation of small thyroid volume with acceptable accuracy and reproducibility on both conventional and spiral CT.

Key words: Thyroid gland, Goiter, Volume, Computed tomography

INTRODUCTION

In vivo quantification of organ or mass volume is useful or important for the diagnosis, therapy and follow-up of diseases. For example, measurements of thyroid volume have been performed for calculation of an appropriate therapeutic dose of ^{131}I for toxic diffuse(1-4), multinodular(5,6) goiters, non-toxic large or multinodular goiters(7-11) and follow-up of them after ^{131}I therapy(4,7-12) or L-thyroxine therapy(13), for the studies of thyroid changes in normal population(14), healthy women(15) and pregnancy(16), and for the epidemiological studies of goiters(17-19). Estimation of thyroid mass has been traditionally made by palpation and scintigraphy(1). Recently ultrasonography is routinely and widely used for measurements of thyroid volume(2-4,6,7,10,12-19).

Computed tomography (CT) is also one of such modalities to estimate the organ volume and the summation-of-areas technique was shown to be a simple and accurate volume estimation method for the organs such as the liver, spleen and kidney(20,21). However these organs are relatively large and most of them are not complicated in shape. As for the thyroid volume estimation by CT, comparison between the volume measured by this technique and the weight of relatively large resected thyroid tissue (42 - 697 g, mean 243 g) was made and the authors suggested that it was a reliable and reproducible method (22). However, it is unknown whether the technique is also applicable to estimation of the smaller thyroid volume. Therefore we studied experimentally the accuracy and reproducibility of the summation-of-areas technique for estimation of the volume of

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smaller thyroid shaped phantoms on CT.

MATERIALS AND METHODS

The first experiment was done to examine the accuracy and reproducibility of the summation-of-areas technique for 10 and 5 mm slice thickness by conventional CT, because we have clinically used a 10 or 5 mm slice thickness for estimation of the thyroid volume by conventional CT. The second experiment was done to examine whether a 3 mm slice thickness can improve the accuracy of the summation-of-areas technique for estimation of the thyroid phantom volume on conventional CT and the accuracy and reproducibility of this technique for estimation of the thyroid phantom volume on spiral CT, because the CT apparatus worldwide available now is almost spiral CT.

We used the commercially available paper clay (PT521-250, Kutsuwa, Co., Japan) to make thyroid phantoms of various size. The clay was made of calcium carbonate, pulp fibers and paste and was easily transformed into thyroid shape in various size and clearly visualized and demarcated on CT. The initial shape of one piece of the clay was rectangular, 16 x 9 x 3 cm in size and 960 g in weight. Two pieces of the clay were used and cut into 11 pieces different in size every 10 cc, from 10 cc to 130 cc. Then the actual volume was measured by the water displacement method. The resultant 11 thyroid phantoms were 10, 20, 30, 38, 48, 64, 70, 80, 94, 100 and 126 cc in volume, respectively. The individual rectangular clay was then transformed into the thyroid shape. Every thyroid phantom was put on a neck phantom made for measurements of radioiodine thyroid uptake ratios (an acrylic resin cylinder with 12.4 cm in diameter and 12.6 cm in height with a hole of 5.8 cm in diameter and 10.5 cm in height, Kyoto Kagaku Co., Japan) and CT scans were performed for each thyroid phantom.

Conventional CT scans were performed on a commercially available CT scanner, X-Vigar (Toshiba Co., Japan). The scan parameters were a slice thickness of 10 or 5 mm, 10 or 5 mm scan spacing, table feed of 1 slice/s, 120 kV, and 160 mA. The table feed was carried out in the cephalic direction, starting from the upper edge to the lower edge of the neck phantom with at least one scan totally above and one below the thyroid phantom to ensure that its entire volume was included in the series. Scans were performed at first with a 10 mm slice thickness and then a 5 mm slice thickness in the individual thyroid phantom.

The borders of the gland were traced manually on the scanner screen using a mouse-controlled cursor after setting the window level on +100 and the window width on 200. The traced segmented surface area (region of interest, ROI) was automatically calculated by multiplying a pixel size and the number of pixels in the ROI in the installed scanner soft ware. A pixel size was determined by 512 x 512 matrix and the diameter of field of view (240 mm), and was obtained in square millimeters. This procedure was done first for the lowest slice showing the thyroid gland and repeated every 10 or 5 mm cephalically, until the gland was no longer visible. The number of slices was 3 for the 10 mm slice thickness and 7 for the 5 mm slice thickness in the smallest 10 cc thyroid phantom and 10 for the 10 mm slice thickness and 20 for the 5 mm slice thickness in the largest 126 cc thyroid phantom. Then the ROI areas were added up. **Fig.1** shows an example of the

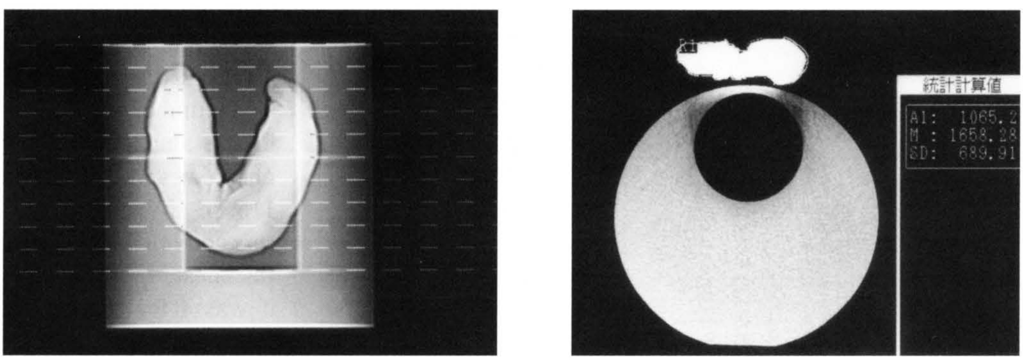

FIGURE 1. An example of the scanogram of a thyroid phantom (A) and a manually traced ROI over a CT image of the phantom and its automatically calculated area values (B).

TABLE 1. Estimation of Thyroid Phantom Volume by Conventional X-CT*

Slice thickness	Actual volume	CT estimated volume (cc)		CT estimated volume/actual volume (%)	
(mm)	(cc)	Mean ± S.D.	Range	Mean ± S.D.	Range
	10	12 ± 0	11_12	118 ± 4	110_120
	20	23 ± 1	23_24	117 ± 3	115_120
	30	32 ± 1	31_33	106 ± 2	103_110
	38	42 ± 0	42_43	111 ± 1	111_113
	48	53 ± 1	52_53	109 ± 1	108_110
10	64	69 ± 1	67_70	107 ± 1	105_109
	70	77 ± 1	76_78	110 ± 1	109_111
	80	85 ± 1	85_86	107 ± 1	106_108
	94	101 ± 1	100_103	108 ± 1	106_110
	100	107 ± 1	106_108	107 ± 1	106_108
	126	138 ± 1	137_140	110 ± 1	109_111
			Total (n=99)	110 ± 4	103_120
	10	12 ± 0	12_12	120 ± 0	120_120
	20	24 ± 0	24_25	121 ± 2	120_125
	30	32 ± 1	32_33	108 ± 2	107_110
	38	41 ± 1	40_42	108 ± 2	105_111
	48	53 ± 1	52_53	109 ± 1	108_110
5	64	69 ± 1	68_70	107 ± 1	106_109
	70	76 ± 1	76_77	109 ± 1	109_110
	80	88 ± 1	87_89	110 ± 1	109_111
	94	100 ± 0	100_101	106 ± 0	106_107
	100	106 ± 1	105_106	106 ± 1	105_106
	126	136 ± 1	134_138	108 ± 1	106_110
			Total (n=99)	110 ± 5	105_125
	9	11 ± 0	11_11	122 ± 0	122_122
	19	22 ± 0	22_23	117 ± 2	116_121
	26	29 ± 1	28_29	110 ± 2	108_112
	33	36 ± 1	35_38	110 ± 3	106_115
	44	46 ± 0	46_47	105 ± 1	105_107
	59	61 ± 1	59_62	103 ± 2	100_105
3	65	68 ± 2	66_70	105 ± 3	102_108
	76	76 ± 1	75_77	100 ± 1	99_101
	84	88 ± 1	88_90	105 ± 1	105_107
	91	94 ± 1	93_94	103 ± 1	102_103
	116	118 ± 1	117_118	102 ± 1	101_102
			Total (n=99)	107 ± 7	99_122

*The volume of each thyroid phantom was calculated 3 times by 3 observers on CT (n=9).

TABLE 2. Estimation of Thyroid Phantom Volume by Spiral X-CT*

Slice thickness	Actual volume	CT estimated volume (cc)		CT estimated volume/actual volume (%)	
(mm)	(cc)	Mean ± S.D.	Range	Mean ± S.D.	Range
	9	12 ± 1	11_12	129 ± 6	122_133
	19	23 ± 0	23_23	121 ± 0	121_121
	26	30 ± 1	30_31	116 ± 2	115_119
	33	38 ± 1	37_38	114 ± 2	112_115
	44	46 ± 1	46_48	105 ± 3	105_109
10	59	62 ± 1	61_63	105 ± 2	103_107
	65	69 ± 0	68_69	106 ± 0	105_106
	76	79 ± 1	78_80	104 ± 1	103_105
	84	91 ± 0	90_91	108 ± 0	107_108
	91	95 ± 1	95_96	104 ± 1	104_105
	116	120 ± 1	118_121	103 ± 1	102_104
			Total (n=99)	111 ± 8	102_133
	9	11 ± 0	11_11	122 ± 0	122_122
	19	22 ± 0	22_23	117 ± 2	116_121
	26	29 ± 1	28_30	112 ± 2	108_115
	33	37 ± 1	36_37	111 ± 2	109_112
	44	47 ± 2	45_46	107 ± 6	102_105
	59	61 ± 1	60_61	103 ± 1	102_103
5	65	67 ± 1	67_69	104 ± 1	103_106
	76	77 ± 0	76_77	101 ± 0	100_101
	84	89 ± 1	88_90	106 ± 1	105_107
	91	95 ± 1	95_96	104 ± 1	104_105
	116	118 ± 1	117_120	102 ± 1	101_103
			Total (n=99)	108 ± 7	100_122
	9	11 ± 0	11_11	122 ± 0	122_122
	19	22 ± 0	21_22	115 ± 2	111_116
	26	29 ± 1	28_29	111 ± 2	108_112
	33	37 ± 1	36_37	111 ± 2	109_112
	44	45 ± 0	45_47	102 ± 0	102_107
	59	61 ± 1	60_61	103 ± 1	102_103
3	65	67 ± 0	67_68	103 ± 1	103_105
	76	77 ± 1	76_77	101 ± 1	100_101
	84	88 ± 0	88_88	105 ± 0	105_105
	91	94 ± 1	92_95	103 ± 1	101_104
	116	119 ± 1	118_119	103 ± 1	102_103
			Total (n=99)	107 ± 7	100_122

*The volume of each thyroid phantom was calculated 3 times by 3 observers on CT (n=9).

scanogram of a thyroid phantom put on the neck phantom and its CT image with an automatically calculated ROI area. The volume (cc) was the added area (mm^2) x 0.01 x 1.0 cm in case of the 10 mm slice thickness and the added area (mm^2) x 0.01 x 0.5 cm in case of the 5 mm slice thickness. The obtained figure was rounded off to the integer because the actual volume was represented as an integer. The above tracing procedures were independently done 3 times for each thyroid phantom by 3 observers (A:HT, B:HN and C:MN). Thus the individual thyroid phantom was measured 9 times for the 10 mm and 5 mm slice thickness, respectively.

The second experiment was performed using the same CT scanner and manner with the first experiment. The thyroid phantoms made of the paper clay were 9, 19, 26, 33, 44, 59, 65, 76, 84, 91 and 116 cc in volume. The conventional scan parameters for the 3 mm slice thickness were 3mm scan spaces, table feed of 1 slice/sec, 120 KV and 160 mA. The spiral scan parameters were 10 mm/sec, 5 mm/sec and 3 mm/sec table feeds, 1:1 pitch, 120 kV and 160 mA. The number of slices was 12 in the smallest 9 cc thyroid phantom and 31 in the largest 116 cc thyroid phantom for the conventional 3 mm slice thickness. In the spiral scans, it was 4 for the 10 mm slice thickness, 7 for the 5 mm slice thickness and 11 for the 3 mm slice thickness in the smallest

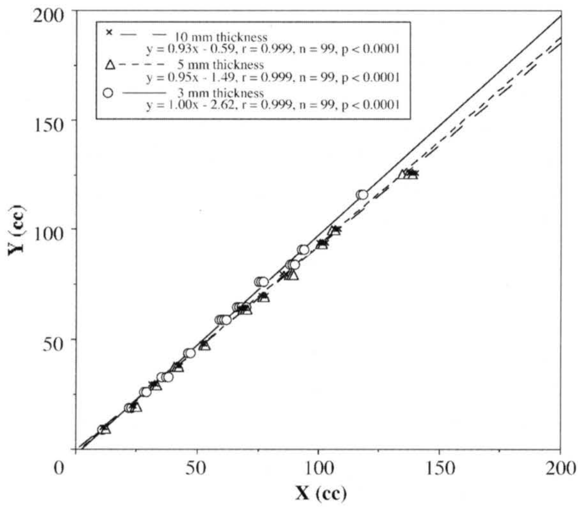

FIGURE 2. Conventional CT-estimated volume of thyroid phantoms (X) vs. their actual volume (Y).

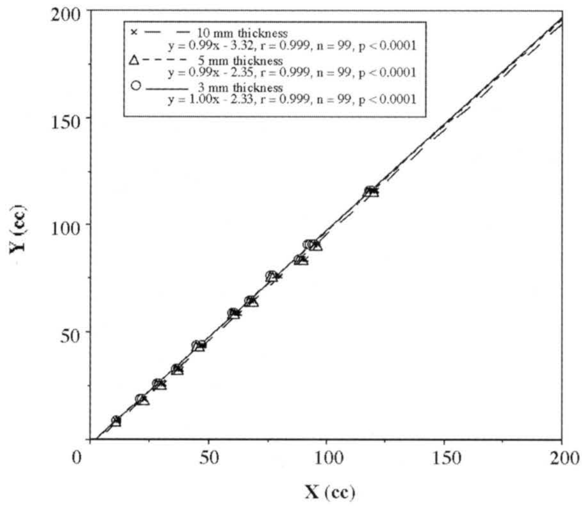

FIGURE 3. Spiral CT-estimated volume of thyroid phantoms (X) vs. their actual volume (Y).

TABLE 3. Intraobserver Differences in Estimation of Thyroid Volume by X-CT

		CT estimated volume/actual volume (%) and coefficient of variation (C.V., %)						
		First		Second		Third		
Observer	N	Mean ± S.D.	C.V.	Mean ± S.D.	C.V.	Mean ± S.D.	C.V.	Statistical significance*
A	22	111 ± 5	4.5	111 ± 5	4.5	111 ± 4	3.6	NS
B	22	109 ± 4	3.7	109 ± 4	3.7	110 ± 5	4.5	NS
C	66	109 ± 7	6.4	109 ± 7	6.4	109 ± 7	6.4	NS
D	44	108 ± 8	7.4	108 ± 8	7.4	108 ± 8	7.4	NS
E	44	107 ± 7	6.5	107 ± 7	6.5	108 ± 7	6.5	NS

*NS; not significant.

TABLE 4. Interobserver Differences in Estimation of Thyroid Volume by X-CT

		CT estimated volume/actual volume (%) and coefficient of variation (C.V., %)										
		Observer										
		A		B		C		D		E		
Experiment	N	Mean±S.D.	C.V.	Mean±S.D.	C.V.	Mean±S.D.	C.V.	Mean±S.D.	C.V.	Mean±S.D.	C.V.	Statistical significance*
First	66	111 ± 5	4.5	109 ± 5	4.6	110 ± 5	4.5	-----	-----	-----	-----	NS
Second	132	-----	-----	-----	-----	109 ± 7	6.4	108 ± 8	7.4	107 ± 7	6.5	NS

*NS; not significant.

9 cc phantom and 9 for the 10 mm slice thickness, 19 for the 5 mm slice thickness and 31 for the 3 mm slice thickness in the largest 116 cc phantom. Tracing of the ROIs was done by C, D(ST) and E(MJ). The volume (cc) was the added area (mm^2) x 0.01 x 0.3cm in case of the 3 mm slice thickness.

Every statistical analysis was performed using the normalized thyroid volume data, values of CT estimated volume x 100/actual volume (%). Student-Newman-Keuls (SNK) test was used after Kruskal- Wallis H-test was done to determine significant differences among 6 CT estimation methods. Mann-Whitney-U-test was used to determine significant differences between two groups of smaller and larger thyroid phantoms. The correlations between the volume of the thyroid phantoms estimated by CT and their actual volume were calculated using Spearman's correlation coefficients. Intra- and interobserver differences were tested by Kruskal-Wallis H-test. Coefficient of variation (100xSD/mean%) was also obtained for each observer. The significant level was considered to be $p < 0.05$.

RESULTS

Tables 1 and 2 show conventional and spiral CT estimated volumes for individual actual volumes and the ratios of the former to the latter. This CT calculation method overestimated the actual volume in almost all thyroid phantoms. The mean overestimation was 10±4% (3 - 20%) in 10 mm thickness scans and 10±5% (5 - 25%) in 5 mm thickness scans and 7±7%(-1-22%) in 3 mm thickness scans on conventional CT and 11±8%(2-33%) in 10 mm thickness scans, 8±7%(0-22%) in 5 mm thickness scans and 7±7%(0-22%) in 3 mm thickness scans on spiral CT. The 3 mm slice thickness was statistically better than the 5 mm ($p<0.05$) and 10 mm slice thickness ($p<0.05$) on conventional CT and the 10 mm slice thickness ($p<0.01$) on spiral CT. The 5 mm slice thickness was also better than the 10 mm slice thickness ($p<0.01$) on spiral CT. However the differences were small as shown in the above mentioned mean±SD values. Overestimation was larger in phantoms with 20 cc or less volumes than in the phantoms with 26 cc or more volumes: 18±3% vs.8±2% in the 10 mm slice thickness , 21±2% vs. 8±2% in the 5 mm slice thickness and 19±3% vs.5± 4% in the 3 mm slice thickness on conventional scans and 25±6% vs.8±4% in the 10 mm slice thickness, 19±3% vs.5±4% in the 5 mm slice thickness and 18±4% vs.5±4% in the 3 mm slice thickness on spiral scans(each: $p<0.0001$). The CT estimated volume was plotted vs. the actual volume in **Figs.2** and **3**. There were excellent correlations between the actual volume and the CT estimated volume ($r = 0.999$, $P<0.0001$) in all estimation methods.

As shown in **Tables 1** and **2**, in 66 CT volume estimations, each of which was calculated 3 times by 3 observers, the standard deviation (S.D.) values ranged from 0 cc to 1 cc, except for 2cc in two CT estimations and the difference in CT volume ranged from 0 cc to 4 cc. The median difference in each CT volume to the averaged CT volume of 3 times measurements by each observer was 0 cc and ranged from - 1 cc to + 1 cc. In this connection, there were no statistically significant differences in mean ±S.D. values among three times measurements in each observer and among 3 observers in the first or second experiment as shown in **Tables 3** and **4**, indicating no significant intra- and interobserver differences. The coefficient of variation of each observer in intraobserver and interobserver differences ranged from 3.6% to 7.4% and from 4.5% to 7.4%, respectively, indicating intraobserver and interobserver variations were small. Thus the reproducibility of this technique was high.

DISCUSSION

The summation-of-areas technique used in CT is the simplest, most practical means of calculating organ or mass volume by which the volume is determined by adding the products of the cross-sectional areas and the scan spacing (slice thickness in our present study)(21). The accuracy of measurements of the volume by this technique was previously tested for relatively large immobile vegetables (200 - 1000 cc) and organs such as dog kidneys (43 - 88 cc) and human spleens (309 - 3675cc) and the mean percentage error was 4-5 % (21). The accuracy and reproducibility of this technique were ±5% and ± 3%, respectively, when the organs were liver(422-1218 cc), kidney(36-93 cc), and spleen (190-528 cc) in dogs (20). This technique was also applied to measuring of the volume of human enlarged thyroids on CT and the accuracy was a mean difference of +12% with a wide range error(+57.3 ~ −13.9%) when compared with the operated thyroid tissue weight (mean;243g ± 157g, range; 42 -697g) (22). However the volume of the operated thyroid tissue cannot be consider the true in vivo volume, because of manipulation, squeezing, bleeding during operation and the thyroid tissue left in situ (22). Therefore, it is worthwhile to examine the accuracy of this technique by using thyroid-shaped phantoms with known volume.

We used small thyroid-shaped phantoms whose volumes were measured by water displacement. The paper clay used could be easily transformed into thyroid shapes and had calcium which yielded high density and made the borders of the phantoms clear.

The error was overestimation in our study. The reasons for this can be considered as follows: 1) We set the window level + 100 to visualize the neck phantom simultaneously. The CT values of the phantoms ranged from +1800 to +2100. Therefore we tested the difference between the actual rectangular area (90x31 mm^2) of a cubic phantom made of the clay and the area measured by the rectangular ROI under the condition of window level +100 and window width 200. The rectangular ROI yielded an area of 91x31 mm^2. Thus the overestimation was 1.1% and this was an intrinsic factor. 2) The areas displayed were pure white and the cursor line was also white. Thus the observers might have unconsciously drown the lines slightly outside the white thyroid phantom area to avoid the indistinguishable overlap. 3)

Error due to thyroid phantom shapes. If the phantoms were spheroid, the overestimation of the lower parts should be cancelled by underestimation of the upper parts. In our thyroid phantoms, overestimation of the lower large parts might be larger than underestimation of the upper small parts of the phantoms **(Fig.1.A)**, resulting in overestimation in a total .

The 3 or 5 mm slice thickness CT was statistically better than the 10 mm slice thickness CT, but the difference in overestimation was small (3-4%). This agreed with the results of previous reports; 1 cm vs. 2 cm scan spacing in larger volume organs (20) and the 5 mm vs. 10 mm slice thickness in enlarged thyroid volume calculation (21). This may be due to that doubling or triplicating of the error caused by manual tracing of areas may cancel the advantage of double or triplicate scan slices. In addition, the thinner the slice is, the longer the time to trace manually the ROI is. In fact, the time required for tracing ROIs for obtaining a phantom volume ranged from 4 to 15 minutes for the 10 mm slice thickness, from 7 to 23 minutes for the 5 mm slice thickness and from 14 to 45 minutes for the 3mm slice thickness in the 9-116 cc phantoms of the second experiment. Thus the 10 or 5 mm slice thickness may be convenient and time-saving in a clinical setting.

Three of the 5 observers had little experience with tracing of the areas by a cursor on the CT monitor. Tracing of areas for the study began after training of tracing an area twice or 3 times. The reproducibility was high: There were no intraobserver and interobserver differences and the largest coefficient of variation for 132 measurements among 3 observers was 7.4%. This means that determination of thyroid volume by the summation-of-areas technique on CT does not depend on the observers and is objective.

Hegedüs reviewed various methods for estimation of thyroid size (23): Palpation is subjective, inaccurate and cannot be standardized. The estimates were within 10% of actual weight only in 25% of the patients and an average error of approximately 20% or 24% when compared with the surgically removed thyroid and approximately 32% or 34% when compared with ultrasonography. Isotope planar scintigraphy also seems to be inaccurate and only marginally more accurate than palpation; a mean positive error of approximately 49%, an average positive error of approximately 15% with a maximum of 60% or a maximal error of about 40% with an average of ± 20%. SPECT or PET is more accurate, but its routine use is restricted for estimation of thyroid volume. Ultrasonography is more accurate to estimate the thyroid volume than palpation and radionuclide scintigraphy; an average error of approximately 16% or 7% without any consistence over- or underestimation. However the inaccuracy of the volume determination increases with increasing amount of thyroid tissue located substernally. In addition, it requires skill and approximately 3 months of training.

Although ultrasonography is cost effective and easily available and 3-dimensional measurement is recently possible and accurate when the thyroid located above the sternum (24), it requires skill and training as mentioned above. Magnetic resonance imaging was also used for volume determination of goiters (9,25,26) and its high reproducibility was shown (25), but its accuracy remains to be clarified. The disadvantages of CT are its higher cost and radiation exposure, but CT has the advantages of acceptable accuracy and reproducibility. A recent study in which ultrasonography and CT were compared for thyroid volumetry recommended the use of CT for measurement of thyroid volume of goiters with substernal extension(27).

In conclusion, our experimental results suggest that the summation-of-areas technique can be applied to CT volume estimation of complex shaped small thyroids with acceptable accuracy and reproducibility.

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