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Krzysztof Waldemar Romański

Evaluation of the Methods Estimating Gallbladder Volume Using Geometric Models Simulating Natural Gallbladder Contours

Ocena metod szacowania objętości pęcherzyka żółciowego z zastosowaniem modeli geometrycznych imitujących naturalny kształt pęcherzyka żółciowego

Department of Animal Physiology, Faculty of Veterinary Medicine, University of Agriculture, Wrocław, Poland

Abstract

Background. There are some inconsistencies regarding the accuracy of ellipsoid method widely used for estimation of gallbladder volume.
Objectives. The aim of this work was to evaluate the ellipsoid method and to compare it with some other rapid methods for estimation of gallbladder volume using geometric models of the gallbladder.
Material and Methods. Three theoretical models simulating the most common gallbladder shapes presented in four sizes each were used. Their precise volumes were calculated and then their sizes were measured in similar manner as natural gallbladders after ultrasonographical imaging. Parameters were measured according to the formulas of several rapid methods estimating gallbladder volume. The methods approximating gallbladder shape to the cone, frustum of cone, ellipsoid (three formulas) and barrel (two formulas) were applied.
Results. The results showed that any of the method applied is not accurate while one modified ellipsoid formula provided the most repeatable but lowered results. The results of method approximating gallbladder shape to a cone were the lowest.
Conclusions. It is concluded that accuracy of simple, rapid methods is strongly dependent on gallbladder shape and should be used with caution (**Adv Clin Exp Med 2004, 13, 6, 903–908**).

Key words: methods estimating gallbladder volume, geometric models, ultrasonography.

Streszczenie

Wprowadzenie. Istnieją wątpliwości odnośnie do dokładności metody elipsoidy, szeroko stosowanej w szacowaniu objętości pęcherzyka żółciowego.
Cel pracy. Ocena metody elipsoidy i porównanie jej z innymi szybkimi metodami szacowania objętości pęcherzyka żółciowego z zastosowaniem geometrycznych modeli pęcherzyka żółciowego.
Materiał i metody. Użyto trzech modeli teoretycznych symulujących najbardziej powszechne kształty pęcherzyka żółciowego przedstawionych w czterech wymiarach każdy. Obliczono dokładne objętości tych modeli, które następnie były mierzone podobnie jak naturalne pęcherzyki żółciowe podczas badania ultrasonograficznego. Parametry mierzono zgodnie ze wzorami wielu szybkich metod szacowania objętości pęcherzyka żółciowego. Stosowano metody przybliżające kształt pęcherzyka żółciowego do stożka, stożka ściętego, elipsoidy (trzy wzory) oraz beczki (dwa wzory).
Wyniki. Wyniki wykazały, że żadna z metod nie jest dokładna, chociaż wyniki jednej z użytych modyfikacji metody elipsoidy były powtarzalne, choć zaniżone. Najniższe wartości otrzymano po zastosowaniu metody przybliżającej kształt pęcherzyka żółciowego do stożka.
Wnioski. Dokładność prostych i szybkich metod zależy w znacznym stopniu od kształtu pęcherzyka żółciowego i te metody powinny być stosowane ostrożnie (**Adv Clin Exp Med 2004, 13, 6, 903–908**).

Słowa kluczowe: metody szacowania objętości pęcherzyka żółciowego, modele geometryczne, ultrasonografia.

The ellipsoid method is commonly used for estimation of gallbladder volume [1–3]. It was validated in man and dog by several authors [4, 5] who finally concluded that this method is accurate and comparable with other methods including sum-of-cylinder method [6]. However, more detailed studies revealed that ellipsoid method is not always accurate [7, 8] and currently it is recommended only for estimation of volume of regular gallbladders [9]. Further studies confirmed that ellipsoid method is inaccurate when gallbladder shape is asymmetric, i.e. it does not resemble solids like the ellipsoid or the sphere [10, 11]. Therefore, it was decided to further evaluate the accuracy of ellipsoid method using three geometric models resembling most typical gallbladder shapes. Application of these models enables precise calculation of these volumes and good comparison of the results of the methods estimating gallbladder volume with precisely calculated gallbladder volumes. Additionally, the accuracy of ellipsoid method was further analyzed and the method was compared with other simple and rapid methods including known method of Cano et al. [12].

Material and Methods

Theoretical Gallbladder Models

Three gallbladder models resembling most typical gallbladder shapes [9, 13] were elaborated. The first model was composed of half of ellipsoid figure (triangular shape at longitudinal section) and of frustum of cone (Fig. 1). These two constituents were the same in all three models. Second model contained the same figures at both ends of the solid and in the middle of the solid two figures were inserted: obliquely transected half of the cylinder with small height and the entire cylinder (Fig. 1). In the third model, three oblique half of cylinder and two whole cylinders were inserted and these elements were identical to those in the second model (Fig. 1). Then, the calculations of their exact volumes were performed. For the first model the following structural formula (composed of the formulas of each element) was used:

$$V = (\pi : 6 \cdot {}^1\!/\!_2 b^2 \cdot e) + [(\pi \cdot h) : 3 \cdot (b^2 + bd + d^2) : 2],$$

where V – calculated total volume of the solid. Explanations of other symbols, see Figure 1.

The second model was described with structural formula:

$$V = (\pi : 6 \cdot {}^1\!/\!_2 b^2 \cdot e) + \pi \cdot {}^1\!/\!_2\, b^2 \cdot h_1 + [(\pi \cdot b^2) : : 2 \cdot h_2] + [(\pi \cdot h) : 3 \cdot (b^2 + bd + d^2) : 2],$$

where V – calculated total volume of the solid. Explanations of other symbols as in Figure 1.

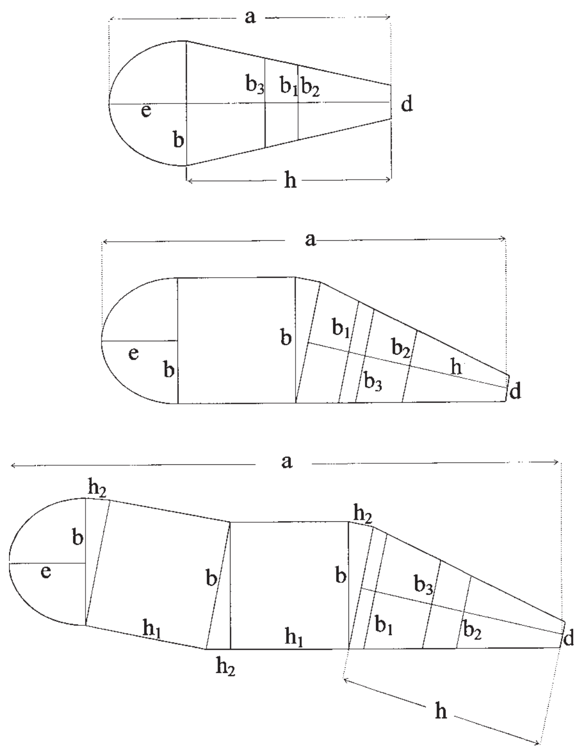

Fig. 1. Three geometric models of the gallbladder serving as a reference point for testing the methods estimating gallbladder volume. Upper model: a – total length of the solid, b – maximal height of the solid (no asymmetry in transverse section was designed), d – minimal height of the solid, e – length of the half of ellipsoid that is the first element of the solid, h – length of the frustum of cone part of the solid that is second element of this model, b_1 – height of frustum of cone in two-third length of the whole solid, b_2 – height of frustum of cone in its half length, b_3 – height of frustum of cone in proximal one-third of its length. Model in the middle: h_1 – length of the cylinder, second element of the solid, h_2 – length of the half of low cylinder representing third part of the solid. Other explanations as in upper model. Lower model contains the similar elements of the same size as in both upper models and explanation of symbols does not differ

Ryc. 1. Trzy modele geometryczne pęcherzyka żółciowego służące jako punkt odniesienia w testowaniu metod szacowania objętości pęcherzyka żółciowego. Model górny: a – całkowita długość bryły, b – maksymalna wysokość bryły (nie wprowadzono asymetrii w przekroju poprzecznym), d – minimalna wysokość bryły, e – długość połowy elipsoidy jako pierwszego elementu bryły, h – długość stożka ściętego jako drugiego elementu bryły, b_1 – wysokość stożka ściętego w dwóch trzecich długości całej bryły, b_2 – wysokość stożka ściętego w połowie jego długości, b_3 – wysokość stożka ściętego w jednej trzeciej bliższej jego długości. Model środkowy: h_1 – długość walca jako drugiego elementu bryły, h_2 – długość połowy niskiego walca jako trzeciej części bryły. Inne objaśnienia jak w modelu górnym. Model dolny zawiera podobne elementy tych samych rozmiarów co elementy obu powyższych modeli, dlatego objaśnienia symboli są takie same

The third model was described with structural formula:

$$V = (\pi : 6 \cdot {}^{1}/_{2}b^2 \cdot e) + 2\pi \cdot {}^{1}/_{2}b^2 \cdot h_1 + 3[(\pi \cdot b^2) : : 2 \cdot h_2] + [(\pi \cdot h) : 3 \cdot (b^2 + bd + d^2) : 2],$$

where V – calculated total volume of the solid. Explanations of other symbols as in Figure 1.

All models were presented in four sizes each.

Methods Used for Estimation of Gallbladder Volume

The following methods were applied for estimation of models volume and for comparison with calculated "true" models volumes:

1. Method of Cano et al. [12] approximating gallbladder shape to a cone according to the formula:

$$V_1 = ({}^{1}/_{3}\pi) \cdot a \cdot ({}^{1}/_{2}b)^2,$$

where V_1 – estimated gallbladder volume. Explanations of other symbols as in Figure 1.

2. Method approximating gallbladder shape to a frustum of cone according to the formula:

$$V_1 = (\pi \cdot a) : 3 \cdot ({}^{1}/_{2}b^2 + {}^{1}/_{2}b \cdot {}^{1}/_{2}d + {}^{1}/_{2}d^2),$$

where V_1 – estimated gallbladder volume. Explanations of other symbols as in Figure 1.

3. Ellipsoid method [1, 2] according to the formula:

$$V_1 = (\pi : 6) \cdot a \cdot b^2,$$

where V_1 – estimated gallbladder volume. Explanations of other symbols as in Figure 1.

4. Modification of ellipsoid method according to the formula:

$$V_1 = (\pi : 6) \cdot a \cdot [(b + d) : 2]^2,$$

where V_1 – estimated gallbladder volume. Explanations of other symbols as in Figure 1.

5. Further modification of ellipsoid method according to the formula:

$$V_1 = (\pi : 6) \cdot a \cdot [(b + b_1) : 2]^2,$$

where V_1 – estimated gallbladder volume, b and b_1 height values measured in 1/3 and 2/3 of the total length of solid. Other explanations as in Figure 1.

6. Approximation of gallbladder shape to a barrel [14] according to the formula:

$$V_1 = 0.5236 \cdot a \cdot 8b_3^2 + (4 \cdot b_3 \cdot b) + 3b^2,$$

where V_1 – estimated gallbladder volume, b_3 – height measured in 1/3 of the frustum of cone element. Other explanations as in Figure 1.

7. Modification of barrel' formula:

$$V_1 = 0.5236 \cdot a \cdot 8b_2^2 + (4 \cdot b_2 \cdot b) + 3b^2,$$

where V_1 – estimated gallbladder volume, b_2 – height measured in ${}^{1}/_{2}$ of the frustum of cone element. Other explanations as in Figure 1.

Comparison of Various Ellipsoid Formulas

Three ellipsoid formulas were compared and applied to the next theoretical gallbladder ellipsoid models (Fig. 2). Two gallbladder ellipsoid models were presented, first composed of two hemispheres connected with cylinder and second, typical ellipsoid. The length and maximal height of both these figures were the same. First formula used for the first model was as follows:

$$V_2 = {}^{4}/_{3} \cdot \pi \, {}^{1}/_{2}d_1^3 + \pi \cdot {}^{1}/_{2}d_1^2 \cdot h,$$

where V_2 – exact volume of the solid composed of two hemispheres and cylinder. Other explanations as in Figure 2.

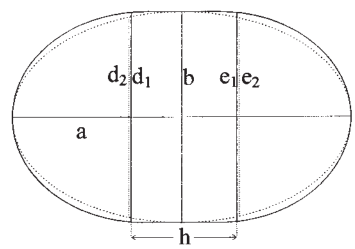

Fig. 2. Two contours of the ellipsoid model with the same maximal length and maximal height: a – total length of the solid, b – maximal height of the solid, d_1 – height of the greater contour of solid measured in one-third and in two-third of the solid length, d_2 – height of the smaller contour measured in one-third and in two-third of the solid length

Ryc. 2. Dwa kształty modelu elipsoidy posiadające taką samą maksymalną długość i maksymalną wysokość: a – całkowita długość bryły, b – maksymalna wysokość bryły, d_1 – wysokość większego konturu bryły mierzona w jednej trzeciej i w dwóch trzecich jej długości, d_2 – wysokość mniejszego konturu bryły mierzona w jednej trzeciej i w dwóch trzecich jej długości

Second formula (modification of first formula) used for second model was as follows:

$$V_2 = 4/3 \cdot \pi \, {}^{1}/_{2}d_2^3 + \pi \cdot {}^{1}/_{2}d_2^2 \cdot h,$$

where V_2 – exact volume of the ellipsoid. Other explanations as in Figure 2.

For both models also typical ellipsoid formula [1, 2] was used:

$$V_2 = {}^{1}/_{6}\pi \cdot a \cdot b^2,$$

where V_2 – exact volume of the ellipsoid. Other explanations as in Figure 2.

The results were statistically elaborated where appropriate and mean values with standard deviations (± SD) were calculated.

Results

Sizes of the models (maximal length and maximal and minimal heights) and their precise volumes were summarized in Table 1. All three models were presented in four magnitudes each which differed in height but not in length. Longitudinal dimensions of the given model constituents were the same in each model. Vertical dimensions differed only among the various model magnitudes (sizes). Length of half of ellipsoid (e), first constituent of each model was 15 mm (Fig. 1). Length of the frustum of cone (h), last element of each model was 30 mm (Fig. 1). Height of each cylinder component (h_1) of the models 2 and 3 was equal to 15 mm (Fig. 1). Height (basis of the figure, h_2) of each half of low cylinder in the models 2 and 3 was equal to 5 mm (Fig. 1).

Gallbladder volumes estimated with various methods according to the formulas described in previous chapter are presented in Table 1. In this Table also percentages of exact model values have been shown. These results comprise all four magnitudes of each model.

Further analysis of ellipsoid method was illustrated in Figure 2. Two various types of ellipsoid are proposed and the total length and maximal height (also maximal width) of both solids were identical. Two various formulas estimating volume of these types of solids were applied. Third formula was of typical ellipsoid equation [1, 2]. Volume of the first type of solid (Fig. 2), composed of three elements (two hemispheres and a cylinder) was approximated precisely using the relevant geometric formula (first formula, see previous chapter) and obtained volume was 197.82 ml. This formula applied for second classical ellipsoid model (second formula, see previous chapter) brought the result 165.76 ml. When the classical ellipsoid formula [1, 2] was used to calculate the volume of the first (greater) type of solid, the result was 169.56 ml. Volume of the second type of solid resembling the classical ellipsoid (Fig. 2) estimated with ellipsoid method [1, 2] was the same.

Discussion

The ellipsoid method is currently the simplest method widely accepted and used for estimation of gallbladder volume [1–3, 15, 16]. However, because of some inaccuracy of this method its application should be limited [7–9]. Therefore, the method was further validated [10, 11] and these studies confirmed that it can be sometimes not very accurate and precise. However, this validation seemed unsufficient because testing of ellipsoid method with the use of theoretical models was too inconspicuously. Thus, the present work was devoted mainly to this problem. Theoretical model seem to be the best available method to

Table 1. Principal dimensions and exact volumes of three geometric models of the gallbladder presented in four sizes each

Tabela 1. Najważniejsze wymiary i dokładne objętości trzech modeli geometrycznych pęcherzyka żółciowego przedstawione w trzech rozmiarach każdy

		Maximal length (Maksymalna długość) mm	Maximal height (Maksymalna wysokość) mm	Minimal height (Minimalna długość) mm	Number of elements (Liczba elementów)	Exact volume (Dokładna wartość) ml
Model I	size 1	45	10	3	2	1.88
	size 2	45	15	4.5		4.22
	size 3	45	20	6		7.50
	size 4	45	25	7.5		11.73
Model II	size 1	61.5	10	3	4	3.25
	size 2	61.5	15	4.5		7.31
	size 3	61.5	20	6		13.00
	size 4	61.5	25	7.5		20.31
Model III	size 1	81	10	3	7	4.82
	size 2	81	15	4.5		10.84
	size 3	81	20	6		19.28
	size 4	81	25	7.5		30.12
Mean ± SD	size 1				n = 3	3.32 ± 1.47
	size 2				n = 3	7.46 ± 3.31
	size 3				n = 3	13.26 ± 5.89
	size 4				n = 3	20.72 ± 9.20

Table 2. Volumes of geometric models of the gallbladder estimated with various methods and expressed in original values (ml) and in per cent of exact value (%)

Tabela 2. Objętości modeli geometrycznych pęcherzyka żółciowego szacowane przy użyciu różnych metod i podane jako wartości oryginalne (ml) oraz w procentach dokładnej wartości (%)

		Volumes in ml (Objętość w mm)				% of exact value* (Procent dokładnej wartości)	%: mean ± SD (Średnia ± SD)
		size 1 (rozmiar 1)	size 2 (rozmiar 2)	size 3 (rozmiar 3)	size 4 (rozmiar 4)		
Method of cone [12] (Metoda) stożka)	model I	1.18	2.65	4.71	7.36	62.76	**52.08**
	model II	1.61	3.62	6.44	10.06	49.52	±
	model III	2.12	4.77	8.48	13.25	43.97	**9.65**
Frustum of cone (Stożek) ścięty)	model I	1.64	3.68	6.55	10.23	87.24	**72.40**
	model II	2.24	5.03	8.95	13.98	68.83	**±**
	model III	2.95	6.63	11.78	18.41	61.12	**13.42**
					n = 6	**62.24 ± 15.27**	
Ellipsoid method [1, 2] (Metoda elipsoidy)	model I	2.36	5.30	9.42	14.72	125.53	**104.17**
	model II	3.22	7.24	12.87	20.12	99.03	±
	model III	4.24	9.54	16.96	26.49	87.95	**19.31**
Modification of ellips. method (Modyfikacja metody elipsoidy)	model I	1.00	2.24	3.98	6.22	53.04	**44.01**
	model II	1.36	3.06	5.44	8.50	41.84	±
	model III	1.79	4.03	7.16	11.19	37.16	**8.16**
Further modif. of ellips. method (Dodatkowa modyfikacja metody elipsy)	model I	1.51	3.39	6.03	9.42	80.33	**79.92**
	model II	2.46	5.54	9.86	15.40	75.82	±
	model III	4.03	9.07	16.12	25.18	83.60	**3.91**
					n = 9	**76.03 ± 28.30**	
Barrel method [14] (Metoda beczki)	model I	2.13	4.79	8.52	13.32	113.59	**92.96**
	model II	2.86	6.44	11.44	17.88	88.03	±
	model III	3.72	8.38	14.90	23.27	77.26	**18.66**
Modification of barrel method (Modyfikacja metody beczki)	model I	2.62	5.91	10.50	16.40	139.90	**114.72**
	model II	3.53	7.95	14.13	22.08	108.70	±
	model III	4.61	10.36	18.42	28.79	95.56	**22.77**
					n = 6	**103.84 ± 22.11**	
Total (Razem)					**n = 21**	**80.04 ± 27.80**	

* Value was identical for each size

* Wartość identyczna dla każdego rozmiaru.

assess the accuracy of given method since it enables to obtain precise reference values. The results showed that the values of gallbladder volume estimated with ellipsoid method are fairly dispersed when various models are tested. One of modifications of ellipsoid formula showed more stable results while it lowered gallbladder volumes as compared with "true" values. Furthermore, the ellipsoid formula showed inaccuracies even when the gallbladder model was of ellipsoid shape.

Portincasa et al. [9] suggest that ellipsoid formula can be applied when gallbladder shape is regular. In the situation tested in the present work, gallbladder shape was very regular. In spite of it, the results calculated with an ellipsoid method were nearly 20% lower as compared with exact value what was clearly dependent on the shape of the solid. These findings provided further arguments towards the limitations in the use of ellipsoid method in estimation of gallbladder volume.

Other simple methods possible to use for estimation of gallbladder volume were also tested. Method approximating gallbladder shape to a cone [12], frustum of cone and one of modifications of ellipsoid method showed much lowered results and thus they are rather unacceptable. However, the barrel method [14] and its slight modification provided similar results to an ellipsoid method.

It is concluded that simple methods estimating gallbladder volume can be inaccurate and should be used with caution. Greater accuracy can be achieved when gallbladder shape is very similar to the given solid, according to the proper formula. Some formulas related to ellipsoid formula can be equally or more accurate while the accuracy of barrel methods is comparable with ellipsoid method.

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Address for correspondence:

Krzysztof Waldemar Romański
Department of Animal Physiology,
Faculty of Veterinary Medicine
University of Agriculture
Norwida 31
50-375 Wrocław
Poland

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