RELIABILITY OF MEASURING VOLUME BY DIFFERENT METHODS FOR TUMORS OF THE MUSCULOSKELETAL SYSTEM

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In the present study different methods for determining the volume of a tumor were evaluated. For 12 models, the real volume, the volume according to measurement of the surface area on MRI, an ellipsoid and a cylindrical approximation of the volume, as well as the maximum diameter, were determined. There appeared to be a good correlation between all calculated volumes and the real volume. The error (mean : 17%) and the standard deviation (SD : 14%) on this error were smallest if the volume was determined by means of determination of the surface area. The ellipsoid approximation resulted in a smaller error (mean : 0%) but a higher standard deviation (SD : 27%). The cylindrical approximation resulted in unacceptable deviations (mean : 51%; SD : 40%). Volume was significantly related to the maximal diameter to the power of 2.3. Volume calculated according to this power resulted in an error of 18%. Standard deviation in this case however was unacceptable (SD : 89%).

Volume calculation based upon the determination of the surface area has given the best and most reliable results. Ellipsoid approximation was less reliable, but faster and cheaper. Cylindrical approximation was unacceptable. Size, expressed as maximal diameter of the tumor, was also unacceptable as a parameter for volume.

Keywords : tumor ; volume ; measurement.
Mots-clés : tumeur ; volume ; mesure.

INTRODUCTION

The volume of tumors is used as a prognostic factor (17) as well as for the evaluation of response to therapeutics (5, 11). It is however impossible to measure the real volume, because isolation of the tumor from the healthy tissue after resection makes the determination of the surgical margins unreliable. Therefore, the maximal diameter (13) or approximations of the volume by means of surface area measurement on CT scan or MRI are commonly used (2, 8, 16, 17). Volume or size, expressed as maximal diameter, is usually divided into two or more groups and used as an ordinal parameter (2, 10, 12). The value of these approximations has however been poorly examined (4, 14). The aim of the present study is to evaluate the reliability of the different parameters available for volume determination.

MATERIALS AND METHODS

Twelve models were made from organic material. The real volume (Vr) was measured by immersion. An MRI (Symphony®) in two perpendicular planes was made of each model : parallel to the shortest diameter (MRI1) and parallel to the longest diameter (MRI2). Each slice was 7 mm thick. Depending on the length of

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Table I. — Volumes and diameters of models (volume in cubic cm, diameter in cm) : Vr = real volume, VMRI1 or2 = volume calculated by measuring surface areas on MRI in plane 1 or 2, Vell = volume calculated by ellipsoid approximation, Vcy = volume calculated by cylindrical approximation, max d = maximal diameter on MRI

	shape	Vr	VMRI1	VMRI2	Vell	Vcy	Max d
1	cylinder	275	322	312	242	366	9.5
2	bar	100	129	121	73.5	111	7.3
3	bar	62.7	73.4	91.5	65.7	99.2	8.3
4	cone	62.0	74.4	77.4	51.9	78.3	7.2
5	cylinder	106	126	102	98.2	148	6.8
6	cylinder	136	159	152	120	181	7.0
7	cylinder	74.0	88.3	89.0	66.2	100	5.9
8	ellipsoid	47.0	56.7	56.6	40.4	61.0	4.7
9	ellipsoid	59.3	72.2	69.8	65.0	98.1	5.3
10	ellipsoid	70.0	90.7	69.0	75.4	114	5.5
11	cone	18.0	15.6	21.3	32.0	48.4	6.2
12	cone	276	293	272	270	407	10.2

the model, the distance between the slices varied from 1.4 mm to 2.3 mm for MRI1 and from 0.7 mm to 1.8 mm for MRI2. The surface area of each slice was calculated digitally (Imagika®) by marking at least 12 border points of the surface. The algorithm itself looks for the maximum transition of grey values near the indicated point, and registers it as the border value. The surface area is then multiplied by the thickness of the slice and the distance between two slices. The average of the volumes of two consecutive slices was calculated. The total volume (VMRI) was then calculated by finding the sum of these averages. The error created by this approximation method was estimated by dividing spheres with a variable diameter in slices 7 mm and 10 mm thick and then calculating the volume by calculating the sum of the volumes of the slices, next to a calculation of the exact volume as a sphere : 4/3*π*radius**3. The three maximal diameters : d1, d2 and d3 were also determined digitally on MRI images. The volumes were approximated by an ellipsoid : Vell = 4/3*π*d1/2*d2/2*d3/2 and by a cylinder : Vcy = π*d1/2*d2/2*d3.

Each measurement was repeated three times, and the average was used for further calculations. The variation of the error due to the measuring method was evaluated by having the length and the surface area of eight sections measured by three investigators.

Volume, shape and maximal diameter of the models can be found in table I.

Correlations were measured by the Spearman test. A comparison between the volumes was made by the paired t-test. A relation between the volume calculated by means of the maximal diameter and the real volume was estimated by a curve estimation. The influence of the use of volume as a dichotomic variable was calculated by using the rank of size instead of the size itself.

RESULTS

1. Measurement error

When measuring the real volume by immersion, there appeared to be an average standard deviation of 0.9% (SD : 1.1%). There was an average standard deviation of 2.8% (SD : 3.7%) for surface areas and of 5.2% (SD : 7.0%) for diameters in the MRI measurements. These deviations showed a negative correlation with volume (p = 0.00, C.C. (correlation coefficient) = -0.37) and diameter (p = 0.00, C.C. = -0.27). When eight different sections were measured by three different investigators, there appeared to be a significant (p = 0.000) difference between the measurements (interobserver). The difference between the measurements of the different investigators was maximally 42% (mean 8.2%). Intraobserver deviation was not significant.

2. Calculation error

The error due to the calculation method via the sections depends on the diameter of the sphere and thickness of the slices. The error, which is always an underestimation compared to the real volume,

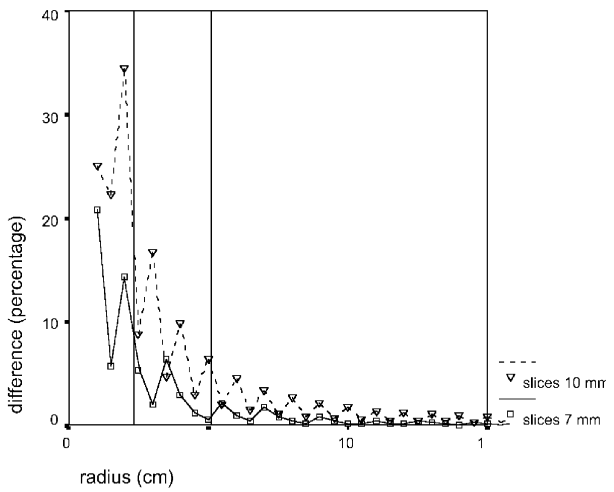

Fig. 1. — Difference of volume calculated by the exact formula of a sphere (4/3*π*radius**3) and by sum of volumes of slices with a thickness of 10 mm (▽) and 7 mm (☐). Two reference lines on the radius axis mark the radius interval of the models : 2.35 < radius < 5.10.

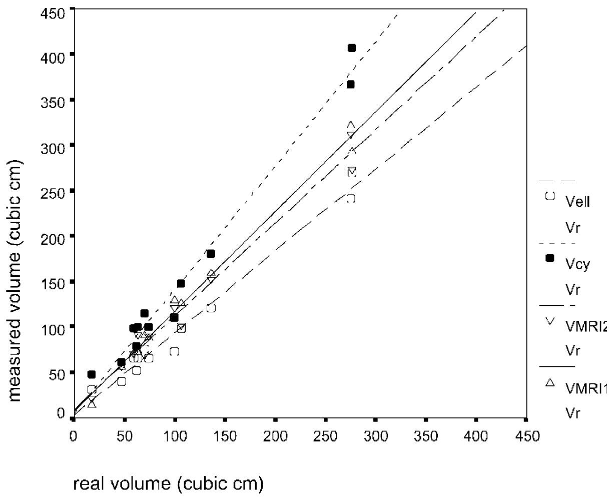

Fig. 2. — Real volume compared, linear regression, with calculated volumes. (Vcy : volume calculated by cylindrical approximation (■), Vell : volume calculated by ellipsoid approximation (☐), VMRI1 or 2 : volume calculated by MRI in plane 1 or 2 (△▽)).

increases if the diameter gets smaller and the slices get thicker (fig. 1). The average error for slices 7 mm thick is 2.6% (SD : 2.3%), and for slices 10 mm thick this is 8.1% (SD : 5.4%), for the same range of diameters as those of the models.

3. Global error

☐ strong (C.C. = 0.972 to * 0.930) and significant (p = 0.000) correlation ▽ was found between the real volume and all calculated volumes of the △ models (fig. 2). The differences between the volumes can be found in table II. Especially the volumes calculated by cylindrical approximation showed a high error with a high standard deviation. Paired t-test showed that only between the real volume and Vell was there no significant difference (p = 0.094). The differences between the real volumes and the respective calculated volumes were not significantly related to shape. The deviation significantly increases with volume (fig. 3).

The maximal diameter also correlates with real volume (p = 0.018). This correlation however is clearly less distinct than the correlation between the mutual volumes (C.C. = 0.664). Due to the limited number of models, a relation with shape could not be demonstrated. Especially conic and bar shapes seem to give deviating values. The real volume and the spherical approximation are significantly (p = 0.000) related to the maximum diameter to the power of 2.3. However, the deviation, and especially the standard deviation of the calculated volume : maximum diameter ** 2.3, compared to real volume is considerable : 18% (SD : 89%). Here too, especially the conic and the bar shapes seem to account for the large deviation. The rank of size of the real volume and of the maximal diameter are significantly (p = 0.018) correlated (C.C. = 0.66). The differences however are large, and when classifying the volumes according to a calculation based on maximal diameter, this gives rise to a wrong classification of the volumes (fig. 4).

DISCUSSION

Tumor volume as a prognostic factor is discussed in the literature (2, 6, 10, 12, 13, 19). All described volumes are approximations however, as measuring the volume or diameter of a tumor after resection makes determination of the surgical margins unreliable. An approximation is therefore necessary. *In vitro* measurement of volume summing the volumes on CT scan results in an error of 3.12% to 4.95% compared with real volume (4,

Table II. — Difference between real volume (Vr) and calculated volume of models in percentage of real volume (VMRI1or 2 = volume calculated by measuring surface areas on MRI in plane 1 or 2, Vell = volume calculated by ellipsoid approximation, Vcy = volume calculated by cylindrical approximation).

		95% C.I.		
	Mean	lower	upper	Std. dev
(VMRI1-Vr)/Vr*100	16.9	9.8	24.0	11.3
(VMRI2-Vr)/Vr*100	15.6	6.9	24.3	13.7
(Vcy-Vr)/Vr*100	50.9	25.2	76.6	40.4
(Vell-Vr)/Vr*100	0.0	-17.0	16.9	26.7

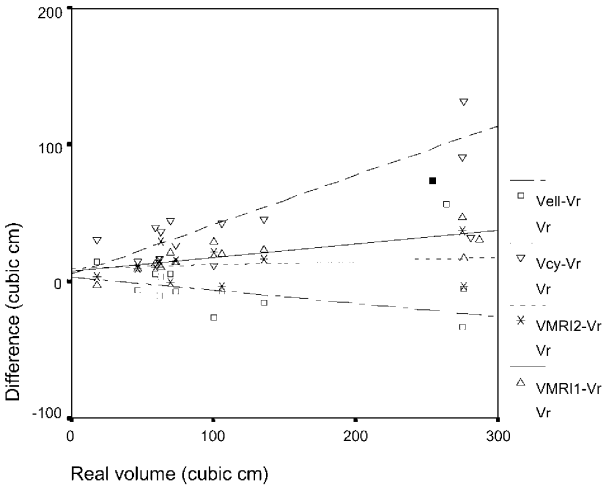

Fig. 3. — Linear regression of difference between calculated volume of models and real volume (Vr = real volume, VMRI1 or 2 = volume calculated by measuring surface areas on MRI in plane 1 or 2, Vell = volume calculated by ellipsoid approximation, Vcy = volume calculated by cylindrical approximation).

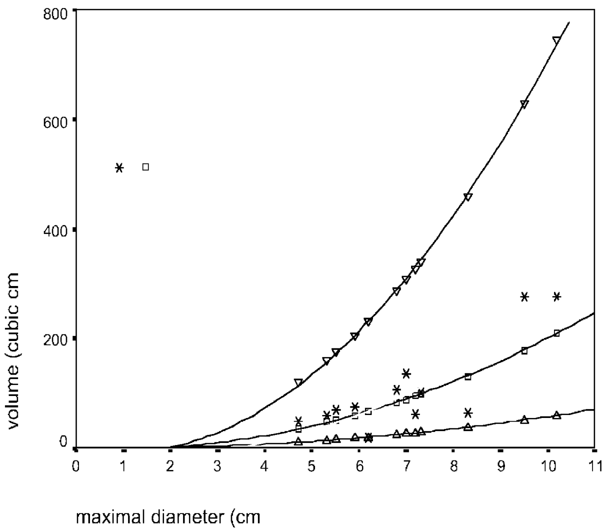

Fig. 4. — Real volume (*) and calculated volume (□) : Volume = maximal diameter**2.30; ▽ = upper 95% confidence interval, △ = lower 95% confidence interval.

15). The determination of tumor borders with healthy tissue, and especially soft tissue, is difficult however on CT scan (3, 9). MRI is therefore more appropriate (18). For *in vitro* measurement of small volumes by means of MRI, Long *et al.* report an overestimation of 20% to 25% (14). Especially small volumes measured by means of thick slices give large errors. The thickness of the slices should be smaller than 1/5 of the diameter of the tumor (7). Tumors are less geometrically formed than models. Moreover, it is sometimes difficult to determine the exact borders on MRI, which results in a significant interobserver error. Therefore, even more important errors are to be expected *in vivo* (3, 14).

Size, expressed as maximal diameter, seems to be easy to determine on MRI, and is mostly used as a parameter for volume (12, 13, 19). The measurement itself however already shows an error of 5%. This is a relatively large error for a simple measurement. It is even more difficult to determine the maximal diameter of an irregularly shaped object. Although there is an acceptable correlation between maximal diameter and volume, there is a large dispersion (fig. 4). Therefore, size is not equivalent to volume and will, especially if it is used as a dichotomic variable, lead to a wrong classification (fig. 5). For these reasons, size is not reliable as a parameter for volume.

Volume is used less generally (2, 10, 16), although it would have more predictive value than diameter (8). The measurement of a surface area on MRI can easily be reproduced, regardless of the plane in which the surface areas are calculated. The calculation method to determine the volume by means of surface area however leads to an underestimation of 3% to 8%. Standard deviation of both these errors together, measurement and calculation, is situated between 6% and 11%. Notwithstanding these methodological errors, calculation of the volume by means of surface area gives a good approximation of the real volume. An average overestimation of 17% was seen. Volume calculated by means of MRI results in the smallest variability of error (14%) compared to the real volume, and is therefore the best approximation. Measuring the surface areas automatically or semi-automatically *in vivo* was impossible because the borders of the tumor with muscular tissue or nonaffected bones could not be recognized by the computer. All measurements therefore have to be carried out manually, which is very time-consuming. It also has to be pointed out that deviations compared with real volume were measured on models. These are variable in shape, but regularly formed. The errors in measuring tumors will be even larger.

Another approximation of volume, which is simpler and faster, is the cylindrical or ellipsoid approximation. Both these approximations differ in only one constant. The cylindrical approximation is not satisfactory, as the average error and the standard deviation of this error are too high. The ellipsoid approximation gives, contrary to the study of Bauman *et al.* (1), a smaller average error compared to the real volume than the approximation by means of determination of the surface area, but shows a much higher standard deviation (27%). Therefore this approximation is unreliable, notwithstanding the small average error in this study.

Ellipsoid approximation is very practical, but the error can be considerable. Approximation by means of determination of the surface area is more reliable, but requires quite some investment in time and software, and still results in an error of 16% or more in reality. Size is unreliable as a parameter for volume. Classifying the measured volumes in groups is unreliable, as too many of them are wrongly classified.

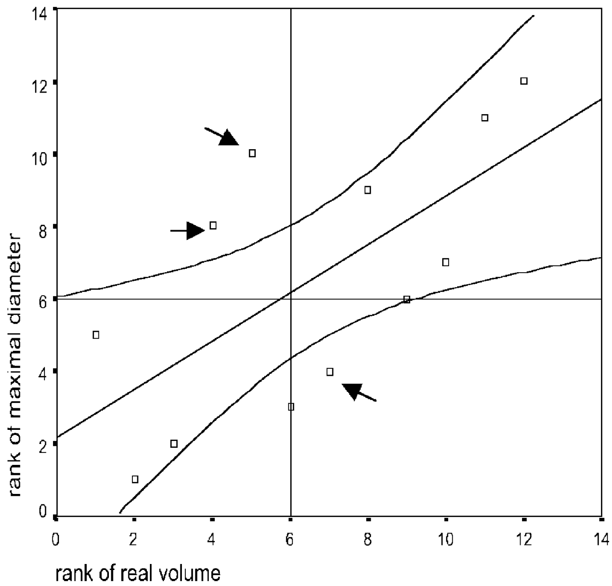

Fig. 5. — Real volume and maximal diameter classified according to rank. Linear regression (R^2 = 0.441) and 95% confidence interval. Arrows mark a wrong classification for maximal diameter if real volume is used as a dichotomic variable with volume of case 6 as the cut-off point.

REFERENCES

1. Bauman G., Pahapill P., Macdonald D. Low grade glioma : A measuring radiographic response to radiotherapy. Can. J. Neurol. Sci., 1999, 26, 18-22.
2. Bieling P., Rehan N., Winkler P. Tumor size and prognosis in aggressively treated osteosarcoma. J. Clin. Onc., 1996, 14, 848-858.
3. Böhm P., Yousry T., Kraus B. Role of magnetic resonance imaging in the radiological management of musculoskeletal tumours. Arch. Orthop. Trauma Surg., 1991, 110, 127-131.
4. Breiman R., Beck J., Korobkin M. Volume determinations using computed tomography. Am. J. Radiol., 1982, 138, 329-333.
5. Burgers J., Oldenburger F., de Kraker J. Ewing’s sarcoma of the pelvis : Changes over 25 years in treatment and results. Europ. J. Cancer, 1997, 33, 2360-2367.
6. Davis A., Bell R., Goodwin P. Prognostic factors in osteosarcoma : A critical review. J. Clin. Onc., 1994, 12, 423-431.

7. Firbank M., Coulthard A., Harrison R., *et al.* Partial volume effects in MRI studies of multiple sclerosis. Mag. Res. Imag., 1999, 17, 593-601.
8. Göbel V., Jürgens H., Etspüler G. Prognostic significance of tumor volume in localized Ewing's sarcoma of bone in children and adolescents. Cancer Res. Clin. Oncol., 1987, 113, 187-191.
9. Gong Q., Tan L., Roumaniuk C., *et al.* Determination of tumour regression rates during radiotherapy for cervical carcinoma by serial MRI : Comparison of two measurement techniques and examination of intraobserver and interobserver variability. Brit. J. Radiol., 1999, 72, 62-72.
10. Hoffmann C., Ahrens S., Dunst J., *et al.* Pelvic Ewing sarcoma. Cancer, 1999, 85, 869-877.
11. Holscher H., Bloem J., Nooy M., *et al.* The value of M.R. imaging in monitoring the effect of chemotherapy on bone sarcomas. Am. J. Radiol., 1990, 154, 763-769.
12. Kawai A., Healey J., Boland P., *et al.* Prognostic factors for patients with sarcomas of the pelvic bones. Cancer, 1998, 82, 851-859.
13. Lee F., Mankin H., Fondren G. Chondrosarcoma of bone : An assessment of outcome. J. Bone Joint Surg., 1999, 81-A, 326-338.
14. Long S., Arriaga M., Nelson R. Acoustic neuroma volume : MRI-based calculations and clinical implications. Laryngoscope, 1993, 103, 1093-1096.
15. Nawaratne S., Fabiny R., Brein J., *et al.* Accuracy of volume measurement using helical CT. J. Comp. Assist. Tomog., 1997, 21, 481-486.
16. Ozaki T., Hilmann A., Lindner N., *et al.* Chondrosarcoma of the pelvis. Clin. Orthop., 1997, 337, 226-239.
17. Saeter G., Elomaa I., Wahlqvist Y. Prognostic factors in bone sarcomas. Acta Orthop. Scand., 1997, suppl. 273, 156-160.
18. Seung H., Byung I., Hyo P., *et al.* Uterine cervical carcinoma : Comparison of CT and MR findings. Radiology, 1990, 175, 45-51.
19. Sheth O., Yasko A., Johnson M., *et al.* Chondrosarcoma of the pelvis. Cancer, 1996, 78, 745-750.

SAMENVATTING

J. SOMVILLE, L. DE BEUCKELEER, A. DE SCHEPPER, J. VERSTREKEN, A. TAMINIAU. Betrouwbaarheid van verschillende methoden van volumemeting van tumoren van het musculoskeletaal stelsel.

In deze studie worden verscheidene methoden om het volume van een tumor te bepalen geëvalueerd. Bij twaalf modellen worden het reële volume, het volume door oppervlaktebepaling op MRI, een ellipsoïde en cilindrische benadering van het volume en de maximale diameter bepaald. Een goede correlatie wordt bekomen tussen alle berekende volumes en het reële volume. De fout (gemiddeld : 17%) en de standaard deviatie (SD : 14%) op deze fout is het kleinst bij de volumebepaling langs oppervlaktebepaling om. De ellipsoïde benadering geeft een kleinere fout (gemiddeld : 0%) maar een grotere standaarddeviatie (SD : 27%). De cilindrische benadering geeft onaanvaardbare afwijkingen (gemiddeld : 51%; SD : 40%).

Het volume is significant verbonden met de maximale diameter tot de macht 2.3. Het volume berekend volgens deze macht geeft een gemiddelde fout van 18%. De standaarddeviatie hierop is echter onaanvaardbaar (SD : 89%).

Volume berekend met oppervlaktebepaling geeft de beste en de betrouwbaarste resultaten. Ellipsoïde benadering is minder betrouwbaar maar sneller en goedkoper. Cilindrische benadering is onaanvaardbaar. Maximale diameter als parameter voor volume is evenmin aanvaardbaar.

RÉSUMÉ

J. SOMVILLE, L. DE BEUCKELEER, A. DE SCHEPPER, J. VERSTREKEN, A. TAMINIAU. Fiabilité des différentes méthodes de détermination du volume tumoral pour les tumeurs de l'appareil locomoteur.

Les auteurs ont évalué dans cette étude différentes méthodes utilisées pour déterminer le volume d'une tumeur. Ils ont déterminé pour 12 fantômes le volume réel, le volume calculé d'après la mesure de la surface en IRM et aussi par approximation sur base d'une ellipsoïde ou d'un cylindre, et le diamètre maximal de la tumeur. Ils ont constaté une bonne corrélation entre tous les volumes calculés et le volume réel. L'erreur (moyenne 17%) et l'écart type (14%) de cette erreur sont les plus faibles si l'on détermine le volume d'après la surface de la lésion. L'approximation sur base d'une ellipse entraîne une erreur plus petite (moyenne : 0%) mais un écart type plus élevé (27%). L'approximation sur base d'un cylindre aboutit à des résultats trop divergents (erreur moyenne : 51% ; écart type : 40%). Il existe une relation significative entre le volume et le diamètre maximum à la puissance 2,3. Le calcul du volume sur cette base se traduit par une erreur de 18% mais avec un écart type inacceptable, à 89%.

Le calcul du volume à partir de la détermination de la surface donne les résultats les plus fiables. L'approximation ellipsoïde est moins fiable mais plus rapide et plus expéditive. L'approximation cylindrique est inacceptable, tout comme l'utilisation du diamètre maximal de la tumeur.