THREE-DIMENSIONAL POSTERIOR SEGMENT ULTRASONOGRAPHY: CLINICAL EXPERIENCE

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SUMMARY

Purpose:
to introduce a commercially available three-dimensional ultrasonography unit into everyday clinical practice and to evaluate the qualitative and quantitative information of the acquired images and to clarify the indications for 3-D echography.

Materials and methods:
3-D scanning was performed on 59 referred patients with indications for conventional B/A-scan. On 7 patients with an intraocular mass with well-delineated borders 10 repeated volume measurements were carried out.

Results:
The duration of the ultrasound examination was extended with 8-10 min. 3-D echography offered images of unique perspectives, not previously available with conventional B-scan. The digital technology allowed easy (re)evaluation and follow-up. The coefficient of variation of the repeated volume measurements was less than 5% for all the patients. The standard deviations ranged from 2.22 to 4.75 mm^3.

Conclusions:
At its current level of technological development 3-D posterior segment ultrasonography left the status of an entirely research laboratory tool and entered the clinical practice. Nevertheless 3-D imaging is neither a rival nor a substitute of conventional B-scan since it is static and needs time intervals for reconstruction. However 3-D ultrasonography is a useful clinical supplement to conventional B/A echography in departments to which a substantial number of complicated cases (esp. intraocular tumours) is referred. It enables volume measurements with good intraobserver reproducibility and is excellent for teaching and training purposes of ophthalmology residents.

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RÉSUMÉ

But:
Présenter un système d'échographie tridimensionnelle actuellement sur le marché. Evaluer les informations qualitatives et quantitatives des images obtenues. Eclaircir les indications de l'échographie tridimensionnelle.

Matériel et méthodes:
Une échographie en 3 dimensions a été effectuée chez 59 patients référés pour une échographie A/B. Sept patients présentaient une masse intraoculaire aux limites bien définies. Les mesures de volume ont été répétées 10 fois.

Résultats:
La durée de l'examen échographique a été prolongée de 8 à 10 min.. L'échographie tridimensionnelle a permis d'obtenir des images d'une perspective unique. La technologie digitale permet une réévaluation et un suivi aisé. Le coëfficient de variation de mesures de volume répétées était de moins de 5%. La déviation standard était de 2,22 à 4,75 mm^3.

Conclusion:
L'échographie 3-D du segment postérieur a dépassé le stade expérimental et est devenue une technique d'application clinique. Néanmoins, comme cette technique est statique et nécessite des intervals

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pour la reconstruction des images, elle ne remplace pas un B-scan conventionnel. Néanmoins, l'échographie 3-D complémente de façon intéressante l'échographie conventionnelle B/A dans les départements cliniques où de nombreux cas de pathologie compliquée, en particulier de pathologie tumorale, sont référés. Cette technique permet des mesures de volume avec une bonne reproducibilité des résultats et est excellente pour la formation des résidents en ophtalmologie.

KEY-WORDS

Three-dimensional, ultrasonography, B-scan, reproducibility, volume measurement

MOTS-CLÉS

Ultrasonographie tridimensionnelle, B-scan, reproducibilité, mesure de volume.

INTRODUCTION

Ultrasonography obtained wide - spread acceptance for the evaluation of eye and orbit, being an easily employed, useful and reliable method for assessment of intraocular diseases. [17] For an adequate analysis of the A/B scan findings and a sound clinical decision the ophthalmologist should mentally reconstruct the acquired one- and two-dimensional (2-D) images into a three-dimensional (3-D) picture of the lesion. [2] The 3-D character of the findings can be appreciated only through the entire process of kinetic examination from different angles while varying the device parameters and through some educated guesswork. [4] Furthermore the 3-D impression is "virtual" - it exists only in the mind of the examiner. The printed images show merely a moment of the procedure and are not entirely representative of it. Unlike röntgenograms, computed tomography and magnetic resonance imaging, the echograms cannot be satisfactorily interpreted from still photographs in a retrospective fashion even when a written protocol is available. In ophthalmic ultrasonography the equipment is highly sophisticated, but like other clinical examination techniques the results are not better than the individual examiner who performs the test. [4]

In the early nineties certain attempts were made for 3-D ultrasound imaging and volume measurement of ocular tumours. [10,13] However the technology to acquire, reconstruct and process large series of B-scan slices was not readily available until the development of contemporary computer hardware.

In this report we evaluate our experience with a commercially available 3-D ophthalmic ultrasonography device in everyday clinical practice.

MATERIALS AND METHODS

Ultrasonography equipment

The ultrasound system consists of a B-scan, based on IBM-compatible PC (i-Scan, OTI, Ontario, Canada). An additional handheld transducer holder, first introduced by Downey et al [5], containing an automated electromechani-

cal motor is used to rotate the ultrasound probe in a programmed fashion. During the rotation of 180 degrees (in 5s, 7.5s or 15s) respectively 60, 90 or 180 2-D B-scan slices are grabbed and stored in a Power Macintosh G3 computer (Apple Computer Inc., Cupertino, CA, USA). The software (3D i-Scan, OTI, Ontario, Canada) allows interactive reconstruction and processing of a 3-D image, which can be rotated, sliced along any planes, including those not possible to acquire by just changing the transducer's angle or position. Images of many perspectives (horizontal, vertical, coronal, oblique) can be further manipulated with surface-rendering techniques. In addition, the software allows a digital video record of the kinetic B-scan examination.

Examination methodology

Within the period 01.02.2000 - 01.06.2000 all patients referred for ophthalmic ultrasonography were preliminarily screened by conventional B-scan. If the findings were considered to be unusual, rare or didactic, the examiner (BK) recorded a digital video of the kinetic ultrasonographic exam. Then the probe was put into the scanning assembly and 3 to 5 3-D scans were performed through the closed eyelid, well lubricated with methylcellulose (Methocel 2%, Ciba Vision). The examination technique is not very different from the routine procedure except that both the examiner and the patient should be motionless. The scans were reviewed for a coarse movement artefact and if such was found they were deleted.

Patients included

From 01.02.2000 till 01.06.2000 3-D ultrasonography was performed on 57 patients with the following findings: vitreous haemorrhage (VH) with partial/total posterior vitreous detachment – 9; retinal detachment (RD), accompanied by a VH or a choroidal detachment – 15; rhegmatogenous RD – 6; retinoschisis – 2; naevus – 2; malignant melanoma – 6; subretinal haemorrhage due to AMD – 3; metastasis – 1; haemangioma – 1; choroidal detachment – 7; endophthalmitis – 2; posterior scleritis – 2; asteroid hyalosis – 1.

Reproducibility of volume measurements

A single examiner (BK) outlined the tumour area manually (by clicking the computer mouse) on a consecutive series of parallel cross-sections to obtain a volume measurement. Every area was multiplied by the slice separation (1 mm). Finally the software summed the volumes of all sections to obtain the total lesion's volume. Volume measurements were repeated ten times in seven eyes with a high quality scan of a well-delineated intraocular mass lesion in order to evaluate the intraobserver reproducibility. Mean volume, range, standard deviation and coefficient of variation were calculated.

RESULTS

The duration of the conventional ultrasound examination was extended with 8 to 10 minutes in average for performing and saving a digital video record, for 3-D scanning and its brief quality evaluation. 3-D scanning was performed on 53 patients with a rotation time of 7.5 s, on the remaining with a rotation time of 15 s.

The 3-D images, when manipulated, revealed images from new perspectives that could not be obtained by conventional B-scan technology. The 3-D scan could be further processed by 'surface rendering', a software module. Thus the vitreous, which has a low acoustic reflectivity and therefore appears 'black' on the image, becomes transparent and the retinal and/or choroidal surfaces are disclosed. [15] We acquired unique images of a retinal tear in a rhegmatogenous retinal detachment and a vortex vein in a choroidal detachment (figures 1, 2) by such image manipulation.

A single 3-D image of 7 patients with an intraocular mass (5 malignant melanomas - MM, an haemangioma and a subretinal haemorrhage in AMD) was measured 10 times with the volume calculation module of the software. The coefficient of variation ranged from 2.54 to 4.92. (See table 3 for full elaboration of the data findings). When performing volume calculations we found outlining the tumour area by multiple clicks of the computer mouse easier and better controlled than through dragging it over the edges.
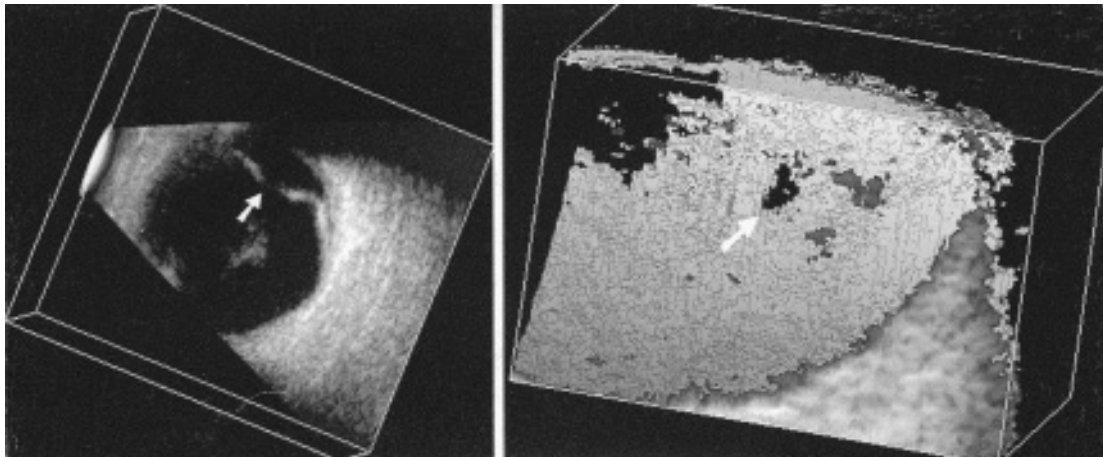
Fig. 1: Retinal detachment in the superior temporal quadrant with a retinal tear (white arrow).
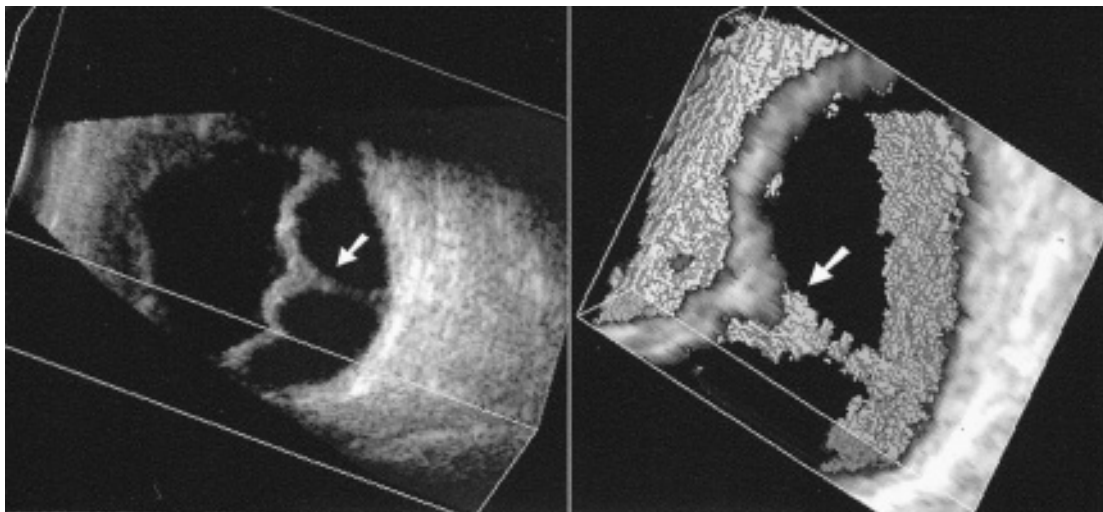
Fig. 2: Choroidal detachment with an observed vortex vein (white arrow).

Table 1   *Measures of variability*

Patient	Mean volume mm^3	Range mm^3	Standard deviation mm^3	Coefficient of variation %
1. MM	65.41	62.3 - 68.2	2.22	3.39
2. Haemangioma	106.24	102.7 - 109.9	2.70	2.54
3. MM	131.1	124.5 - 140.5	4.75	3.60
4. MM	78.53	74.6 - 83.1	3.04	3.86
5. MM	84.04	78.2 - 89.3	3.82	4.54
6. Subretinal haemorrhage in AMD	84.06	80.9 - 87.5	2.53	3.00
7. MM	71.58	66.6 - 76.3	3.52	4.92

DISCUSSION

Examining technique

The slower the probe rotates, the larger is the series of B-scan slices to be captured and the more reliable is the 3-D reconstruction. In order to obtain a good quality 3-D scan, however, a steady hand of the examiner and an immobile patient are crucial as well. Even a slight movement of either can deteriorate the correct spatial reconstruction and cause an artefact. An acceptable solution appears to be the 7.5 seconds period of scanning with 90 images to be processed. The 15 seconds scanning period (with 180 images) proved to be appropriate only for patients with best compliance: 6 out of 57 patients (10.5%) in our series.

New perspectives of well-described diseases

The rotation and slicing of the 3-D image revealed new perspectives for viewing ocular findings with classical descriptions in textbooks. The possibility to move interactively the rendered surface of a retinal detachment, to reveal the tear, to observe a tumour elevation as through an "ultrasound" ophthalmoscope (Fig. 3), to change the orientation and zoom on the details, significantly facilitates the interpretation of the findings. [3] Thus the learning period for residents to understand the basics of ocular echography and develop practical skills to perform it, is shortened. Lesion's topography through the 3-D static images and its kinetic features, through the 2-D digital video records can be explored as frequently and as long as needed. This leads to better (re)evaluation and follow up.

Volume measurement of an intraocular lesion

One of the most challenging tasks of ophthalmic ultrasonography is the detection, differential diagnosis and follow-up of an intraocular tumour. The tumor volume of a malignant melanoma is estimated to be a statistically significant indicator of the prognosis. [1] An accurate and reproducible ultrasonography measurement technique for volume would help the evaluation of the natural evolution of the tumour and its response to therapeutic intervention. Silverman et al [16] concluded that volume measurements, made by delineation of tumour areas in successive parallel scans, were more accurate than theoretical models (rotational and
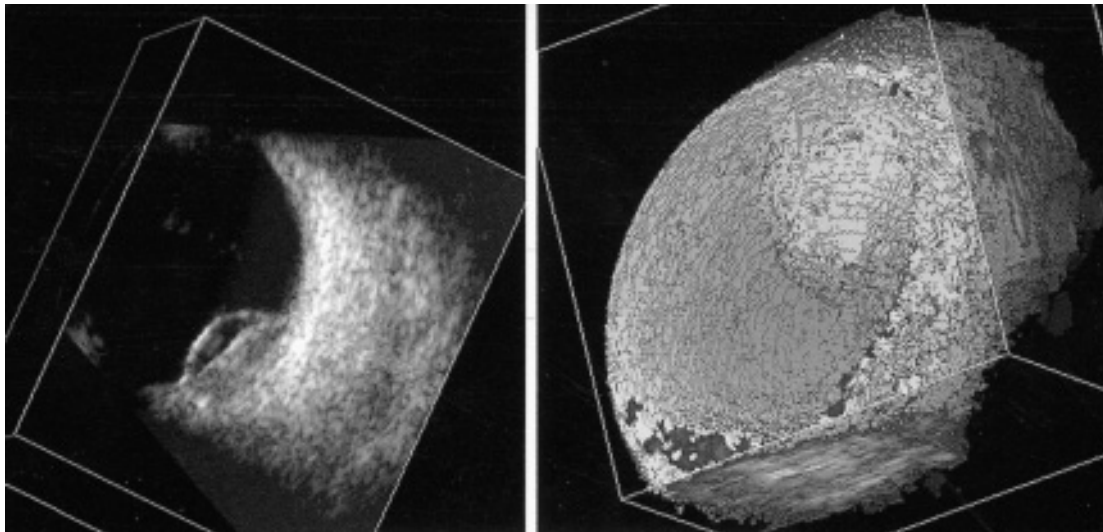

Fig. 3: Malignant melanoma post ruthenium plaque therapy with an overlying retinal detachment.
Left   - a two-sliced image.
Right - a surface-rendered image with the retinal elevation as seen through a direct "ultrasound" ophthalmoscope.

Table 2 *Advantages/Disadvantages of contact 3-D posterior segment ultrasonography*

Advantages	Disadvantages
1. Accurate and reproducible volume measurements in vitro. Reproducible intraobserver measurements in vivo.	1. 3-D images are static.
	2. Performed only through closed eyelid with some ultrasound attenuation and loss of detail.
2. Additional unique perspectives.	3. Lesions in the fundus periphery are scanned with difficulties.
3. Easy replay and storage aids (re)evaluation, follow-up and teaching.	4. A single 3-D scan cannot view the whole posterior segment.
4. Digital technology.	

ellipsoidal). The system described here demonstrates a high degree of accuracy and reproducibility in volume tests in vitro on ocular phantoms. [8] There is lack of data concerning in vivo reproducibility in clinical routine. The calculated coefficient of variation (below 10%) indicates good intraobserver reproducibility and respectively low variability. [9] The standard deviations are lower than 7.8 mm^3, mentioned in another report. [7] Future studies should however also address interobserver and intersession reproducibility. We believe that an appropriate scanning protocol has to be followed in order to obtain reliable volume measurements. It is advisable to perform a preliminary screening by conventional B-scan technique in order to detect and localise the lesion of interest because the hand feels clumsy when performing kinetic examination with the heavy and large scanning assembly. Enough coupling gel should be applied on the eyelid to prevent from twisting the skin together with the rotating probe, which may be seen in elderly patients. The lesion of interest should be as close to the image centre as possible with the gain set at an appropriate level to obtain the best definition of its borders. Searching for coarse artefacts in the just acquired scan (the 3-D reconstruction takes 5 - 6 seconds) proved to be useful as the rotation scanning could be repeated immediately since the patient is still available with or without changing the rotation mode from 15 s to 7.5 s.

2-D versus 3-D ultrasonography

The described method of contact 3-D imaging, based on reconstruction of multiple B-scan slices, taken through rotation of a standard transducer, cannot be performed separately or opposed to conventional 2-D ultrasonography as was reported by Finger et al. [7] However sharing some of B-scan limitations and artefacts[8] contact 3-D posterior segment ultrasonography at its current state has certain advantages and disadvantages (Table 2).

On the basis of our initial clinical experience and the literature survey we are convinced of the following indications for 3-D ultrasonography: intraocular tumour volume measurement, confirmation of postoperative location of episcleral brachytherapy plaques [7], evaluation of extrascleral tumour extension [14], examination of vitreoretinal traction [6] and location of foreign bodies. For teaching purposes the indications for 3-D echography coincide with the indications for ophthalmic ultrasonography in general.

CONCLUSION

At its current level of technological development 3-D posterior segment ultrasonography left the status of an entirely research laboratory tool and entered the clinical practice. Nevertheless 3-D imaging is neither a rival nor a substitute for conventional B-scan since it is static and needs time intervals for reconstruction. The next logical step is the appearance of real-time 3-D echography. However the described approach is a useful clinical tool for departments to which a substantial number of complicated cases (esp. intraocular tumours) is referred. 3-D ultrasound imaging offers unique perspectives and is excellent for teaching and training purposes.

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