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Clinical Evaluation of a Three-Dimensional Ultrasonography System in the Ophthalmic Field

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Clinical use of a 3-dimensional ultrasonography system with a new ophthalmic imaging device using conventional 2-dimensional ultrasound tomography in the ophthalmic field was evaluated in 5 patients with different ocular conditions. With the system, surface rendering and volume measurement were easy in 3-dimensional ultrasonographic examinations. In a patient with rhegmatogenous retinal detachment, the surface rendering made the image cube transparent, revealing interior surface details. In a patient with lens luxation resulting from Marfan's syndrome, the shape of luxated spherophakia was detected stereographically. In a patient with choroidal detachment, we could evaluate the effect of administration of aspirin on the amelioration of this disease by measuring the volume of the choroidal lesion. In a patient with aberration of a lens fragment into subretinal space during cataract surgery, we grasped the whole ocular condition in the 3-dimensional image only by just one manipulation. In a patient with optic disc melanocytoma, we could detect the volume change in detail using the 3-dimensional images-saving system. No discomfort occurred in these patients during examination. Based upon the above findings, we considered that this device was useful in making diagnosis and grasping the whole ocular conditions and outcome in breathtaking 3-dimensional views, and in causing no discomfort for patients.

Key words: 3-dimensional images-saving system; 3-dimensional ultrasonography system; 2-dimensional ultrasound tomography; surface rendering; volume measurement

It has been 3 and half decades since ophthalmic ultrasound was at the forefront of ultrasound technology when the first array scanner was built for ophthalmic use (Buschmann, 1992). Since then, conventional ophthalmic ultrasonography has been an established diagnostic technique that is essential for clinical practice of ophthalmology. The eye has advantages in the use of 3-dimensional imaging technology rather than in the use of 2-dimensional technology: the eye is reasonably small, which means the 3-dimensional ultrasound images require only moderate amounts of random access memory, and it is relatively immobile with a high fluid content and is well known as an excellent

Abbreviations: B-mode, brihtness mode; B-scan, brightness scan; IOL, intraocular lens acoustic medium, with no air or calcification in it (Downey et al., 1996).

Thus a newly devised 3-dimensional ultrasonography system using conventional 2-dimensional ultrasound tomography has been evaluated in imaging the eye, along with the current development of computers (Downey et al., 1996; Cusumano et al., 1998; Finger et al., 1998; Fisher et al., 1998; Romero et al., 1998; Endo et al., 2000). Using this new system, we examined 5 patients with different ocular diseases, and summarized the observations.

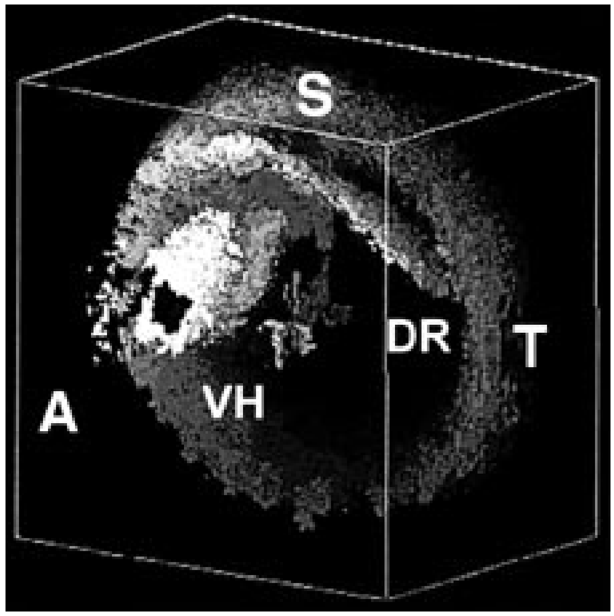


Fig. 1. Rendering image of the 3-dimensional ultrasonography of the left eye of patient 1 with rhegmatogenous retinal detachment with vitreous hemorrhage. It reveals the inside view of the detached retinal surface and vitreous hemorrhage. A, anterior side; DR, detached retina; S, superior side; T, temporal side; VH, vitreous hemorrhage

Materials and Methods

Five representative patients with different ocular conditions were selected for clinical evaluation of a 3-dimensional ultrasonography system in August 1998, and examined over 2 years to September 2000 at our Clinic of Ophthalmology, Tottori University Hospital. The tenets of the Declaration of Helsinki were followed. Upon giving informed consent, all patients participated in the present study. They were asked to grade the level of discomfort during the examination as mild, moderate or severe according to the report of Downey and his co-workers (1996).

3-Dimensional ultrasonography

Three-dimensional ultrasonographic examinations were performed with a 3-dimensional ultrasound tomogram (i-Scan Ophthalmic Tomographic Ultrasound, Ophthalmic Technologies Inc., Tronto, Canada). To obtain the 3-dimensional ultrasound image, the conventional brightness mode (B-mode) probe was inserted into a motorized, hand-held probe rotation assembly (Scanner Asembly, Ophthalmic Technologies Inc.), and held gently against the patient's lid. The probe was held in a position to obtain a coronal image, avoiding the lens as applied for standard brightness scan (B-scan) ultrasonography. Methyl-cellulose solution (1%) was used as a sound coupling agent on the transducer tip.

The inserted B-mode probe was rotated about 180 degrees by the Scanner Assembly through its central axis. A personal computer (Power Macintosh 7600, Apple Computer, Inc., Cupertino, CA) controlled the probe motion, which simultaneously recorded a series of 2-dimensional B-scan images.

The numerous 2-dimensional images obtained were reconstructed into a 3-dimensional image by using a 3-dimensional visualization software run on another personal computer (Power Macintosh G4, Apple Computer, Inc.). The data reconstruction time was 140 s.

The visualization software allowed the data to be viewed in different ways. The 3-dimensional image as a multi-sided object (cube) could be sliced in any direction. With the 3-dimensional images-saving system, this device could measure the length, the area and even the volume of target lesions in the eye, including surface rendering as an advanced feature.

The whole procedures of an examination including patient set-up, scanning review, data reconstruction and 3-dimensional image examination, were completed within 7 min in the present survey.

Patients and Observations

Patient 1 was a 66-year-old man with rhegmatogenous retinal detachment with vitreous hemorrhage in the left eye. Figure 1 shows a rendering image by 3-dimensional ultrasonography of the left eye using a rendering surface technique, indicating the inside view of the detached retinal surface and vitreous hemorrhage. The rendering image makes it easy to comprehend the relation between the detached retina and vitreous hemorrhage. That is, the surface rendering made the image cube transparent, revealing interior surface details.

Patient 2 was a 45-year-old woman with lens luxation resulting from Marfan's syndrome in the left eye. Figure 2a shows a 3-dimensional image of a sagittal section of the left eye observed at the supine position. It is possible to see the spherophakia dropped at the bottom of the posterior pole. Figure 2b shows another 3-dimensional view at the seating position, which clearly visualized the dropped spherophakia moving to the equator.

Patient 3 was a 72-year-old woman with choroidal detachment which occurred 3 years after intraocular lens (IOL) implantation in the left eye. Figure 3a shows a 3-dimensional image in a frontal section of the left eye at the first examination, which revealed choroidal detachment on the temporal side. Figure 3b shows another 3-dimensional view obtained 3 days after the oral administration of aspirin (1.2 g/day). It was difficult to decide whether this treatment was effective or not. Then, we measured the volume of the choroidal lesion using an integral technique described below, after tracing the area of choroidal detachment in a given "slice" by an examiner. As a result, the volume of the choroidal lesion was 783 mm^3 before the treatment (Fig. 3a), but 3 days after the treatment, the volume was decreased to 601 mm^3 (Fig. 3b). Following the continuous administration for 7 days, the volume became 191 mm^3 (Fig. 3c). Thus we could evaluate the effect of the aspirin treatment

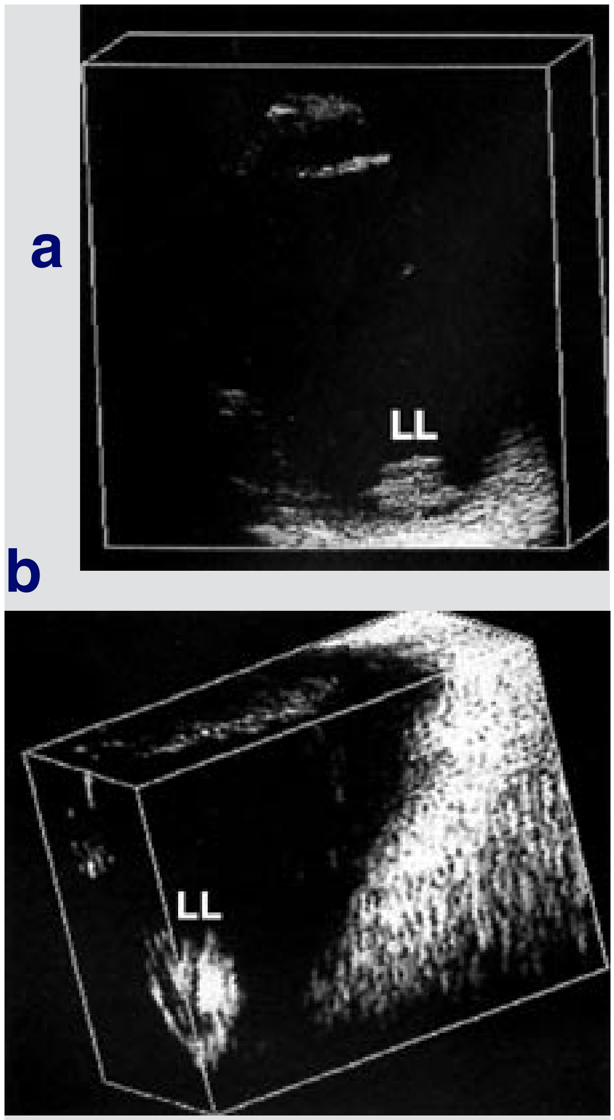


Fig. 2. Sagittal sections of the 3-dimensional images of the left eye of patient 2 with Marfan's syndrome showing lens luxation. LL, luxated lens.
a: At the supine position.
b: At the seating position.

on the amelioration of this entity by measuring the volume of the choroidal lesion. In fact, the choroidal lesion kept being decreased and finally disappeared 22 days after the aspirin treatment: these changes were also detected on the 3-dimensional views at the final stages of the treatment.

Patient 4 was an 80-year-old woman with aberration of a lens fragment into subretinal space during cataract surgery of the right eye. A sagittal

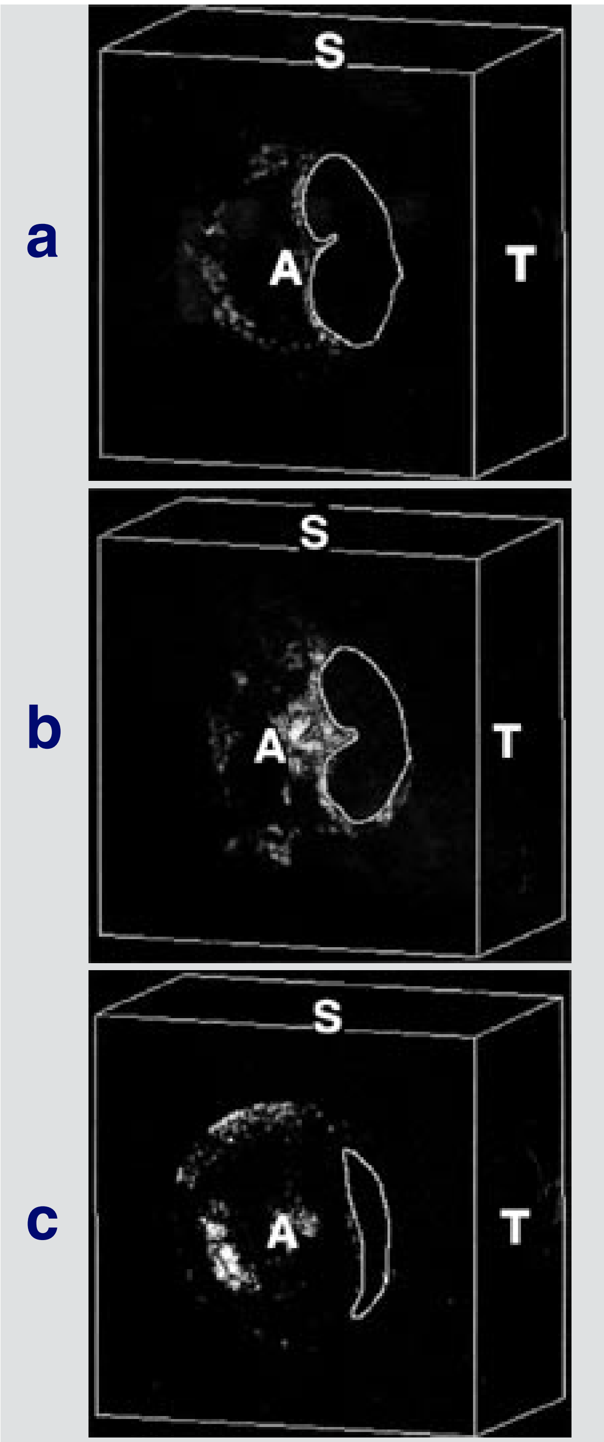


Fig. 3. Frontal sections of the 3-dimensional images of the left eye of patient 3 with choroidal detachment after IOL implantation. The choroidal lesion in each slice can be traced to measure its volume. A, anterior side; S, superior side; T, temporal side.
a: At the first examination.
b: 3 days after the administration of aspirin (1.2 g/day).
c: 7 days after the aspirin treatment.

section of a 3-dimensional image showed a lens mass under the detached retina (Fig. 4), which happened to occur during the surgery. We could not see the fundus ophthalmoscopically due to severe phacolytic inflammation after the surgery. The 3-dimensional ultrasonography seems to be valuable in grasping the unpredictable condition of the invisible fundus like in this patient, because this new imaging system can detect the whole ocular information by just one manipulation.

Patient 5 was a 39-year-old man with melanocytoma of the optic disc in the right eye. Figure 5a shows a frontal section of the rendering image, where the protuberant lesion on the optic disc was clearly detected. Figure 5b shows sagittal slices of the tumor lesion stepping to 1 mm. With the integral technique, the volume of the melanocytoma could be calculated by moving the outlining processor to adjacent "slices" known distances away (for example, 1 mm) and repeating the outlining process. The volume of the structure was obtained by summing the area in each "slice" and multiplying it by the distance between "slices". That is, we can detect the volume change in detail using the 3-dimensional images-saving system. The volume

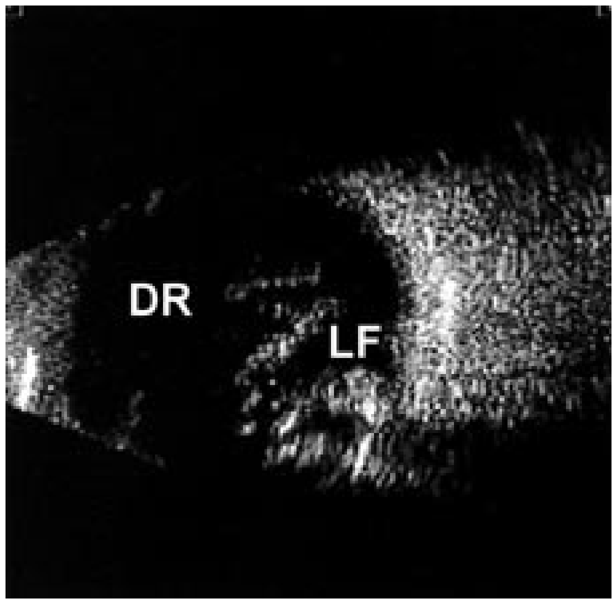
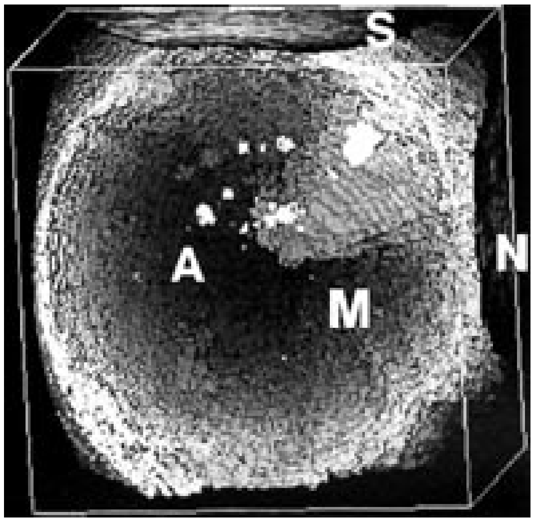


Fig. 4. Sagittal section of the 3-dimensional image of the right eye of patient 4 with aberration of a lens fragment into subretinal space during cataract surgery. DR, detached retina; LF, lens fragment.

a



b

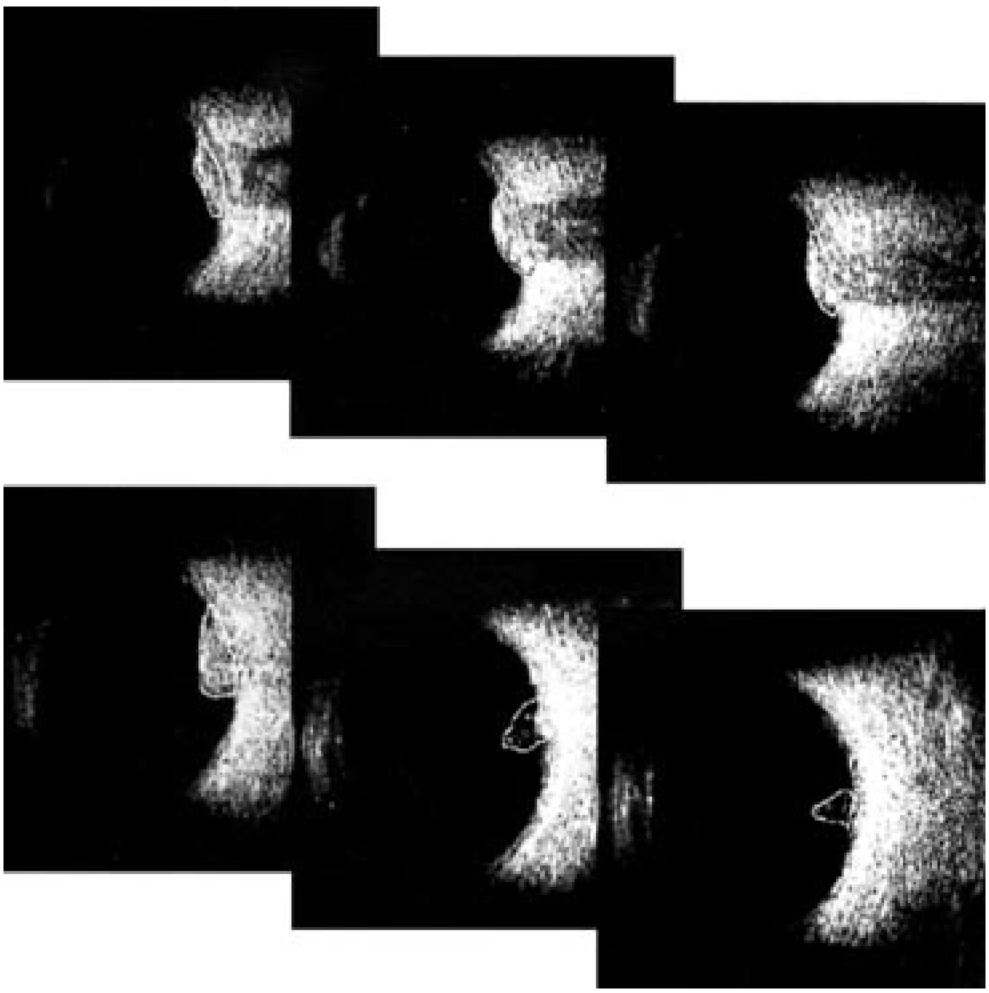


Fig. 5. Rendering images of the 3-dimensional ultrasonography of the right eye of patient 5 with melanocytoma of the optic disc.

a: A frontal section of the rendering image. A, anterior side; M, melanocytoma of the optic disc; N, nasal side; S, superior side.

b: Sagittal slices of optic disc melanocytoma stepping to 1 mm. The tumor lesion in each slice can be traced to measure its volume.

measurement seems to be very useful to follow up the tumor lesion.

No patients answered any discomfort when they were asked to grade the level of discomfort (Downey et al., 1996) face to face during the examination.

Discussion

The 3-dimensional i-Scan Ophthalmic Tomographic Ultrasound used in the present study is quite simply a new way to look at B-scan ultrasound. By capturing and combining hundreds of separate 2-dimensional images, it provides breathtaking 3-dimensional views of the eye. Advanced features such as surface rendering and volume measurement are also easy to use.

Indeed, conventional 2-dimensional ophthalmic ultrasonography is an established diagnostic technique and is essential for clinical practice of ophthalmology (Buschmann, 1992), but 3-dimensional ultrasonography has many possible advantages to make an important contribution to clinical practice even of such several other diseases as malignant melanoma of the iris and ciliary body (Cusumano et al., 1998), choroidal melanoma (Downey et al., 1996; Finger et al., 1998; Romero et al., 1998), traumatized eye with hypotony (Cusumano et al., 1998), post-traumatic vitreous hemorrhage and retinal detachment (Downey et al., 1996), choroidal hemorrhage and associated retinal detachment (Cusumano et al., 1998), Behçet's disease resulting in invisible fundus due to intraocular inflammation (Endo et al., 2000) and displaced IOL in the anterior segment (Cusumano et al., 1998), as well as the presently described ocular diseases.

In conclusion, this device is useful in making diagnosis and grasping the whole ocular conditions and outcome in the breathtaking 3-dimensional images, with no patient discomfort. The volume measurement seems to be very useful to follow up the tumor, as this device is equipped with the 3-dimensional images-saving system. Moreover, as the 3-dimensional images are digital and can be transferred by usual methods of digital data transfer (for example, diskettes, telephone lines and computer networks), remote consultations and discussion are possible (Downey et al., 1996). That is, the ability to transfer this digital data through computer networks makes it easy to communicate its information. Further work is required to widen clinical utility of this newly devised 3-dimensional ultrasonography system even in the ophthalmic field.

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