Interdisciplinary Neurosurgery: Advanced Techniques and Case Management 6 (2016) 45–50

Contents lists available at ScienceDirect

Interdisciplinary Neurosurgery: Advanced Techniques and Case Management

journal homepage: www.inat-journal.com

Technical Note & Surgical Technique

Dual optical channel three-dimensional neuroendoscopy: Clinical application as an assistive technique in endoscopic endonasal surgery

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ARTICLE INFO

Article history:
Received 4 August 2016
Revised 9 August 2016
Accepted 20 August 2016

Keywords:
Three-dimensional endoscopy
Dual optical channel
Endonasal surgery

ABSTRACT

Three-dimensional (3D) high-definition endoscopy is an innovative technical advancement that helps surgeons gain precise depth perception and spatial recognition during endoscopic surgery. Here, we describe a new dual optical channel 3D neuroendoscopic technique and its clinical application. We performed endoscopic endonasal surgery on 88 patients using 3D and two-dimensional (2D) endoscopes in conjunction. We evaluated the usefulness of stereoscopic images acquired by dual optical channel 3D endoscopy during endoscopic surgery and compared the image resolution between dual optical channel 3D endoscopy and 2D endoscopy. Additionally, we compared the stereoscopic images acquired by dual optical channel and Visionsense 3D endoscopy in three cases. Combination surgery using 3D and 2D endoscopy was found to be safe. Stereoscopic images were useful in several surgical steps, especially in recognition of complex bony structures, bone drilling, and suprasellar manipulation. The magnitude of binocular disparity was greater in dual optical channel 3D endoscopy than in Visionsense 3D endoscopy. Stereoscopic images acquired by dual optical channel 3D neuroendoscopy were of adequate quality and were useful for endoscopic endonasal surgery. In consideration of its lower image resolution compared to that of 2D high-definition endoscopy, dual optical channel 3D neuroendoscopy can be applied as an assistive technique in endoscopic endonasal surgery. The magnitude of binocular disparity is one of the key factors to be considered for evaluation of the clinical significance of 3D endoscopy.

1. Introduction

Endoscopic endonasal surgery has gained popularity in recent years owing to the availability of techniques for panoramic and angled visualization. Additionally, the introduction of high-definition (HD) endoscopic imaging techniques has enabled acquisition of clearer images in the surgical view. Despite these advantages, lack of stereoscopic view is a drawback of two-dimensional (2D) endoscopic surgery. The development of three-dimensional (3D) endoscopy is an innovative technical advancement that addresses this limitation [1,2,4,9,10,12,13]. As mentioned in a recent review by Zaidi et al. [14], 3D endoscopy enables improved surgical dexterity by enhancing subjective depth perception and spatial orientation. In their review, the authors retrieved 26 articles involving 3D endoscopy, of which 14 studies had reported the clinical findings of 3D endoscopy. Of the 14 studies, all but one had employed the 3D Visionsense endoscope (Visionsense, Philadelphia, PA, USA); the sole exception was our previous study where we compared the performances of dual optical channel 3D endoscopy and conventional 2D-HD endoscopy [8].

The first aim of this study was to demonstrate the performance of the newly developed dual optical channel 3D endoscopic technique and present our clinical experience of endoscopic endonasal surgery using the new technique, focusing on the assistive role of conventional 2D endoscopy. The second aim of this study was to evaluate the theory that the stereoscopic effect exhibited by various 3D endoscopic techniques varies according to the integrated 3D endoscopic technology,

Abbreviations: 3D, three-dimensional; 2D, two-dimensional; HD, high-definition.

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http://dx.doi.org/10.1016/j.inat.2016.08.001
2214-7519/

and, therefore, the significance of 3D endoscopy needs to be evaluated individually on the basis of the integrated 3D technology. Finally, we attempted to review the process of obtaining depth cues by monocular and binocular visualization, which is processed as depth perception and spatial recognition during endoscopic surgery, in order to gain a better understanding of the clinical significance of stereoscopic visualization during endonasal endoscopic surgery.

2. Materials and methods

2.1. Patients

We retrospectively retrieved the data of patients who underwent endoscopic endonasal surgery at the Kyushu University Hospital, Kyushu, Japan, between 2008 and 2016. These patients included 64 male and 84 female patients with a mean age of 49 years (age range 7–84 years; median age, 52 years). Even before the endoscopic techniques used in this study were granted approval for use as medical devices, we obtained ethical committee approval for this study from the review board of the Kyushu University Hospital as well as written informed consent from each patient.

2.2. Dual optical channel 3D endoscope

A 3D-HD endoscope with improved operability because of downsizing and lightening of the apparatus and ability to acquire clear images has been recently developed by Shinko Optical Corporation (Tokyo, Japan) and commercialized by Machida Endoscope Corporation (Tokyo, Japan). This rigid endoscope has two lenses (dual optical channels) and a single HD charge-coupled device (CCD) camera. The length and diameter of the scope are 180 mm and 4.7 mm, respectively (Fig. 1). The endoscope has auto-focus function, and the depth of field is greater than 0.5 cm. There are two types of endoscopes—the straight and 30°-angled scopes—which are easily exchangeable during surgery by loosening the locking the screw. This imaging technology involves a dual-channel optical scope connected to a single video CCD camera delivering two images through a relay lens transmission system. The images are displayed side-by-side on the same CCD image sensor, and a single image is generated in the convertor. The images from the right and left eyes are displayed horizontally on a stereoscopic screen in alternate lines. Images in the stereoscopic view are displayed on a 32-inch flat full-HD liquid crystal display (LCD) monitor (EJ-MDA32N-K, Panasonic, Tokyo, Japan), which has an integrated X-pol polarizer filter, thus allowing the visualization of 3D images using polarizing glasses. Notably, 3D images from either lens of the scope can be converted to 2D images by a one-touch operation. In addition, this system allows the comparison of 3D and 2D images of the same operative field acquired using the same CCD camera. Although the image signals are horizontally compressed by half in this system, the 3D display system naturally reproduces the depth of images. It also causes less flickering, reduces eye fatigue, and allows all medical staff to watch the screen at the same time. The polarizing nature of the viewing glasses prevents the loss of stereoscopic vision even when the wearer's head is tilted or the wearer is looking left or right.

2.3. Fully endoscopic endonasal surgery

The patient was placed recumbent with a 3-point head fixation device in order for us to be able to use the neuronavigation system (StealthStation, Medtronic Sofamor Danek, Coal Creek, CO, USA or BRAINLAN, Brain lab AG, Munich, Germany). Standard fully endoscopic endonasal surgery was performed through a bi or single nostril approach, depending on the tumor size. Before the advent of the dual optical 3D endoscope, endoscopic surgery was performed at our department using 2D standard-definition (SD) endoscopes equipped with pneumatically powered endoscope holders (EndoArm, Olympus Corporation, Tokyo, Japan). After the introduction of the prototype dual optical channel 3D-SD endoscope in 2010, we started to use 3D-SD endoscopy for observational purposes only. Tumor extirpation was mostly performed by 2D endoscopy, as was previously reported [8]. Since the introduction of 3D-HD endoscopy in 2011, we have used dual optical channel 3D-HD endoscopy in conjunction with either EndoArm (before 2014) or 2D-HD endoscopy (Karl Storz, Tuttlingen, Germany; after 2015). When not using EndoArm, the 3D and 2D endoscopes were held by either a surgeon or a holding device adapted to the tables in order to allow the surgeon the use of both hands during surgery. Bony structures in the sphenoid sinus and the sellar and parasellar regions were drilled using an electronic high-speed drill (Midas Rex Legend EHS high-speed surgical Drill, Medtronic, Minneapolis, USA). To prevent high-flow cerebrospinal fluid leaks after surgery, multilayer reconstruction using fat grafts with or without dural suturing was performed. Depending on the manipulation process, 3D or 2D endoscopy were used as described below (Fig. 2).

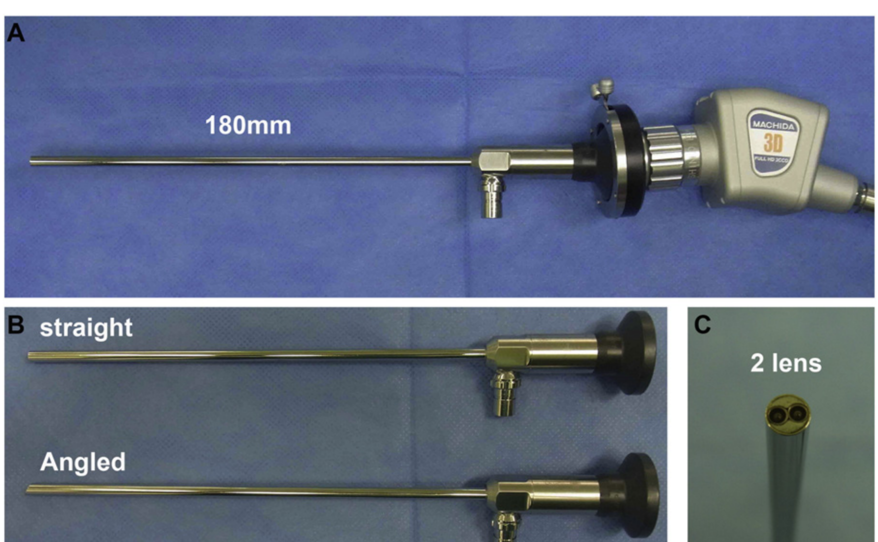

Fig. 1. Photographs of a dual optical channel three-dimensional endoscope. The length and diameter of this rigid endoscope are 180 mm and 4.7 mm, respectively (A). It has a single high-definition charge-coupled device camera as well as straight and 30°-angled scopes (B) with dual optical channels (C).

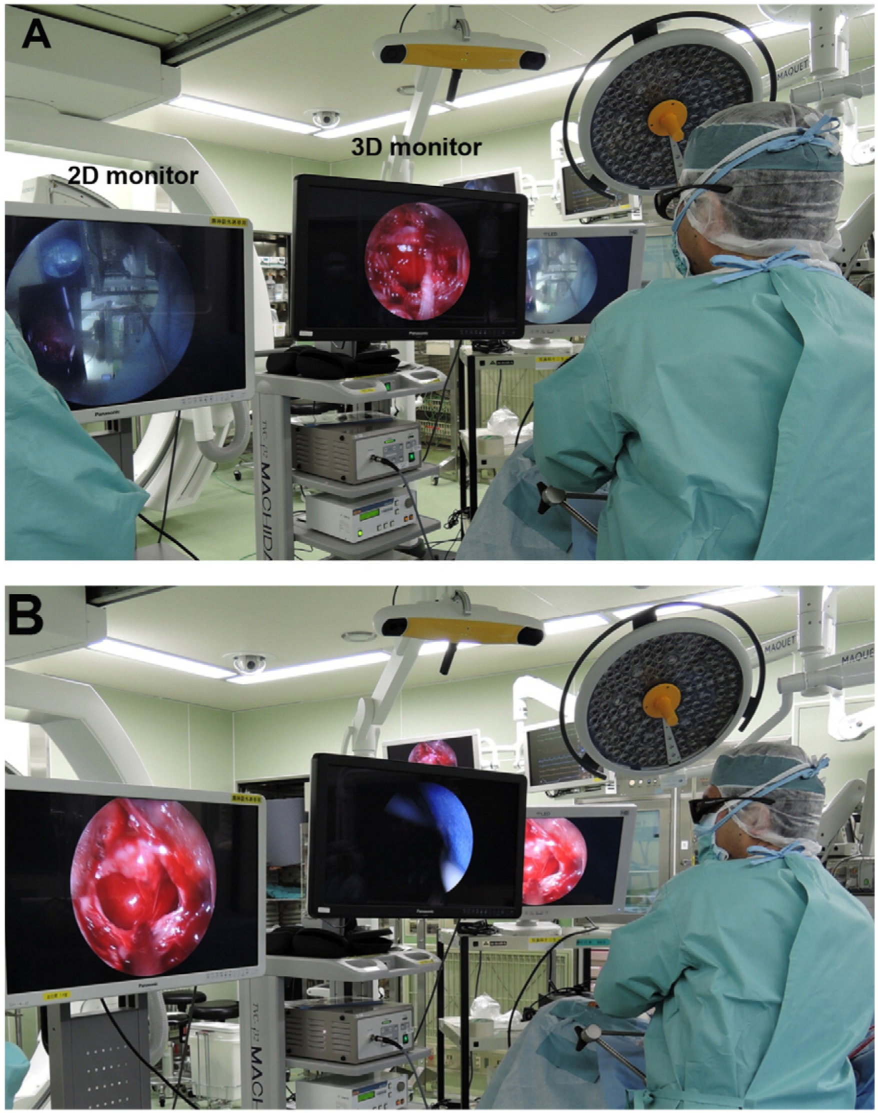

Fig. 2. Intraoperative photographs of combination surgery using three-dimensional (3D) and two-dimensional (2D) endoscopy. The surgeon switches between endoscopic techniques depending on the surgical step — 3D endoscopic surgery is performed wearing polarizing glasses (A) and it is sometimes switched to the 2D mode of surgery (B), which can be performed with the polarizing glasses on, thus reducing the time spent on taking them on and off (B).

3. Results

3.1. Patient demographics and clinical information

At our department, we switched from microscopic endonasal surgery to fully endoscopic endonasal surgery in 2008. Between 2008 and 2011, the first author (KY) performed fully endoscopic transsphenoidal surgery on 60 patients using only 2D endoscopy. Upon the introduction of dual optical channel 3D endoscopy in 2011, we performed combination surgery using 3D and 2D endoscopy on 88 patients between 2011 and 2016. The 16 patients were included in the previous study [8]. All surgical procedures were performed by a single surgeon (KY, the first author). The demographic and clinical information of the patients operated upon at our department between the 2008 and 2011 are presented in Table 1.

3.2. Combination surgery using 3D and 2D endoscopy

Surgery in all 88 of the cases was safely accomplished by 3D-HD endoscopy in conjunction with 2D endoscopy. The operative information for these patients is presented in Table 1. There were no significant differences in patient and surgical characteristics between 2D surgery and combination surgery. In combination surgery, the exact operative

Table 1
Patient demographics and clinical information.

	2D only (N = 60)	3D and 2D (N = 88)
Patient demographics		
Male (%)	27 (45)	37 (42)
Mean age (min–max) {std. dev.}	47 (12–77) {16}	50 (7–84) {19}
Tumor characteristics		
Maximum diameter, mm		
Mean (min–max) {std. dev.}	22 (3–55) {10}	22 (3–55) {12}
Diagnosis		
Non-functioning tumors (%)	25 (42)	32 (36)
Functioning tumors (%)	17 (28)	29 (33)
Craniopharyngioma (%)	5 (8)	7 (8)
Other tumors (%)	12 (20)	20 (23)
Operative information		
Operative time, min	214 (33–480) {85}	196 (70–467) {93}
Mean (min–max) {std. dev.}		
Blood loss, g	54 (0–516) {94}	76 (0–540) {128}
Mean (min–max) {std. dev.}		

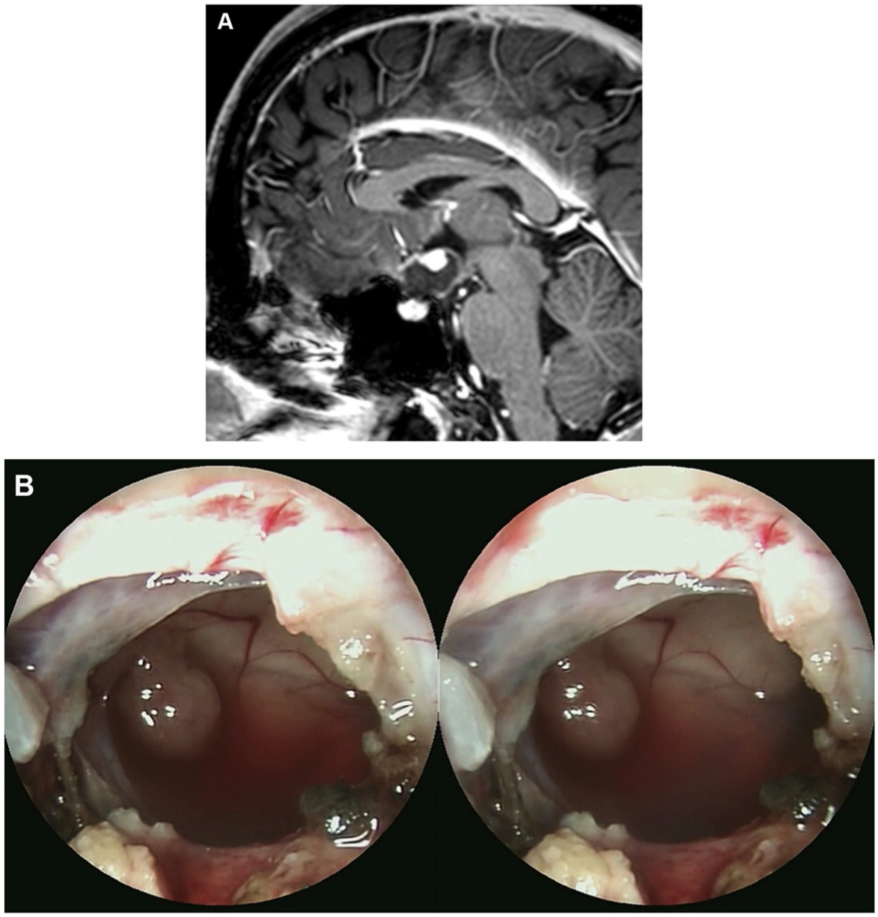

Fig. 3. Representative intraoperative images acquired by three-dimensional (3D) endoscopy in a six-year old patient with craniopharyngioma (A and B). The intraoperative images were displayed side-by-side so that a stereoscopic image could be obtained by crossing. An enhanced nodule located beneath the optic chiasm is identified deep in the intraoperative image (B).

time and blood loss attributable solely to 3D endoscopy could not be evaluated because 3D and 2D endoscopes were frequently exchanged with each other. There were no intraoperative complications related to the use of 3D endoscopy in this study. The dual optical channel 3D endoscope provided depth perception and spatial recognition during surgery, as shown Fig. 3. In addition, because the depth of field of this endoscope has a dynamic range of 0.5–4 cm, and the system is equipped with auto-focus function, we were able to acquire focused stereoscopic images from the entrance of the sphenoid sinus to the sella. Although, in our study, the surgeon held the endoscope during surgery, the dual optical channel 3D endoscopy system can be adjusted to function with various types of operating holders. There were no incidences of side effects associated with stereoscopic vision, such as vision fatigue, headache, and feeling of illness. However, one of the drawbacks of the dual optical channel 3D-HD endoscope was its lower image resolution compared to that of the 2D-HD endoscope. In addition, because of the small size of the individual optical channels, the viewing angle of the dual optical channel 3D endoscope was smaller compared to that of the 2D endoscope. Therefore, we switched between 3D and 2D endoscopy depending on the surgical manipulation step. Although the main surgical procedures were performed by 3D endoscopy, we encountered situations such as the identification and differentiation of tumor and normal tissues and detection of residual tumor tissues, where 2D endoscopic inspection was desirable because of the superior image resolution of 2D endoscopy compared to that of 3D endoscopy. In these situations, we preferred 2D endoscopy over the 3D technique. However, the criteria for application of 3D and 2D endoscopy are likely to be subjective.

Based on our experience of combination surgery by 3D and 2D endoscopy, we believe that the feasibility of 3D endoscopy is variable depending on the surgical procedure. Given that the relatively simplicity of the nasal structure, the usefulness of stereoscopic vision was minimal in the nasal phase of endoscopic endonasal surgery. However, in the sphenoidal to sellar phases, stereoscopic vision enabled instant recognition of complex bone structures such as the septum and sella turcica, especially in cases of multiple surgeries for tumor recurrence, where the normal bone structure had already been destroyed. Additionally, it was found to be ideal for bone drilling. During tumor removal, stereoscopic vision was useful in identifying the precise locations of anatomical structures. In the suprasellar region, it enabled the acquisition of operative images similar to those acquired with the microscopic procedure. However, the significance of stereoscopic vision for intrasellar manipulation in cases such as resection of microadenomas was low. During dural suturing for the repair of the skull base, stereoscopic vision helped in not only gaining a precise hold of the needle, but also suturing.

3.3. Comparison of stereoscopic effect between dual optical channel and Visionsense 3D endoscopic techniques

As described above, the 3D endoscopic technique presented in this study is based on a dual optical channel technology similar to human vision, whereas the Visionsense VSIII endoscopic technique is based on "insect-eye technology", which involves the incorporation of a single objective lens that splits light along two paths, reconstructing a 3D image [13]. Therefore, the stereoscopic effects exhibited by the two endoscopic techniques are different from each other. Since the Visionsense VSIII endoscopic system was introduced at the end of 2015, we compared stereoscopic images acquired using both techniques side-by-side in three operative cases. Our results indicated that the stereoscopic

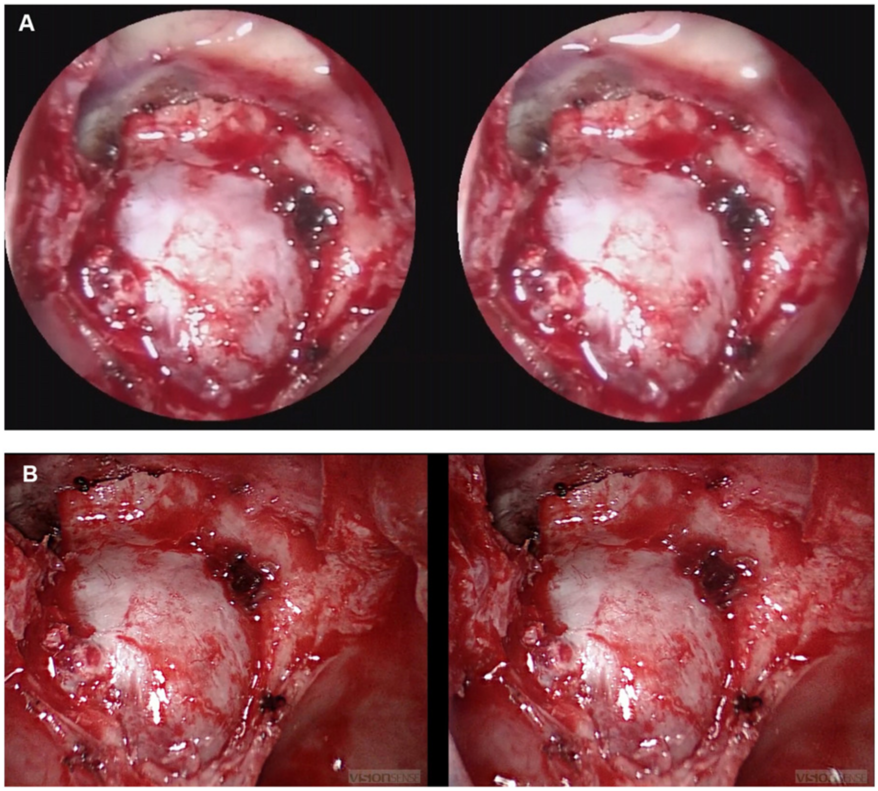

Fig. 4. Representative images acquired by dual optical channel three-dimensional (3D) endoscopy (A) and Visionsense 3D endoscopy (B) in the same operative field and patient. Although these images do not completely reflect the stereoscopic effect of either technique, they were also displayed side-by-side so that a stereoscopic image could be obtained by crossing. Images A and B demonstrate the posterior aspect of the sphenoid sinus and dura of the sella. Note that the magnitude of binocular disparity is greater in A than in B, although image resolution of B is better compared to that of A.

effect of dual optical channel 3D endoscopy is stronger compared to that of Visionsense VSIII (Fig. 4), which might be because the dual optical channel technology is based on binocular depth perception.

4. Discussion

Depth perception and spatial recognition are vital parameters for endoscopic endonasal surgery and require the application of 3D endoscopy. Although 3D endoscopy enables improved surgical dexterity by enhancing subjective depth perception and spatial orientation, no clinical advantages of 3D overconventional 2D endoscopic surgery in terms of duration of hospitalization, estimated blood loss, operative time, or rate of complications have been reported [1,9,13]. In addition, because of the present technical limitations of 3D endoscopy, including its relatively low image resolution and narrow viewing angle, conventional 2D endoscopic surgery is still more popular than the former technique. Therefore, we need to consider the mechanism of depth perception of the target in order to discuss the significance of 3D endoscopy in addition to its technical limitations.

In the human eye, depth perception of the target is acquired by monocular as well as binocular depth cues (i.e., stereopsis) [5]. Monocular depth cues include parameters such as occlusion, texture gradient, familiarity of size, relative size, light shading, motion parallax [6,7,11], which indicates that depth perception can be obtained without stereopsis in certain situations. In case of conventional 2D endoscopic surgery, depth perception is acquired as monocular cues in terms of data of these parameters. Therefore, it can be said that, in situations where monocular depth cues provide satisfactory depth perception—in other words, when the manipulative or operative procedure is simple and familiar—2D endoscopic surgery is comparable to 3D endoscopic surgery in terms of depth perception [11]. In particular, we tend to reconstruct the 3D structure of a familiar-sized target from its 2D image, as in the standard step of endoscopic surgery from the nasal to sellar phases. These are the reasons why no previous study has reported any clinical benefit of 3D over conventional 2D endoscopic surgery [1,9,13].

So, what is the clinical significance of 3D endoscopy? We believe that 3D endoscopy has clinical significance in steps where depth perception and spatial recognition cannot be acquired by monocular cues, but require binocular cues (i.e., stereopsis). Based on the surgical experience of the first author, these situations include spatial recognition of the complicated sphenoid sinus structure—especially in case of patients with a history of multiple surgeries, where the normal anatomical structure has been destroyed—and depth perception during bone drilling. Suprasellar manipulation deep in the operative field is another step where stereopsis is useful. Overall, we recognize that the significance of stereopsis with 3D endoscopy varies with the surgical procedure and clinical situation. Considering its technical limitations of low image resolution and narrow viewing angle, we advocate that dual optical channel 3D endoscopy has significance as an assistive technique during conventional 2D endoscopic surgery. In routine endonasal endoscopic surgery, we frequently switch between 2D and 3D endoscopy and proceed with surgery by 3D endoscopy in steps where stereopsis is desired, such as those described above. Moreover, we often encounter surgical situations where we feel that the spatial relationship of anatomical structures cannot be fully recognized by 2D endoscopy. In such cases, we apply stereopsis by 3D endoscopy in order to understand the spatial relationship of anatomical structures and then switch back to 2D endoscopic surgery. Therefore, our strategy can be designated as combination surgery using 2D and 3D endoscopy.

Stereoscopic effect is determined by the magnitude of binocular disparity, which is one of the key factors to be considered during the evaluation of efficacy of stereopsis [3,11]. Binocular disparity is translated into the sense of extrusion and depth of the anatomical structure. It has been reported that, even in cases where the stereoscopic effect is evident, the magnitude of binocular disparity determines the duration of search for the target. Since dual optical channel and Visionsense 3D endoscopic techniques are based on different technologies, they exhibit different magnitudes of binocular disparity. As described in our results, dual optical channel 3D endoscopy exhibits greater magnitude of binocular disparity than the Visionsense technique, which means that surgical and manipulative procedures cannot be performed with equal efficacy using the former technique. However, the magnitude of binocular disparity ideal for endoscopic surgery remains to be validated. In consideration of this technical aspect, we need to exercise caution while evaluating the significance of 3D endoscopy — apart from the complexities of the manipulative and surgical procedures, the 3D endoscopic technique itself is a key factor affecting its performance.

In summary, we have described a new dual optical channel 3D endoscopic technique and reported our clinical experience with the same. In recognition of its high magnitude of binocular disparity, this 3D endoscopic technique has clinical significance as an assistive technique in situations where stereoscopic operative view is useful. It has been reported that applications involving dual optical channel technology might exhibit imbalance of focus and color, causing vision fatigue, headache, and nausea. However, as has been previously reported, the dual optical channel 3D endoscopic system has an integrated technology that serves to minimize the side effects of the dual optical channel technology [8]. Evaluation of clinical significance of 3D endoscopic surgery requires consideration of not only image quality but also the magnitude of binocular disparity. The technology of 3D endoscopy is rapidly improving, and, therefore, the significance of this 3D technology needs to be evaluated in combination with its integrated equipment.

Conflicts of interest

The authors declare no conflicts of interest concerning this study.

Acknowledgements

We thank Masaki Yoshida, Kohji Tai, and Jiro Miyabe (Panasonic Healthcare, Tokyo, Japan) for their technical assistance with 3D image display and Tsuneo Fukuyo (Shinko Optical Corporation, Tokyo, Japan) for his technical advice regarding dual optical channel 3D endoscopy.

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