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# Development of D-to-D-to-P telemedicine at a remote island hospital using smart glasses

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**Background:** Medical resources on remote islands are limited, which makes it difficult for patients to receive specialized medical care.

**Purpose:** This study aimed to develop and evaluate a method to perform doctor-to-doctor-to-patient (D-to-D-to-P) telemedicine.

**Methods:** The-D-to-D-to-P telemedicine was implemented to provide specialized medical support from a neurologist at Nagasaki University Hospital to a rural physician wearing camera-equipped smart glasses at Goto Chuoh Hospital on a remote island, which was called a virtual neurological outpatient (VNO). For the first six months, the rural physician independently saw patients with Parkinson's disease (PD), and then for the next six months, VNO was implemented. Comparisons were made before and after the implementation of the VNO. Next, by adding a 4 K overhead camera, in-person examinations of a single outpatient were compared between the rural physician with VNO and another neurologist unrelated to the VNO.

**Results:** The clinical efficacy of VNO was not superior to no VNO, but had a learning effect on rural physicians and was satisfactory for patients. By adding a 4 K overhead camera to the VNO, the accuracy of the in-person examination by the rural physician was shown to be equivalent to that of an in-person neurologist.

**Conclusion:** VNO using smart glasses could be applied for D-to-D-to-P telemedicine in neurology. However, to promote telemedicine on remote islands, it will be necessary to improve the system to make it more accessible to rural physicians.

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**Key words:** telemedicine, smart glasses

## Introduction

The field of neurology encompasses several diseases, from common diseases such as stroke, dementia, PD, and epilepsy to rare neurological intractable diseases. When examining these neurological disorders, visual inspection is especially important for facial appearance, ocular movements and pupils, limb atrophy and movements, standing, and walking. Therefore, telemedicine using video conferencing is expected to be particularly useful in rural areas with limited medical resources[1,2]. To date, telemedicine has been practically applied for stroke[3], mainly for diagnostic imaging, to determine the indication for acute treatment, but no systems have yet been established for chronic neurological diseases.

Recently, a randomized, controlled trial of video-conferenced Doctor to Patient (D to P) telemedicine by specialists in PD showed a reduction in travel distance and time to care compared with face-to-face care provided by non-specialists, but achieved no difference in the quality of life, treatment efficacy, or caregiver burden[4]. Alternatively, the specialist intervention

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increased compliance with hospital quality indicators and reduced the risk of hospitalization due to worsening symptoms, nursing home admission, hip fracture, and death[5]. Therefore, we hypothesized that the closer the telemedicine specialist intervention is to the specialist's in-person care, the more comparable the expected medical benefits.

Although expectations for telemedicine have recently been increasing, the accuracy of diagnosis and effectiveness of treatment has not yet been fully investigated. This study, therefore, aimed to develop a VNO on a remote island using smart glasses and to evaluate its usefulness with an emphasis on quality, especially for chronic neurological diseases, including PD.

## Methods

The BT-300 (Epson Moverio®) is a wearable computer "smart glasses", which comprises a high-definition display on a see-through binocular screen and a 5-megapixel (MP) front-facing camera capable of transmitting high-quality videos back to a remote networked partner (Figure 1A). This device was originally developed for hands-free remote work in industrial settings, such as factories. In the VNO of this study, the BT-300 was adapted as a real-time communion tool to allow visualization of a rural physician's viewpoint in a remote island hospital shared with a neurologist at Nagasaki University Hospital as a specialist (Figure 1B).

First, a one-year prospective cohort study was conducted at Goto Chuoh Hospital on a remote island of Nagasaki Prefecture, for patients who had already been diagnosed with PD and were interested in visiting the VNO. After obtaining informed consent, the first six months were used as a control period, during which the rural physician independently saw the PD patients. Outpatient visits without VNO were scheduled at 1, 3, and 6 months after the start of the study. VNOs were performed at 7, 9, and 12 months. During VNO, the rural physician examined patients with PD and adjusted anti-parkinsonism medications following advice from a neurologist at Nagasaki University Hospital.

The assessment items included the PD unified scale-updated (MDS-UPDRS), on and off time of the wearing-off phenomenon, presence of dyskinesia, PD-specific quality of life scale questionnaire (PDQ-39), clinical general impression (CGI-C), Montreal Cognitive Assessment (MoCA), levodopa equivalent total drug dosage, comorbid comorbidities (e.g., fractures), patient assessment of chronic illness care system (PACIC), and a dedicated questionnaire. The evaluation method was used to compare the changes in the endpoints before and after the specialized medical intervention by the VNO.

Subsequently, a 4K overhead camera with zoom and remote-control functions was placed at a corner behind the physician in the examination room of the VNO to eliminate blind spots of the smart glasses and provide clearer observation. The video from the front-facing camera of BT-300 is viewed on the PC and the video from the 4K overhead camera is viewed on the LCD monitor in a room at Nagasaki University Hospital. As a single outpatient trial, the neurological findings and diagnoses obtained from the rural physician with VNO were compared with those of other neurologists unrelated to VNO for the same patients. An AW-UE70W (Panasonic Remote Camera System) was used as the 4 K overhead camera. A newly developed checklist for remote neurodiagnostics (Table 1) was applied to compare the neurological findings.


**Figure 1A.** The BT-300 (Epson Moverio®) equipment

**Figure 1B.** A view of the examination from the neurologist's side

**Table 1.** Items on the checklist for remote neuro diagnostics and the concordance rates of neurological findings between telemedicine and face-to-face consultations

| neurological findings | concordance rates | neurological findings | concordance rates |
|---|---|---|---|
| antecollis (dropped-head) | 14/14 (100%) | Barre's sign | 13/14 (93%) |
| head backbend | 14/14 (100%) | raising both hands up | 14/14 (100%) |
| camptocormia | 14/14 (100%) | flexion and extension of elbow joint | 14/14 (100%) |
| inclination of the trunk | 14/14 (100%) | flexion and extension of wrist joint | 14/14 (100%) |
| torticollis | 14/14 (100%) | opening and closing of the hand | 14/14 (100%) |
| tremor | 14/14 (100%) | resting tremor | 13/14 (93%) |
| involuntary movement (for example, dyskinesia) | 14/14 (100%) | postural tremor | 14/14 (100%) |
| olfaction | 14/14 (100%) | asterixis | 14/14 (100%) |
| taste | 14/14 (100%) | diadochokinesis | 14/14 (100%) |
| perspective (self-reporting) | 14/14 (100%) | finger-tapping | 14/14 (100%) |
| hearing (self-reported) | 14/14 (100%) | nose finger nose test | 14/14 (100%) |
| field of view | 14/14 (100%) | configuration (Hand in the shape of a fox or dove) | 14/14 (100%) |
| ptosis | 14/14 (100%) | muscle tonus of the upper extremities | 12/14 (86%) |
| ocular position | 14/14 (100%) | standing up | 14/14 (100%) |
| pupillary | 14/14 (100%) | standing on tiptoes and heels | 14/14 (100%) |
| pupillary light reflex | 14/14 (100%) | Romberg's sign | 14/14 (100%) |
| eye movement | 14/14 (100%) | pull test | 14/14 (100%) |
| nystagmus | 14/14 (100%) | gait | 14/14 (100%) |
| raising eyebrows | 14/14 (100%) | tandem gait | 14/14 (100%) |
| closing eyes | 14/14 (100%) | bradykinesia | 14/14 (100%) |
| showing teeth with a smile | 14/14 (100%) | atrophy and deformity of the lower extremities | 14/14 (100%) |
| puffing up cheeks | 14/14 (100%) | hip flexion | 14/14 (100%) |
| lateral difference in nasolabial folds | 14/14 (100%) | knee flexion and extension | 14/14 (100%) |
| facial sensation | 14/14 (100%) | ankle flexion and extension | 14/14 (100%) |
| articulation | 14/14 (100%) | Mingazzini's sign | 14/14 (100%) |
| deglutition | 14/14 (100%) | heel knee test | 14/14 (100%) |
| tongue movement | 14/14 (100%) | deep tendon reflex | 13/14 (93%) |
| pharynx movement | 14/14 (100%) | Babinski's sign | 14/14 (100%) |
| muscle strength in cervical anteversion | 14/14 (100%) | Chaddock's sign | 14/14 (100%) |
| muscle strength in cervical retroflexion | 14/14 (100%) | muscle tonus of the lower extremities | 14/14 (100%) |
| muscle strength in rotation to the right | 14/14 (100%) | clasp-knife response | 14/14 (100%) |
| muscle strength in rotation to the left | 14/14 (100%) | ankle clonus | 14/14 (100%) |
| atrophy and/or deformity of upper extremities | 14/14 (100%) | sense of the whole body | 14/14 (100%) |

## Results

In the first study, 9 PD patients (age; 74.9 ± 8.1 years, duration of disease; 4.5 ± 2.7 years, 66.7% female) were enrolled from January 1, 2019, to December 31, 2020. However, five of the nine enrolled patients were unable to transition to VNO because they had to withdraw from the clinical study early due to hospitalization for fractures (two patients) and infections (three patients) during the control period. After excluding these withdrawal and discontinuation cases, four PD patients (age; 73.6 ± 7.2 years, duration of disease; 5.2 ± 2.7 years, 75% female) who completed VNO for six months were evaluated. No significant differences in the clinical characteristics were found between the withdrawal and non-withdrawal groups.

In four PD patients who completed VNO, the MDS-UPDRS at the end of the control period and the end of VNO showed no obvious difference overall, with one patient improving (31 to 20 points), one patient worsening (87 to 105 points), and two patients remaining almost unchanged (mean MDS-UPDRS score of 65 to 67.5) (Figure 2). Although the number of cases was too small to evaluate the advantage, none of the patients dropped out during the ongoing VNO. Indeed, both patients and physicians expressed high overall satisfaction in a questionnaire survey conducted after the completion of the VNO. In particular, all patients who experienced a VNO were reassured by the collaboration between the specialist and the rural physician, and the rural physician was satisfied with the educational effect on specialty care. However, the rural physician complained of the long time taken to evaluate neurologic findings, the inconvenience of maintaining the electric power and connection to the Internet of the smart glasses. The neurologist sometimes noticed the distortion of the images and the misalignment of viewpoints with the rural physicians. The distortion of the images was attributed to the shaking of the head by the rural physician wearing the smart glasses, causing the images to blur. The misalignment of viewpoints was also attributed to differences from the original viewpoints of the rural physicians because the camera was located outside of the smart glasses. Furthermore, a rare but important problem was that the smart glasses caused blind spots because of their narrow viewing angle, such as when the patient made large movements.

Subsequently, examinations were conducted in the examination room installed with a 4 K overhead camera. In this setup, the neurological findings of 14 patients (5 initial and 9 follow-up visits) who visited the outpatient clinic of neurology at Goto Chuoh Hospital were compared between a rural physician with VNO and a neurologist unrelated to VNO, and their concordance was verified using the checklist for the remote neuro diagnostics.

The neurological findings in the 14 patients were generally consistent. In some cases, examination findings for muscle tone, tendon reflexes, and tremors were inconsistent (Table 1). During VNO, the patient's upper extremities were sometimes incorrectly judged to be hypertonic on the rural physician's

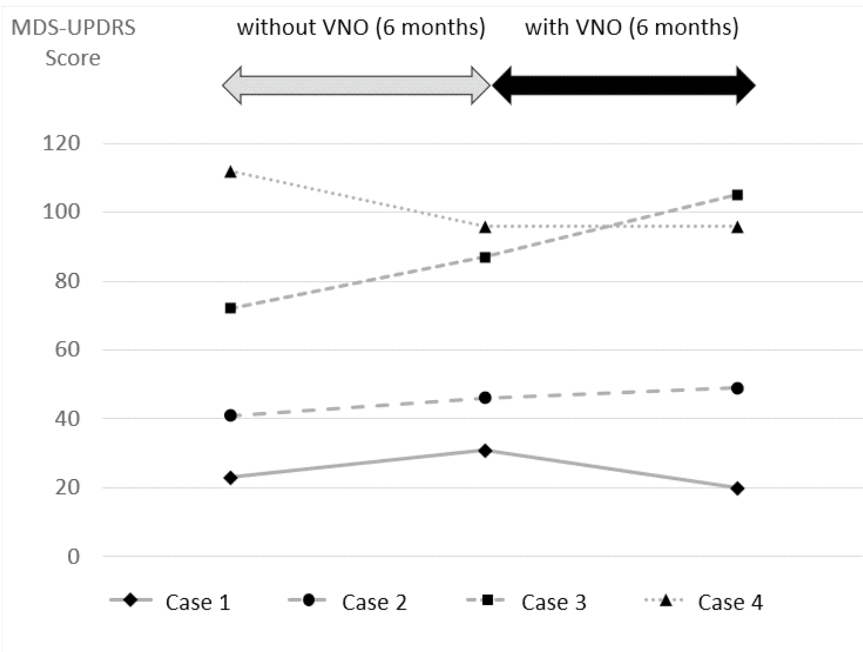


**Figure 2.** Changes in MDS-UPDRS by VNO

examination if they were not sufficiently relaxed. Furthermore, in some cases, tendon reflexes were negative because the appropriate area was not tapped. Tremors were sometimes judged differently because they appeared and disappeared at different times of the day depending on the effect of the medication. The clinical diagnoses of five patients on initial visits were also consistent. Only one case showed a slight difference between PD and Lewy body disease (Table 2).

Finally, we assessed the overall satisfaction level (Figure 3). Patient satisfaction was high (93% for very satisfied and satisfied), suggesting a high demand for D-to-D-to-P telemedicine support. The satisfaction of the rural physicians, however, was not high, with 36% dissatisfied. While rural physicians could benefit from the learning effect of a specialist guidance, the inaccessibility of telemedicine support remains a major issue to be solved.

## Discussion

In this study, we demonstrated the possibility of applying D-to-D-to-P telemedicine in neurology by setting up a VNO using smart glasses. Furthermore, after adding a 4 K overhead camera to cover the blind spots of the smart glasses, the accuracy of the in-person examination by the rural physician was shown to be equivalent to that of the specialist. However, despite the relatively high level of patient satisfaction, the rural physicians were not satisfied. Therefore, to promote D-to-D-to-P telemedicine on remote islands, it will be necessary to improve the system to make it more accessible to rural physicians. The image from the 4K overhead camera was superior to the image from the smart glasses, both in terms of field of view and resolution. However, the smart glasses were useful as a communication tool, and their capabilities

**Table 2.** Differences in diagnosis by the rural physician with VNO and the neurologist

| | age | sex | chief complaint | diagnosis by rural physician | diagnosis by neurologist |
|---|---|---|---|---|---|
| case 1 | 59 | F | weakness in left upper and lower extremities | Parkinson's disease | dementia with Lewy bodies |
| case 2 | 77 | F | gait disturbance | spinocerebellar degeneration<br>lumbar spinal stenosis | spinocerebellar degeneration<br>lumbar spinal stenosis |
| case 3 | 44 | F | transient dysarthria | transient ischemic attack | transient ischemic attack |
| case 4 | 75 | M | gait disturbance | spinocerebellar degeneration | spinocerebellar degeneration |
| case 5 | 24 | F | tremor in both hands | essential tremor | essential tremor |

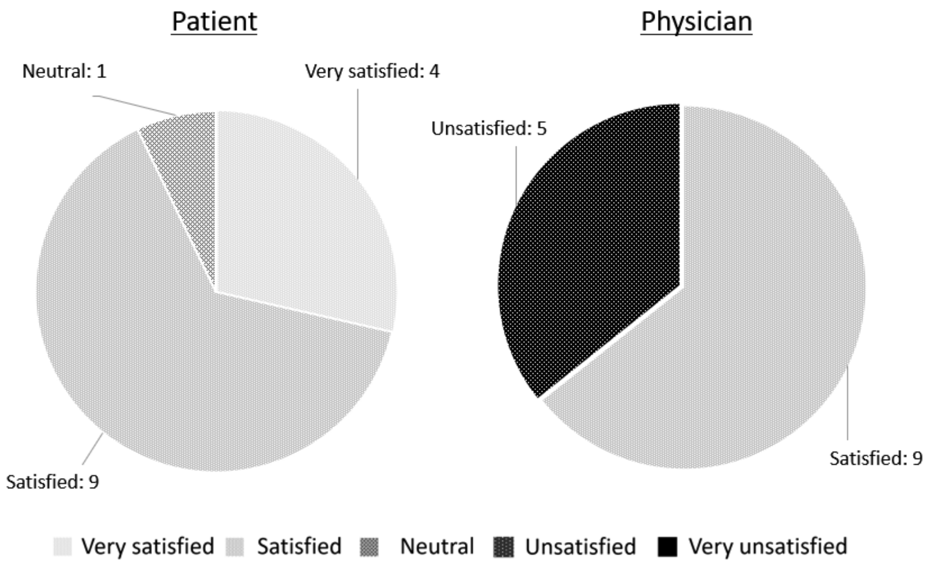


**Figure 3.** Satisfaction level for the VNO

could not be replaced by the 4K overhead camera.

In D-to-D-to-P telemedicine, medical examinations and treatment are performed by the local attending physician with the assistance of a specialist at a remote location. In Japan, D-to-D-to-P telemedicine does not apply to the "Guidelines for the Appropriate Implementation of Online Medical Care" and has no restrictions on the implementation; doctor-to-patient (D-to-P) telemedicine must comply with the guidelines. D-to-D-to-P telemedicine does not necessarily require accompanying patients. However, when the specialist provides medical care directly to the patient in the presence of the attending physician (patient-attended D-to-D-to-P), it is difficult to distinguish between D-to-D-to-P and doctor-to-patient with doctor (D-to-P with D) telemedicine. In this study, direct communication between the specialist and the patient was not conducted, emphasizing the autonomy of rural physicians. We assumed that specialists at university hospitals would be good advisors for rural physicians, providing advice on how to diagnose their patients professionally. However, the satisfaction level of rural physicians was not as high as expected. The reason was thought to be the technical burden, such as the accessibility of communication devices, as well as the possible impact of the psychological burden on the rural physician. Therefore, D-to-P with D telemedicine may be a more or less comfortable method for rural physicians than D-to-D-to-P, and establishing direct communication between the specialist and the patient would be more desirable.

The COVID-19 pandemic, which started in 2020, and thereafter spread globally, has drastically changed many social aspects worldwide. In the healthcare field, the acceptance of COVID-19 patients and the necessity to prevent healthcare collapse have forced restrictions on general medical services, such as the reduction of outpatient and inpatient admissions, and the closure of hospital wards. In these circumstances, telemedicine has attracted attention as a method to facilitate the continuity of medical care and infectious disease control, and its use has subsequently spread worldwide. Even in Japan, where telemedicine has not been widely applied due to relatively strict regulations, its use has increased following temporary and exceptional deregulation, including the extension of target diseases, acceptance of initial consultations, and improved reimbursement for medical services. Whether such widespread use of telemedicine will continue after the pandemic is over will depend on whether telemedicine can help eliminate regional medical disparities and overwork due to uneven distribution or lack of medical care. For this to happen, D-to-D-to-P telemedicine, such as that established in this study, should be applied to depopulated areas, including remote islands and areas, and must be adopted in local communities as common medical care. An important clue to success may be the reduction of the technical and psychological burden on rural physicians. Furthermore, the economics of telemedicine must be considered. Since the VNO of D-to-D-to-P telemedicine is not reimbursed at present, it generates no revenue compared to no VNO. Rather, it would require more working time for rural physicians and the initial cost of setting up telemedicine. On the other hand, patients could be treated without leaving the islands, which saves travel costs and time for the patients.

The limitations of this study were that the sample size was too small for statistical analysis, and the study period was too short to identify differences in clinical efficacy. However, our results nevertheless indicate that it would be worthwhile to implement telemedicine systems using smart glasses and a 4K overhead camera on remote islands in a real clinical setting. In the future, the accessibility of telemedicine should be expanded to rural general physicians to increase the number of patients enrolled. Further studies must also evaluate the economic and educational benefits.

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