Original Paper

Mixed Reality–Based Telemedicine for Patients With Rheumatoid Arthritis in a Remote Island Setting: Single-Center, Observational, Pilot Feasibility Study

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Abstract

Background: Rheumatoid arthritis (RA) requires regular specialist monitoring; however, access to rheumatologists is severely limited in remote island settings. Conventional 2D video-based telemedicine has limitations for detailed remote joint assessment.

Objective: This study aimed to evaluate the technical and operational feasibility of the Nagasaki University Rheumatoid Arthritis Remote Medicine System (NURAS), a mixed reality (MR)–based telemedicine platform, for collaborative RA assessment in a remote island setting and to descriptively explore 12-month changes in clinical and patient-reported outcomes.

Methods: NURAS enables remote rheumatologists to view 3D holographic joint images beyond conventional video telemedicine. In this 12-month single-center pilot feasibility study at Goto Chuoh Hospital, 6 patients with RA were enrolled. An on-site primary care physician and a remote rheumatologist at Nagasaki University Hospital jointly assessed patients at baseline, 6 months, and 12 months using a 28-joint count with real-time MR visualization. Primary outcomes were feasibility metrics, including the numbers of planned, attempted, completed, failed, and rescheduled sessions, connection interruptions, setup and consultation times, technical problems, and completion of planned joint assessments. Secondary outcomes were exploratory changes in disease activity (Disease Activity Score in 28 joints using C-reactive protein [DAS28-CRP] and Clinical Disease Activity Index [CDAI]) and patient-reported outcomes (Health Assessment Questionnaire Disability Index, Rheumatoid Arthritis Impact of Disease, Functional Assessment of Chronic Illness Therapy–Fatigue, pain visual analog scale, and Kessler 6-item psychological distress scale), summarized as medians with IQRs. This study was a noninterventional observational feasibility study and was not prospectively registered. The study was approved by the Nagasaki University Hospital Clinical Research Ethics Committee (approval 21081605).

Results: All 18 planned telemedicine sessions were attempted and completed; 2 sessions were rescheduled for patient-related reasons, and no connection interruptions were documented. All planned joint assessments were completed, and setup required approximately 5 minutes per session with assistance from 1 nurse. Median consultation time was 37 minutes 45 seconds (IQR 33 minutes 19 seconds-47 minutes 34 seconds) at baseline and 17 minutes 47 seconds (IQR 15 minutes 16 seconds-20 minutes 38 seconds) at 12 months. Median DAS28-CRP decreased from 2.98 (IQR 2.60-3.61) to 1.69 (IQR 1.19-1.79) and median

CDAI from 10.0 (IQR 7.1-13.0) to 3.0 (IQR 1.0-5.0), whereas patient-reported outcomes varied across individuals. Clinical outcome changes were interpreted descriptively.

Conclusions: NURAS was technically and operationally feasible for collaborative, specialist-supported RA care in a remote island setting. Larger controlled studies are needed to evaluate diagnostic agreement, acceptability, technical performance, cost, and clinical effectiveness.

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Keywords: telemedicine; mixed reality; rheumatoid arthritis; rural health; health services accessibility; feasibility studies

Introduction

Nagasaki Prefecture has the highest number of remote islands in Japan, with approximately 10% of its population residing on these islands. Goto City, located approximately 100 km west of Nagasaki City, is a remote island region classified as a super-aged society, with 42% of the population aged 65 years or older. This trend is particularly pronounced in remote areas and outlying islands far from urban centers, where single-person households are prevalent. Additionally, small, aging communities are scattered across the mountainous and coastal areas. Ongoing population decline has led to reduced bus services, withdrawal of taxi companies, and an increase in driver's license surrenders among older adults, limiting mobility and making access to medical facilities difficult for many islanders. Accordingly, Goto City also faces a shortage of medical resources and an uneven distribution of specialists.

In the context of geographic isolation and demographic challenges, the management of chronic diseases requiring specialist care, such as rheumatoid arthritis (RA), poses particular difficulties. RA is a systemic inflammatory disease characterized by synovitis, leading to pain, swelling, progressive joint destruction, and functional impairment [1,2]. The therapeutic goals of RA include clinical remission (control of inflammatory symptoms), structural remission (prevention of joint damage and deformities), and functional remission (maintenance of physical function) [1,2]. Early diagnosis and timely treatment are essential prerequisites for achieving these goals [3]. Accordingly, both domestic and international guidelines advocate a treat-to-target approach with regular disease activity monitoring, ideally under the supervision of a rheumatologist [4,5]. However, the severe shortage of rheumatologists on remote islands and in rural areas hinders equitable access to specialist care in these regions [6-8]. In these areas, patients often rely on nonspecialist primary care physicians or are required to travel long distances to mainland hospitals, incurring substantial time, physical, and financial burdens to receive treatment. For older residents living in Goto City, which is separated by the sea and located approximately 100 km from the mainland urban area of Nagasaki City, traveling over 100 km is physically demanding and frequently affected by weather conditions. Therefore, there is a clear need for telemedicine to improve access to rheumatologists on remote islands and in rural areas of Japan.

To address this unmet need, we have developed the Nagasaki University Rheumatoid Arthritis Remote Medicine System (NURAS), a next-generation telemedicine platform based on mixed reality (MR) technology for patients with RA. In collaboration with Microsoft Japan Co, Ltd, Nagasaki Prefecture, Goto City, and Nagasaki Prefectural Goto Chuoh Hospital, we commenced a pilot telemedicine program in 2021 between Nagasaki University Hospital and Goto Chuoh Hospital. The primary objective of this study was to assess the technical and operational feasibility of delivering rheumatologist-supported care using an MR-based telemedicine platform in a remote island setting; clinical and patient-reported outcomes were examined as exploratory secondary end points.

In this article, we describe the development, system architecture, and initial clinical implementation of NURAS and discuss its potential role in improving access to specialized RA care in geographically isolated and aging communities. This study is reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement (Checklist 1) and the RATE-XR (reporting guidelines for the early-phase clinical evaluation of applications using extended reality) reporting guideline for early-phase clinical evaluation of applications using extended reality.

Methods

NURAS System and Telemedicine Workflow

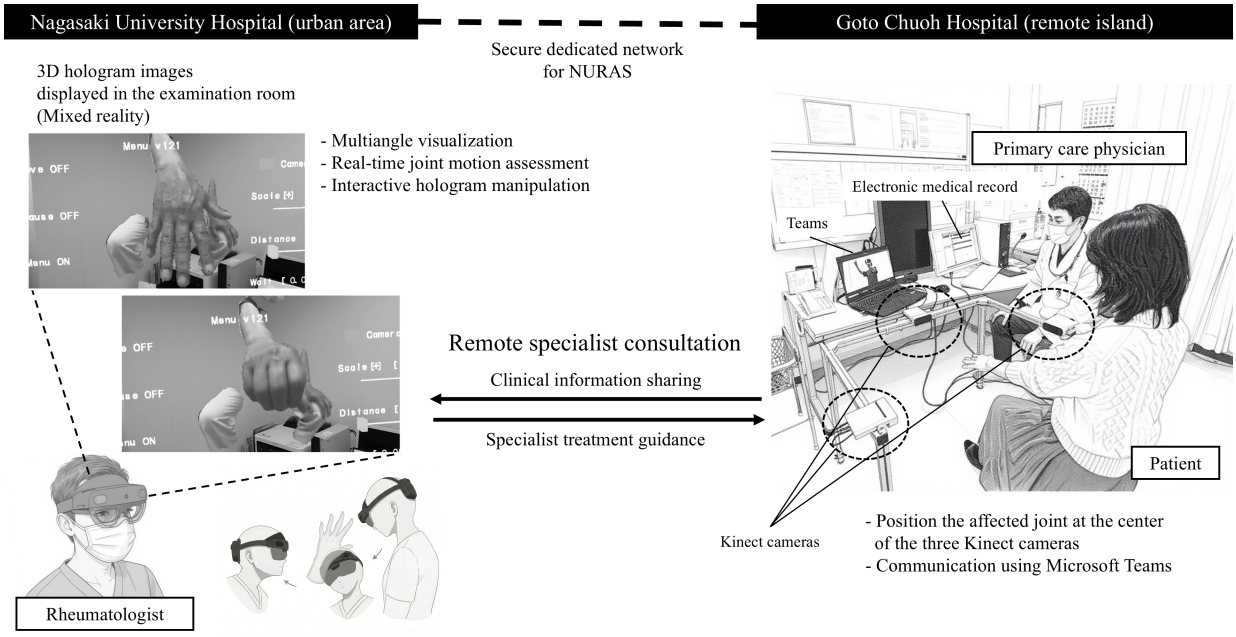
NURAS is a telemedicine platform that integrates Microsoft's MR technology. It combines Azure Kinect DK (depth-sensing cameras), Microsoft HoloLens 2 (head-mounted MR device), and Microsoft Teams (video conferencing and collaboration tool) to enable 3D and real-time visualization and assessment of the affected joints [9,10]. The integrated NURAS system is an original research-use platform assembled from commercially available hardware components and fixtures; it was used under institutional ethics approval for research purposes and has not been approved as a medical device as an integrated system.

NURAS-based telemedicine starts with clinical interviews and information sharing via Microsoft Teams among the patient, an on-site primary care physician at Goto Chuoh Hospital (located in a rural area), and a rheumatologist at Nagasaki University Hospital (located in an urban area). These facilities are geographically separated by approximately 100 km of sea. During the joint assessment, the patient positions the affected joint at the center of the 3 Azure Kinect DK cameras installed at Goto Chuoh Hospital. The cameras

were mounted on a study-specific support structure assembled from commercially available fixtures, fixed at approximately 70 cm above the floor, and arranged in front of and bilaterally around the target joint to capture the affected area from 3 directions and provide a combined 360° field of view around the patient. This configuration captures the joint from multiple angles, generating high-resolution 3D holographic images, including fine skin textures and color tones. These images are projected into the field of view of the specialist wearing the HoloLens 2, creating an MR environment in which the patient's joint appears superimposed in the physician's real-world examination space (Figure 1). This MR-based visualization differs from conventional video telemedicine by providing depth perception and interactive 3D manipulation of holographic joint images. Each telemedicine session was conducted with the patient, the on-site physician, and the remote rheumatologist connected simultaneously via a dedicated internet environment. The remote rheumatologist provided real-time verbal guidance for joint positioning and examination procedures, while the on-site physician performed palpation and assisted with the physical examination under remote supervision.

Setup requirements for each session comprised the camera system, HoloLens 2, a dedicated internet connection, and tablet devices for patient-reported outcome questionnaires. Preparation before each session, including camera positioning and connection checks, required approximately 5 minutes and was performed with the assistance of 1 nurse. 3D image and video data were transmitted in real time through a dedicated internet connection between the 2 hospitals and were used only for live collaborative assessment; these data were not systematically stored as study data, and no session recordings were retained. Data handling was conducted in accordance with institutional privacy protection policies and the ethics approval.

Figure 1. Schematic representation of the Nagasaki University Rheumatoid Arthritis Remote Medicine System (NURAS). The figure illustrates the doctor-to-patient with doctor model showing the integrated telemedicine workflow among the patient, the on-site primary care physician at Goto Chuoh Hospital, and the remote rheumatologist at Nagasaki University Hospital. The figure depicts the mixed reality (MR) setup in which images of the patient's affected joint are captured by 3 Azure Kinect DK cameras and transmitted to the remote rheumatologist via a dedicated internet connection for a 3D joint assessment.



Patients

Outpatients with RA at Goto Chuoh Hospital were enrolled in this 12-month pilot feasibility study if they met the 2010 American College of Rheumatology/European Alliance of Associations for Rheumatology (ACR/EULAR) classification criteria for RA [11], were aged ≥20 years, and provided written informed consent. Potential participants were identified pragmatically by the on-site physician among patients receiving routine care at the hospital; patients considered appropriate for telemedicine consultation and meeting the eligibility criteria were invited to participate. Exclusion criteria were the inability to maintain the required examination position and the inability to input data on the tablet device used for patient-reported outcome questionnaires even with nurse assistance. However, because nurse assistance was available for tablet input during the sessions, prior experience or confidence with digital technology did not affect patient selection. Recruitment was not conducted through a formal consecutive screening log; consequently, the total number of patients screened for eligibility is not available. Between April 2021 and March 2023, 7 patients were approached for participation; 1 patient declined because they preferred to continue care only with the on-site physician, and 6 patients were enrolled. Because this was a pilot feasibility study, no formal sample size calculation was performed; instead, the sample size was determined pragmatically based on feasibility in this clinical setting. All participants continued routine outpatient care at the local

hospital, and telemedicine consultations were incorporated into their routine follow-up visits.

End Points

The primary end point of this study was to evaluate the feasibility of establishing a foundational MR-based telemedicine framework for RA management. Specifically, the feasibility outcomes included the numbers of planned, attempted, completed, failed, and rescheduled telemedicine sessions; documented connection interruptions; setup time; consultation time; technical problems and their resolution; and completion of the planned joint assessments. In addition, patient and on-site physician acceptability were assessed at each study visit (baseline, 6 months, and 12 months) using a 10-point rating scale. The secondary end points were exploratory changes in disease activity and patient-reported outcomes (PROs) at 6 and 12 months after NURAS implementation. We also recorded changes in antirheumatic treatment, corticosteroid use, nonsteroidal anti-inflammatory drug or other analgesic use, additional routine clinic visits, unscheduled visits, and the occurrence of hospitalization during follow-up.

Joint assessment was performed using the 28-joint count throughout the study. During telemedicine consultations, the rheumatologist at Nagasaki University Hospital evaluated swollen joints by freely enlarging and rotating the holographic images, while tender joints were assessed by the on-site physician, who performed palpation. The same on-site physician and the same remote rheumatologist performed all assessments throughout the study period. The on-site physician recorded the joint findings; when interpretations differed between the 2 physicians, the findings were discussed in real time and the final findings were determined by consensus and recorded by the on-site physician. No formal interrater calibration session was conducted before study initiation; however, the same physician pair performed all assessments, and differences were resolved by discussion and consensus. Within this workflow, the MR platform added real-time, multiangle, 3D visualization of joint morphology and skin findings to the on-site physical examination, allowing the remote rheumatologist to participate directly in the assessment of joint swelling and to guide the examination, rather than relying on verbal description or static images alone.

Clinical disease activity was assessed using the Disease Activity Score 28 with C-reactive protein (DAS28-CRP) and the Clinical Disease Activity Index (CDAI). Patients completed PRO questionnaires on tablet devices via Microsoft Forms, with nurse assistance as needed. PRO measures included the Rheumatoid Arthritis Impact of Disease (RAID), Health Assessment Questionnaire Disability Index (HAQ-DI), Functional Assessment of Chronic Illness Therapy–Fatigue (FACIT-F) scale, visual analog scale (VAS) for pain assessment ranging from 0 to 100 mm, and the Kessler 6-item psychological distress scale (K6). PRO data, along with clinical information including medical history, laboratory results, and imaging findings, were shared with the rheumatologist at Nagasaki University Hospital. During the telemedicine sessions, the remote rheumatologist also provided case-specific clinical and educational feedback to the on-site physician, which was documented contemporaneously by the on-site physician in the study records. Acceptability was assessed using a study-specific single-item 10-point numerical rating scale, ranging from 1 (not acceptable at all) to 10 (completely acceptable).

Ethical Considerations

The study was approved by the Nagasaki University Hospital Clinical Research Ethics Committee (approval number 21081605) and conducted in accordance with the Declaration of Helsinki. The study was reported in accordance with the STROBE statement for observational studies [12] and the RATE-XR reporting guideline for the early-phase clinical evaluation of applications using extended reality [13].

Statistical Analysis

Statistical analyses were primarily descriptive because this was a small pilot feasibility study. Continuous variables are presented as medians with IQRs, and categorical variables are summarized as counts and percentages. Given the pilot feasibility design and sample size, clinical outcomes were summarized descriptively without formal hypothesis testing.

Results

Participant Characteristics

Between April 2021 and March 2023, 7 patients were approached for participation; 1 declined, and 6 were enrolled in this 12-month pilot feasibility study. All 6 participants completed the 12-month follow-up. Baseline characteristics are summarized in Table 1.

Table 1. Baseline characteristics of the 6 patients.

Patient	Age (y)	Sex	Disease duration (y)	ACPA[a]	RF[b]	DAS28-CRP[c]	CDAI[d]	PtGA[e] (mm)	HAQ-DI[f]
1	52	Male	3	+	+	3.71	15.5	45	0
2	68	Female	50	+	+	2.60	7.1	31	2.125
3	66	Female	1	–	+	1.48	2.4	19	0.375
4	80	Female	2	+	+	3.61	13.0	50	0.375
5	73	Female	<1	–	+	2.95	11.0	20	0
6	65	Male	<1	–	+	3.0	9.0	71	0.500

[a]ACPA: anticitrullinated protein antibody.

[b]RF: rheumatoid factor.
[c]DAS28-CRP: Disease Activity Score 28 with C-reactive protein.
[d]CDAI: Clinical Disease Activity Index.
[e]PtGA: Patient Global Assessment.
[f]HAQ-DI: Health Assessment Questionnaire Disability Index.

Feasibility of NURAS Telemedicine Sessions

All 18 planned telemedicine sessions were attempted and completed. No sessions failed; 2 sessions were rescheduled for patient-related reasons, and no connection interruptions were documented. All planned joint assessments were completed. Preparation before each session, including camera positioning and connection checks, required approximately 5 minutes with the assistance of 1 nurse. Median consultation time was 37 minutes 45 seconds (IQR 33 minutes 19 seconds-47 minutes 34 seconds) at baseline, 22 minutes 10 seconds (IQR 15 minutes 49 seconds-23 minutes 51 seconds) at 6 months, and 17 minutes 47 seconds (IQR 15 minutes 16 seconds-20 minutes 38 seconds) at 12 months. Patient and on-site physician acceptability were assessed at baseline, 6 months, and 12 months using a 10-point rating scale, and the results are summarized in Table 2.

Table 2. Feasibility outcomes of the Nagasaki University Rheumatoid Arthritis Remote Medicine System telemedicine sessions.

Feasibility outcome	Result
Planned telemedicine sessions, n	18
Attempted telemedicine sessions, n	18
Completed telemedicine sessions, n	18
Failed telemedicine sessions, n	0
Rescheduled telemedicine sessions, n	2
Documented connection interruptions, n	0
Setup time per session	Approximately 5 min, with assistance from 1 nurse
Consultation time, median (IQR)	
Baseline	37 min 45 s (33 min 19 s-47 min 34 s)
6 months	22 min 10 s (15 min 49 s-23 min 51 s)
12 months	17 min 47 s (15 min 16 s-20 min 38 s)
Technical problems	None documented
Completion of planned joint assessments, n/N (%)	18/18 (100)
Patient acceptability score, median (IQR)	
Baseline	10.0 (9.0-10.0)
6 months	10.0 (9.0-10.0)
12 months	10.0 (10.0-10.0)
On-site physician acceptability score, median (IQR)	
Baseline	8.5 (8.0-10.0)
6 months	9.0 (9.0-9.0)
12 months	10.0 (9.0-10.0)

Collaborative Assessment and Educational Feedback

During the telemedicine sessions, the remote rheumatologist and the on-site physician jointly assessed each patient using the 28-joint count. The remote rheumatologist evaluated joint swelling through enlargement and rotation of the holographic images, while the on-site physician performed palpation to assess joint tenderness. When interpretations differed, the findings were discussed in real time and determined by consensus.

In addition to collaborative joint assessment, the remote rheumatologist provided case-specific clinical and educational feedback to the on-site physician during the sessions. Examples of such feedback included interpretation of pain-related symptoms, treatment-related suggestions, vaccination advice when relevant, and consideration of tenosynovitis of a single finger.

Changes in Treatment and Additional Clinical Care

Changes in antirheumatic treatment and additional clinical care during follow-up are summarized in Table 3. Antirheumatic treatment was modified in 5 of the 6 patients during the 12-month follow-up. In addition to the scheduled NURAS visits, routine outpatient follow-up was conducted every 1 to 3 months according to each patient's clinical status, resulting in 2 to 10 visits per patient. Additional unscheduled visits and the occurrence of hospitalization during follow-up were also recorded. Accordingly, the observed clinical improvements cannot be attributed solely to NURAS use.

Table 3. Changes in treatment and additional clinical care during follow-up.

	Antirheumatic treatment	Prednisolone (mg/d)	NSAID[a] or other analgesic use	Additional routine visits, n	Unscheduled visits, n	Hospitalization
Patient 1				3	0	No
Baseline	MTX[b] 16 mg/wk	0	No			
6 months	BAR[c] 4 mg/d and MTX 12 mg/wk	0	No			
12 months	BAR 4 mg/d and MTX 12 mg/wk	0	No			
Patient 2				10	0	No
Baseline	GLM[d] 100 mg/mo	0	No			
6 months	GLM 100 mg/mo and IGR[e] 25 mg/d	0	No			
12 months	GLM 100 mg/mo and IGR 25 mg/d	0	No			
Patient 3				2	0	No
Baseline	MTX 8 mg/wk	0	No			
6 months	MTX 8 mg/wk	0	No			
12 months	MTX 8 mg/wk	0	No			
Patient 4				2	1	Yes[f]
Baseline	BAR 2 mg/d	0	Yes[g]			
6 months	BAR 2 mg/d and IGR[e] 25 mg/d	0	No			
12 months	BAR 2 mg/d and IGR 25 mg/d	5[f]	No			
Patient 5				6	0	No
Baseline	MTX 8 mg/wk and SAR 200 mg/2 wk	7.5	Yes			
6 months	MTX 8 mg/wk, SAR 200 mg/2 wk, and IGR 25 mg/d	0	No			
12 months	SAR[h] 200 mg/2 wk and IGR 25 mg/d	0	Yes[g]			
Patient 6				5	0	No
Baseline	SASP[i] 500 mg/d	0	No			
6 months	MTX 8 mg/wk	0	Yes			
12 months	MTX 8 mg/wk	0	No			

[a]NSAID: nonsteroidal anti-inflammatory drug.
[b]MTX: methotrexate.
[c]BAR: baricitinib.
[d]GLM: golimumab.
[e]IGR: iguratimod.
[f]Patient 4 was hospitalized for a nonrheumatologic condition, and prednisolone 5 mg/d was introduced for that condition rather than for rheumatoid arthritis.
[g]Acetaminophen use, not NSAID.
[h]SAR: sarilumab.
[i]SASP: salazosulfapyridine.

Clinical and PROs

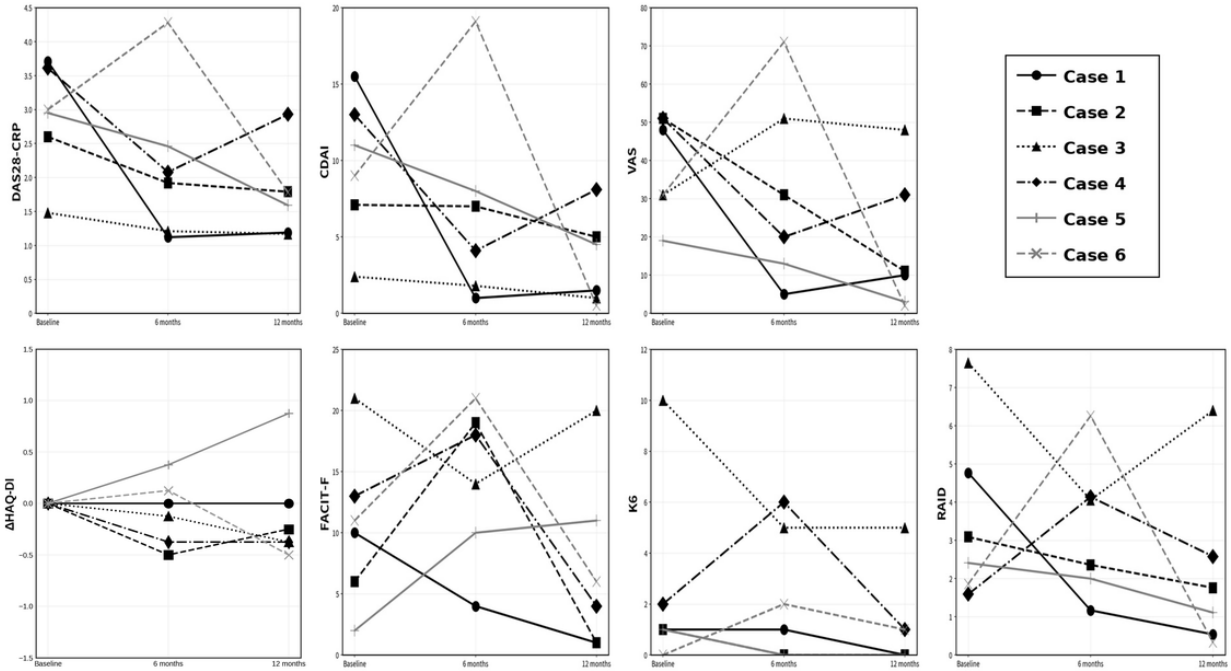
Clinical and PROs over time are summarized in Table 4, and individual trajectories are shown in Figure 2. Median DAS28-CRP decreased from 2.98 (IQR 2.60-3.61) at baseline to 2.00 (IQR 1.21-2.46) at 6 months and 1.69 (IQR 1.19-1.79) at 12 months. Median CDAI decreased from 10.0 (IQR 7.1-13.0) at baseline to 5.55 (IQR 1.8-8.0) at 6 months and 3.0 (IQR 1.0-5.0) at 12 months. Median pain VAS decreased from 39.5 (IQR 31-51) mm at baseline to 25.5 (IQR 13-51) mm at 6 months and 10.5 (IQR 3.0-31.0) mm at 12 months. Other PROs varied across individuals over time. No RA flares requiring an unscheduled visit or treatment escalation were observed during the 12-month follow-up period.

Table 4. Clinical and patient-reported outcomes over time[a].

Outcome	Baseline, median (IQR)	6 months, median (IQR)	12 months, median (IQR)	Change from baseline to 12 months, median (IQR)
DAS28-CRP[b]	2.98 (2.60 to 3.61)	2.00 (1.21 to 2.46)	1.69 (1.19 to 1.79)	–1.02 (–1.36 to –0.68)
CDAI[c]	10.0 (7.1 to 13.0)	5.55 (1.8 to 8.0)	3.0 (1.0 to 5.0)	–5.7 (–8.5 to –2.1)
Pain VAS[d] (mm)	39.5 (31 to 51)	25.5 (13 to 51)	10.5 (3.0 to 31.0)	–24.5 (–38.0 to –16.0)
RAID[e]	2.75 (1.86 to 4.77)	3.21 (2.00 to 4.14)	1.44 (0.54 to 2.58)	–1.32 (–1.53 to –1.25)
FACIT-F[f]	10.5 (6.0 to 13.0)	16.0 (10.0 to 19.0)	5.0 (1.0 to 11.0)	–5.0 (–9.0 to –1.0)
K6[g]	1.0 (1.0 to 2.0)	1.5 (0.0 to 5.0)	0.5 (0.0 to 1.0)	–1.0 (–1.0 to –1.0)
ΔHAQ-DI[h]	0 (0 to 0)	–0.06 (–0.38 to 0.13)	–0.31 (–0.38 to 0.00)	–0.31 (–0.38 to 0.00)

[a]Change denotes the paired within-patient change from baseline to 12 months. Findings are descriptive and exploratory.
[b]DAS28-CRP: Disease Activity Score 28 with C-reactive protein.
[c]CDAI: Clinical Disease Activity Index.
[d]VAS: visual analog scale.
[e]RAID: Rheumatoid Arthritis Impact of Disease.
[f]FACIT-F: Functional Assessment of Chronic Illness Therapy-Fatigue.
[g]K6: Kessler 6-item psychological distress scale.
[h]ΔHAQ-DI: change in Health Assessment Questionnaire Disability Index from baseline.

Figure 2. Individual trajectories of clinical disease activity scores (Disease Activity Score 28 with C-reactive protein [DAS28-CRP] and Clinical Disease Activity Index [CDAI]) and patient-reported outcomes (change in Health Assessment Questionnaire Disability Index [ΔHAQ-DI], Functional Assessment of Chronic Illness Therapy–Fatigue [FACIT-F], Kessler 6-item psychological distress scale [K6], Rheumatoid Arthritis Impact of Disease [RAID], and pain visual analog scale [VAS]) for each patient at baseline, 6 months, and 12 months. The figure illustrates patient-level variability over time in this small feasibility cohort.



Discussion

Principal Findings

In this 12-month pilot feasibility study, the NURAS MR telemedicine platform was technically and operationally feasible for specialist-supported RA care in a remote island setting. All 18 planned telemedicine sessions were attempted and completed, no connection interruptions were documented, all planned joint assessments were completed, and setup required approximately 5 minutes per session with the assistance of 1 nurse. Patient and on-site physician acceptability scores were also favorable across the study visits. Together, these findings suggest that the NURAS platform can support collaborative joint assessment between an on-site physician and a remote rheumatologist in a geographically isolated clinical setting.

Clinical disease activity measures improved over the study period, with decreases in median DAS28-CRP, CDAI, and pain VAS. However, these findings should be interpreted cautiously. Antirheumatic treatment was modified in 5 of the 6 patients during follow-up, and additional routine outpatient care was provided according to each patient's clinical status.

Accordingly, the observed clinical improvements cannot be attributed solely to NURAS use.

Consultation time was shorter at 12 months than at baseline. This may partly reflect increasing familiarity with the system and workflow, but it may also reflect differences between initial and follow-up visits, as baseline consultations required introductory communication and initial sharing of patient information, whereas follow-up visits were conducted after both physicians had become more familiar with the patient's clinical background.

Comparison With Prior Work

Telemedicine has increasingly been applied in rheumatology, particularly for follow-up care, disease monitoring, and improving access to specialist consultation in underserved areas [14-18]. Previous studies have suggested that telemedicine may help reduce travel burden, especially for people living far from specialist centers [15-19]. In addition, the 2022 EULAR points to consider for remote care in rheumatic and musculoskeletal diseases support the selective use of remote care while emphasizing the importance of appropriate clinical context and awareness of its limitations [19].

However, most previously reported telemedicine models in rheumatology have relied on conventional 2D video communication, which may be sufficient for history taking, medication review, and some aspects of follow-up care but remains limited for detailed musculoskeletal examination, particularly when direct visualization of joint morphology and swelling is important [15-19]. In this respect, the present study adds to the literature by demonstrating the feasibility of a telemedicine workflow designed specifically for collaborative joint assessment using real-time 3D visualization in a remote island setting.

MR-Based Telemedicine and the Doctor to Patient With Doctor Model

A key feature of NURAS is that it extends beyond conventional video-based telemedicine by enabling the remote rheumatologist to examine holographic 3D images of the affected joint from multiple angles in real time. This MR-based approach may be particularly relevant in rheumatology, where subtle visual findings, such as swelling, contour changes, and skin features around joints, may contribute to clinical assessment. Rather than replacing the local physical examination, the system was designed to augment it by allowing the remote specialist to participate more directly in the evaluation process.

This functionality is closely linked to the doctor to patient with doctor (D to P with D) model. In this workflow, the on-site physician remains physically present with the patient and performs palpation and other direct examination maneuvers, while the remote rheumatologist contributes specialist interpretation and real-time guidance. Such a model may be especially useful in settings where rheumatologists are unavailable locally but primary care physicians are able to support longitudinal care. In the present study, this approach also enabled case-specific educational and clinical feedback during routine consultations, suggesting that the platform may have value not only for patient care but also for primary care physicians in remote settings.

Clinical Implications

The COVID-19 pandemic accelerated the global uptake of telemedicine [20], and telemedicine use in chronic disease care in Japan has also been reported in other specialties [21]. In parallel, vulnerable patients with rheumatic disease experienced substantial disruption in care during the pandemic [22]. Although telemedicine is often perceived as convenient, concerns regarding the reliability and trustworthiness of remote clinical assessment remain [23]. In this context, the present findings suggest that MR-based telemedicine may represent a practical option for extending rheumatology expertise to remote island settings where regular in-person specialist access is difficult. In such environments, a collaborative model that combines on-site primary care physician involvement with remote rheumatologist input may help maintain continuity of care while reducing the burden associated with travel to mainland hospitals. This may be particularly relevant for older patients and for communities in which transportation barriers and specialist shortages coexist.

In addition, the D to P with D model may be useful not only for follow-up of established RA but also for supporting primary care physicians in remote settings in the interpretation of joint findings and management decisions during ongoing care. Although the present study was not designed to evaluate educational outcomes formally, the real-time exchange between the remote specialist and the on-site physician suggests a potential secondary benefit of this approach in strengthening local clinical capacity.

Limitations

This study has several limitations. First, it was a small single-center pilot study involving only 6 patients, and participants were identified pragmatically by the on-site physician rather than through a formal consecutive screening process. Therefore, selection bias cannot be excluded, and the generalizability of the findings is limited. Second, antirheumatic treatment was modified in 5 of the 6 patients during follow-up, and routine outpatient management continued in parallel with the telemedicine program. Accordingly, the observed clinical improvements cannot be attributed solely to NURAS use. Third, this study was designed to assess feasibility rather than diagnostic performance. No control group or in-person reference examination was included; therefore, diagnostic agreement and interobserver agreement for MR-assisted remote joint assessment were not evaluated. Fourth, some technical performance measures, such as bandwidth, latency, and detailed implementation costs, were not systematically recorded. Finally, although patient and on-site physician acceptability were assessed using a 10-point rating scale, more comprehensive evaluation of usability and acceptability, including qualitative feedback and broader implementation outcomes, was beyond the scope of this pilot study.

Conclusions

We developed NURAS, an MR-based specialist telemedicine system for RA, and demonstrated its technical and operational feasibility over a 12-month pilot study in a remote island setting in Japan. All planned telemedicine sessions and joint assessments were completed with minimal setup support, and the platform enabled real-time collaborative assessment and educational feedback between a remote rheumatologist and an on-site primary care physician within a D to P with D model. Changes in disease activity indices and PROs were descriptive and exploratory and cannot be attributed solely to NURAS use. Beyond this single setting, MR-based collaborative telemedicine may offer a practical approach to mitigating specialist shortages in aging, geographically isolated communities. Larger controlled studies incorporating formal diagnostic agreement analyses, more comprehensive acceptability assessment, and systematic technical performance and cost evaluation are warranted to establish the clinical utility and generalizability of this approach.

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Generative AI Use

The figures in this manuscript were developed with the assistance of a generative AI tool (Genspark AI; Genspark Inc) for visual design support. All figures were reviewed and verified by the authors for accuracy and integrity.

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Data Availability

The datasets generated and analyzed during this study are not publicly available because of patient privacy considerations and restrictions imposed by the ethics approval granted by the Nagasaki University Hospital Clinical Research Ethics Committee.

Authors' Contributions

Conceptualization: FN, SK, AK
Data curation: FN, SK
Formal analysis: FN, SK
Funding acquisition: FN, SK
Investigation: FN, SK
Project administration: FT, TM, YN
Supervision: AK
Writing—original draft: FN, SK
Writing—review and editing: AK

Conflicts of Interest

None declared.

Checklist 1

STROBE checklist.
[DOCX File (Microsoft Word File), 32 KB-Checklist 1]

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Abbreviations

ACR: American College of Rheumatology
CDAI: Clinical Disease Activity Index
D to P with D: doctor to patient with doctor
DAS28-CRP: Disease Activity Score 28 with C-reactive protein
EULAR: European Alliance of Associations for Rheumatology

FACIT-F: Functional Assessment of Chronic Illness Therapy–Fatigue
HAQ-DI: Health Assessment Questionnaire Disability Index
K6: Kessler 6-item psychological distress scale
MR: mixed reality
NURAS: Nagasaki University Rheumatoid Arthritis Remote Medicine System
PRO: patient-reported outcome
RA: rheumatoid arthritis
RAID: Rheumatoid Arthritis Impact of Disease
RATE-XR: reporting guidelines for the early-phase clinical evaluation of applications using extended reality
STROBE: Strengthening the Reporting of Observational Studies in Epidemiology
VAS: visual analog scale

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