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Research Article

Assessing the Acceptability and Cost Consequences of Implementing Elastomeric Devices for Administration of Intravenous Antibiotics at Home: A Mixed-Methods Evaluation

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Introduction: Pressure on NHS services necessitates implementation of innovative solutions to provide appropriate and cost-effective care. This study evaluates the acceptability, feasibility and cost-effectiveness of implementing home medication preparation and elastomeric device filling for the administration of intravenous antibiotics from the UK NHS perspective, focusing on regional implementation.
Method: A mixed-methods design included a targeted literature review, routine patient data, questionnaires tailored to participant groups (community clinicians, remote monitoring clinicians, consultants and patients), and interviews with both patients and clinicians. A total of 24 patients were recruited in Hertfordshire between June and September 2024. Piperacillin with tazobactam (Tazocin) or flucloxacillin was prepared and administered at the patients' home by trained nurses and delivered by the elastomeric pump over 24 h. Economic evaluations compared this home pathway against three alternative pathways using preprepared medications: hospital inpatient care (hospital), outpatient clinic visits (outpatient) and a hypothetical home visit (hypothetical).
Findings: Survey responses were collected from 14 clinicians, five patients and two carers, and interviews were conducted with six clinicians, one patient, and one carer. Patients and carers were satisfied with the home pathway because of the perceived safety and freedom it gave them. Clinicians expressed positive feedback and considered it feasible, provided there was sufficient support for themselves and patients. Concerns were raised about design, ease of filling the elastomeric device and monitoring flow of medication. Other issues related to the type of cannula and concentration of the vials, improvements for care packages, communication and training. The home pathway demonstrated cost savings, with a per-patient cost of £2507.54, significantly lower than the hospital pathway (£6122.70), outpatient pathway (£3603.76), and hypothetical pathway (£4373.37).
Conclusion: Overall, clinicians, patients and carers were pleased with the home pathway, with the additional benefit that the home pathway could be economically and realistically feasible to help the NHS meet the growing demand for high-quality care.

Keywords: cost evaluation; elastomeric devices; service evaluation

Summary

- The first service and economic evaluation of the elastomeric device where medication is prepared and delivered at home.
- The first evaluation to include perspectives from clinicians, as well as patients.
- Identifies a cost consequence analysis for alternative care pathways for intravenous antibiotics.
- Potential to expand the range of medication that can be prepared on-site and delivered by elastomeric devices and the contexts in which they could be used.
- Limited in generalisability, as this study focuses on a region; however, use of a health system perspective for analysis makes the study results relevant to other regions in the UK NHS settings.

1. Introduction

Outpatient parenteral antimicrobial therapy (OPAT) has been in use for over 50 years and continues to expand as an alternative to hospitalisation. Its growth is driven by economic pressures, advancements in medical devices and technology, and the goal of improving patient quality of life. In the United Kingdom, OPAT models include nurse home visits, outpatient visits, and self-administration using elastomeric devices.

Elastomeric pumps are disposable, flexible containers that deliver medication through a narrow bore tube under high pressure and are primed to deliver medication over a specified time ranging from 30 min to 24 h. Despite their simplicity, these devices have limitations. Administration accuracy may fluctuate by up to 50% due to factors such as temperature, medication viscosity, the pump's height during use and storage conditions [1]. However, administering antibiotics intravenously (IV) over 24 h can enhance clinical efficacy, reduce the risk of antimicrobial resistance and benefit patients' mental health, although it also carries a risk of overmedication [1].

While limited research has explored clinician perspectives on elastomeric devices, patient satisfaction tends to be high. In a study comparing OPAT models, all patients reported being satisfied with their care, but those using 24-h self-administered elastomeric pumps were the most pleased [2]. Patients valued early discharge and independence but expressed concerns about potential infection risks and device reliability. They also felt reassured by clinicians' competence and care, though patients who received nurse visits believed they should have been better informed about the care pathway [2].

Recent studies highlight that OPAT is more cost-effective than hospitalization, with costs varying based on the model (outpatient clinic, nurse home visits and self-administered), medication and condition treated [3–6]. For instance, treating skin and soft tissue infections costs £2476 in a hospital setting, compared to £831 for home visits and £802 for outpatient care [4].

In the United Kingdom, NHS trusts are keen to reduce the need for inpatient hospital care and improve patient satisfaction while saving money. Hertfordshire Community NHS Trust (HCT) is one such trust that recently trialled the B. Braun EasyPump II elastomeric device, supported by the Doccla remote monitoring system. B. Braun is a company with a long history of developing medical devices, and it is one of many developing elastomeric devices that can be filled at home, rather than being preprepared in a pharmacy. The B. Braun EasyPump II is soft-shelled rather than hard-shelled, which may have advantages for patients and healthcare professionals. Doccla is a company founded to provide virtual wards for the NHS and supports over 10,000 patients who are admitted to Hospital at Home.

Patients on the elastomeric device at home are monitored remotely, which allows patient data to be manually or electronically transmitted three times daily to a central hub for review by clinicians, while the community administers IV antibiotics during daily home visits. The elastomeric device and remote monitoring are referred to as the 'home pathway'. This evaluation was designed to understand patient and clinician acceptability and its feasibility and to assess the financial impact of this pathway compared to a hospital pathway, an outpatient pathway, and a hypothetical pathway.

The evaluation questions were:

1. How acceptable is the home pathway to patients and clinicians?
2. How feasible is the use of the home pathway, with one nurse visit per day?
3. What is the economic impact of using the home pathway?

2. Methods

2.1. Design. A mixed-methods convergent parallel design [7] was selected to conduct the service and economic evaluation of the home pathway. This design was chosen for the collection of numeric data and in-depth qualitative data and to allow triangulation across all data sets. The independent evaluation was informed by a pragmatic realist approach to understand how the device impacts clinicians and patients in a real-world setting [8]. The methodology was designed in collaboration with the stakeholder group, which included senior clinicians from Hertfordshire Community Trust (HCT) and East and North Hertfordshire NHS Trust (ENHT), members of Health Innovate East (HIE), and a member of Healthwatch Hertfordshire. Health Innovation East provided an incentive of £10 for every completed survey to the Hertfordshire Community NHS Trust Charitable Fund, chosen by the Healthwatch team member.

2.2. Evaluation Measures. Questionnaires and interview guides were designed for each participant group (community clinicians, remote monitor clinicians, patients and carers) to address the research questions. Clinician

acceptability was measured by the perceptions of workload and responsibility. Feasibility was assessed by measurement of the practicalities of using the home pathway in the home setting. Practicalities may also be integrated with patient acceptability. For example, the wearability of the device and how it impacts functional activities such as taking a shower.

Other questions asked about the impact on caring and work responsibilities, and while a validated quality of life instrument was not used, questions were developed to assess key functional and social aspects relevant to the study context. Questions were included to gather data on the time and distance travelled by community nurses and the time remote monitoring clinicians took to monitor patients to provide impact on the costs involved in the home pathway. Questionnaires were anonymous unless respondents volunteered to be interviewed and gave contact details. The questionnaires were tested by the patient representative, clinicians and members of the public not included in the study. Consultants were invited to interview only. In addition, data regularly collected for patients further informed the economic evaluation to assess the costs of the home pathway against three other pathways:

- Hospital inpatient care: Patients remain in hospital for the duration of IV treatment.
- Outpatient clinic attendance: This pathway is typically prescribed following a patient's discharge from hospital. Patients attend outpatient services where a clinician sets up the elastomeric device and administers their antibiotics. Medication administration occurs daily at the outpatient clinic until the course of antibiotics is completed. In this pathway, patients are not remotely monitored; in any case of an adverse event, they are advised to use Accident & Emergency (A&E) services.
- Hypothetical pathway: Patients would be discharged to community care and receive multiple home visits per day to administer prefilled standard IV infusion and monitor their health.

2.3. Setting. Hospital at Home (home pathway) was introduced by HCT, providing community-based care for 1.2 million people living in and around Hertfordshire, and currently has 204 virtual beds to eliminate or reduce the need for hospital admissions. The evaluation of the elastomeric device was conducted between 1 June 2024 and 30 September 2024, and clinicians were funded by Hospital at Home. Standard operating procedure was written by the Hertfordshire Trust for the use of the elastomeric device in patients' homes, and aseptic technique policy was always practised.

2.4. Recruitment. All clinicians (doctors, registered nurses and consultants) in the Hospital at Home team, who had been trained to use the elastomeric device ($n = 39$) or remote monitoring ($n = 8$), were invited to complete the questionnaires. Patients ($n = 24$), 18 years and over, meeting the inclusion criteria (see Supporting Information (available here)) who had been referred from ENHT for IV administration of piperacillin with tazobactam (Tazocin) or flucloxacillin via the elastomeric device at home were included in both the service and economic evaluation. These antibiotics are stable for use in continuous infusion [9, 10].

2.5. Data Collection. Questionnaires for each group of participants were created on the JISC platform, which is supported by UEA for use by researchers. The participant information sheet was embedded into the questionnaires for each group, and participants were prompted to read this first. The questionnaire link was sent to patients via mobile phone at the end of their treatment, and clinicians received the questionnaire via their work email address. All participants received a reminder 2 weeks later. Due to a low response from patients and their carers, members of the remote monitoring teams telephoned to help them complete the questionnaire.

Patients, carers and clinicians who volunteered for interview were contacted by the lead author (SHW) to arrange a mutually convenient date and time. Before the interview, participants were asked to complete an informed consent form and, at the time of the interview, asked for verbal confirmation. Participants could choose to have the interview online using Microsoft Teams or by telephone. Interviews via Microsoft Teams were recorded and transcribed at the time of interview. Telephone interviews were recorded by a digital recording device and transcribed by the research team assistant. Participants were asked if they would like to read their transcript before analyses. Transcripts were anonymised before coding and analysis.

Cost data were gathered from NHS reference costs, literature reviews and surveys with clinicians. These costs included hospital bed occupancy, nursing time, drug administration, travel, consumables and any setup or operational expenses associated with each pathway.

2.6. Data Analysis. All questionnaires were analysed descriptively, and open-ended responses were collated into tables. Data on community clinician travel and visit times were entered into the economic model.

Interview transcripts were anonymised, and participants were coded as Patient, Carer, Consultant, RM (remote monitor clinician), or CC (community clinician) and given an identifying number. All anonymised interview transcriptions were uploaded to NVIVO 14, specialist software for qualitative data analysis. Transcripts were coded using thematic analysis [11] to extract common themes around experiences expressed by patients, carers and clinicians. Themes were generated inductively and compared iteratively across the transcripts. Coding was undertaken by the lead researcher and author, SHW and SK completed verification of the codes, with any discrepancies being discussed to reach agreement. Themes were structured to answer the research questions.

A cost-consequence analysis (CCA) was conducted to compare the economic impact of the four pathways (home, hospital, outpatient and hypothetical) for administering IV

antibiotics [12]. The analysis was conducted from the perspective of the NHS and Personal Social Services (PSS), focusing on direct healthcare costs. Outcomes for analysis were length of inpatient stay (for discharged patients), clinician time, admission avoidance (new admissions and readmissions) and financial cost/savings, using different scenarios: (1) Benefits were projected over 1 and 10 years, considering differing assumptions of increased capacity (10%, 20% and 30%). The discounting rate of 3.5% was applied based on the National Institute for Health and Care Excellence (NICE) recommendation [13]. A list of key assumptions made for the cost-consequences analysis and justification or sources for each assumption are provided in Supporting Information (available here).

Healthcare utilisation data were obtained by assigning utilisation to each individual, and the units of utilisation have been presented in the assumption section and result section of the report. The cost inputs used in the CCA are inflated to 2024 UK pounds and provided in Supporting Information (available here).

2.7. PPI. A member of Healthwatch Hertfordshire joined the stakeholders at the inaugural meeting in November 2023. Research questions, measures and outcomes were designed openly and collaboratively to fully capture the qualitative and quantitative data needed for the evaluation of the elastomeric programme and to assess participant burden for completing the questionnaires. The PPI member was engaged in review of the report and is an author on this publication.

2.8. Ethics. Ethical approval for the evaluation was given by the University of East Anglia (UEA) Faculty of Medicine committee (ETH2324-1819) on 21 March 2024. The evaluation also required approval from the Research Governance Office at Hertfordshire Community Trust, which was given on 21 May 2024. Full NHS ethical approval is not required for service evaluations, where patients are recruited through NHS services.

3. Findings

The age distribution of patients shows that eight were between 60 and 69 years (33.33%), seven were between 70 and 79 years (29.17%), six were between 80 and 89 years (25%), two were between 50 and 59 years (8.33%), and one was between 40 and 49 years (4.1%).

The most common speciality for referral was General Medicine, accounting for 29.17% of the patients. Acute Internal Medicine followed closely at 25%. Respiratory Medicine had a notable share of 16.67%, with Geriatric Medicine at 12.50%. Other specialities included Endocrinology, Gynaecology, Trauma & Orthopaedics and ENT, each contributing 4.17% to the total patient cohort.

Of the 24 patients, seven who were referred to the home pathway had cellulitis (29.17%), four patients had *Pseudomonas* in sputum (16.67%), two patients had pneumonia (8.33%), and one (4.17%) had bronchiectasis with tuberculosis, *Pseudomonas* in wounds, infective discitis, community-acquired pneumonia, tubo-ovarian abscess, osteomyelitis, infective endocarditis, and *Pseudomonas* in urine. The antibiotics, flucloxacillin and piperacillin with tazobactam, were equally prescribed, each used in 50% of the cases, and most patients received antibiotics for 7 days, Table 1.

Most patients ($n = 22$) had positive outcomes, and two patients were readmitted to hospital, Table 2.

Community clinicians generally completed a home visit within 60 min; however, extended times varied from 75 to 110 min, Table 3.

On most visits, it took 30 min to fill the IV (66.67%); however, some visits took longer: 45 min (8.33%) and 60 min (25%).

3.1. Questionnaire and Interviews. Completed questionnaires were received from 14 clinicians (community clinicians = 9, remote monitoring clinicians = 5), of which one was male. Five patients and two carers, aged between 43 and 85 years (male = 4; female = 3), completed questionnaires. The survey response rate was 29% for patients and carers, 62% for remote monitoring clinicians, and 23% for community clinicians. Survey responses can be found in the Supporting Information (available here).

Most of the clinicians (community and remote monitoring) had between 5 and 26 years' clinical experience, and most were at band 7 level. Seven (77%) of community clinicians had used elastomeric devices prior to the evaluation, and all remote monitoring clinicians ($n = 5$) had less than 3 years' experience of monitoring patients remotely.

Of the nine clinicians that volunteered for interview, five gave interviews (community clinicians = 2, remote monitoring clinicians = 3). Of the four consultants invited for interview, one participated. Of the three patients and carers that volunteered for interview—one patient and one carer participated.

Findings from the questionnaires, interviews and data collection were synthesised for the evaluation questions and presented as: (1) patient and clinician acceptability; (2) feasibility of the pathway; and (3) economic impact of the pathway.

3.2. Patient and Clinician Acceptability of Home Pathway. Patients and carers who responded to the survey perceived the ability of community clinicians to give effective care and the care given by community clinicians as excellent ($n = 5$, 71%) or good ($n = 2$, 29%). Furthermore, all patients and carers felt comfortable asking community clinicians questions about their care and felt the answers they received were very good. All patients and carers felt comfortable contacting the remote hub outside of routine visits; however, six rated the responses received from the remote hub as good (43%) and one as fair (14%). A survey respondent stated:

> '*. . .the care I received was excellent and if I had concerns would ask the team, easy to speak to and always found me the answer and on time*' (Patient).

Table 1: Days on antibiotics.

Actual duration (days)	Number of patients	Percentage (%)
7	9	37.50
5	4	16.67
4	4	16.67
30	2	8.33
6	2	8.33
1	2	8.33
Total	**24**	**100**

Table 2: Outcomes of treatment.

Failure of treatment	Number of patients	Percentage (%)
Completed and recovered	18	75
Switch to oral antibiotics	4	16.67
Admission to hospital	2	8.33
Total	**24**	**100**

Note: One patient included in the completed and recovered section, died post treatment for an unrelated health issue.

Table 3: Time taken by community clinicians for home visits.

Time for visit (minutes)	Number of patients	Percentage (%)
60	17	70.83
75	1	4.17
90	2	8.33
100	3	12.50
110	1	4.17
Total	**24**	**100**

Overall, patients and carers surveyed reported that they were satisfied with the treatment they received at home. All remote monitoring clinicians felt that regular monitoring had improved patient satisfaction. They also commented that the elastomeric device had the advantages of giving patients greater freedom whilst being treated, which may be more important for younger people, reduced the number of clinician visits, and reduced hospitalisation. Patients and carers were unanimous that being treated at home was much better than being in hospital, as told by the carer during the interview:

> *'For him, much, much better. Because hospitals, I mean it's just you pick up all sorts of things that you don't really want to pick up in hospital and you can't sleep. The food's all right. Yeah, it's the whole package is not good in hospital if you can possibly do it at home'* (Carer).

The interviewed patient, who was in hospital for 2 weeks and required a prolonged course of antibiotics, of which 30 days were administered IV at home, gave a similar account.

> '*. . .like it will get suppressed and my immune system was very low, and I was susceptible to any infection in the* hospital. *So, I was happy that I could have that option to come home and still have the same treatment'*(Patient).

All patients and carers surveyed thought their ability to continue with caring responsibilities during treatment was helpful. Four patients and carers felt their overall quality of life was excellent (57%) and three as good (43%), and all stated they would use the home pathway again if the need arose, because:

> *'I was very impressed, first time using the service. Easy to use service and gave me confidence in the service'* (Patient).

Four remote monitoring clinicians were comfortable (80%), and one was neutral (20%) about their responsibility to monitor patients on the home pathway. Seven community clinicians were comfortable (77%), and two were neutral (22%) about their responsibility to deliver patient care.

Only two (40%) of remote clinicians stated they were comfortable, and three (60%) were neutral about the number of patients they were assigned to monitor. They unanimously agreed that remote monitoring had improved collaboration between their team and the community clinicians. However, only three (33%) community clinicians felt the use of the home pathway had improved communication and co-ordination with the wider healthcare team, while six (67%) felt there was no change.

3.3. Feasibility of the Pathway. To assess the feasibility of the home pathway, we asked questions on clinician training, information and communication, advantages and disadvantages, functional activities, delivery of care by elastomeric device, delivery of care by remote monitor, safety concerns and potential improvements to the care pathway.

3.3.1. Training. On the survey, eight community clinicians (89%) reported receiving training for using the elastomeric device before the evaluation, and one clinician (11%) had not. Overall, seven (78%) were satisfied, one (11%) was neutral, and one (11%) was dissatisfied with the training they had received. They thought the training was informative, but several commented that it was given too early, or it was rushed. Three (60%) remote monitoring clinicians were satisfied and two (40%) were neutral about the training they received for using monitoring equipment. This result may reflect the variations in training that were reported during the interviews. Some clinicians (community and remote monitoring) received one day of training on monitoring equipment, while others received none.

3.3.2. Information and Communication. All surveyed patients and carers were pleased with the initial setup of the elastomeric device, and most patients and carers (86%) thought the connection to the remote monitoring was generally good, and one rated it as fair (14%).

Only two remote monitoring clinicians (40%) felt that patients were adequately informed and trained to use monitoring equipment, while three (60%) believed the training could be improved. Similarly, community clinicians were divided on whether patients were trained to maintain

the elastomeric device, with six (67%) expressing satisfaction and three (33%) either neutral or dissatisfied. Seven community clinicians reported needing to educate patients during at least half of the visits, while only two indicated that infrequent education was required.

Despite the existence of standard operating procedures and patient leaflets developed by Hospital at Home, interviews with remote monitoring and community clinicians revealed patients were not always fully informed about the home pathway before providing consent. However, the patient and carer who were interviewed felt they had been well-prepared and informed about the home pathway. They noted that other patients might feel overwhelmed and struggle to comprehend the details of the care pathway.

Furthermore, better information and communication are necessary to ensure that other clinicians who refer patients into the home pathway are properly trained to provide detailed information to patients before they consent. The healthcare team must have all the necessary details and equipment to manage patients in the community, as emphasised by clinicians during interviews:

> *'But I think the main thing is patients don't always know they're going to be swapped over to once-a-day visit. So, they're expecting somebody to come four times a day. So, they're a little bit shocked'* (CC1).

> *'However, sometimes there might be delay from the hospital not supplying the kits, or the patient is still in the hospital. Meanwhile we would be expecting the kit number so that it can be activated from our end. We know that this is a communication problem'* (RM3).

3.3.3. Advantages and Disadvantages. Clinicians expressed concerns that some patients might be disadvantaged using remote monitoring, particularly if they had poor internet connections or mobile phone signals. Additionally, mental health issues and dexterity limitations could affect a patient's ability to use the home pathway, and there was a possibility that patients might forget their password. While clinicians reported that all their patients had the mental capacity to manage their care, there were concerns that some patients might struggle without adequate support from carers. Clinicians noted several advantages and disadvantages of using the home pathway:

- Easy to set up.
- The patient and family are safe from the stress of being hospitalised.
- Patients were not left waiting for several nurse visits per day. This meant that where possible, patients could go out following the visit.
- Reduced admission time.
- Ability to recover at home.
- It promotes effective treatment.
- The patient recovered from their infection and was discharged within the planned time.
- Sometimes, the pipe kinks, and this affects the pump.
- Sometimes the pump runs faster before 24 h.

It seems that the clinician's inability to provide specific time slots for visits and the occasional issue of patients not being at home have created challenges in providing consistent care. In contrast, the patient's decision to join the home pathway appears to have been influenced by the convenience of having home visits as part of the care plan:

> [In hospital] *'I was on a 3 times IV fluid, once in the morning, once in the afternoon and once in the evening. On discharge they wanted me to continue the IV for 3 weeks at home, but the district nurse was only able to visit once or twice a day, so it won't cover the three times. I Yes, that was the reason for the introduction of the pump that the pump can take me through the day'* (Patient).

Disadvantages included that it is a single-use item, the weight and shape of the elastomeric pump, lack of monitoring the flow of medication and preparation of the medication for patients requiring large doses:

> *'So, when you have 16 vials to do it. That's 60 milligrams of fluid that you've got to mix up and you do get a lot of RSI in your thumb by the end of the week of doing every single day. You can feel it in your hands. It's, it's quite a lot pressure that you have to use'* (CC5).

3.3.4. Functional Activities. Five (71%) surveyed patients and carers were satisfied, and one was neutral (29%) with their ability to continue to work. These responses were clarified during interviews, as the carer no longer worked and the patient was too unwell to work during treatment.

Most patients and carers were either very satisfied or satisfied with the carrying out of daily activities, such as personal hygiene and sleeping, while wearing the device. Similarly, they found the device discrete and comfortable and maintained a level of independence.

However, during interviews, CC1 and CC5 agreed that they tried to help patients by removing the device to allow them to shower while they were mixing the medication to overcome problems when wearing the device:

> *'Even though they've got a little bum bag. They* [patients] *do still find it quite heavy to carry it around with them and a little bit cumbersome when they're trying to shower. They do complain about being able to shower, potentially because of where it's because it's where the line is positioned. It's not so bad if you've got a carer or a loved one, but if you're on your own and you've got to try and feed it and get your night dress off and make sure you're not knocking your cannula'* (CC5).

3.3.5. Administration With Elastomeric Device. Community clinicians who completed the survey reported patients expressed few concerns about the elastomeric device during the evaluation, and none were detailed in the survey. Six

(66%) of community clinicians felt the device was easy for patients to use, and three (33%) were neutral. Seven community clinicians were confident in patients' ability to use the device, while two (22%) were less confident. Overall, community clinicians felt that elastomeric devices improved patient treatment, and there were few incidences of adverse events reported, which included vascular device-related line infection, line migration/accidental removal, line removal, but a tissue line and inflammation around the cannula entry site.

Medication was generally fully administered at most visits (89%). Similar results were reported for over-administration of medication (88%), but no patient required a top-up dose due to residual medication in the pump.

Seven (78%) community clinicians surveyed reported no drug-related adverse symptoms, and two (22%) reported some in around half of their visits. One community clinician reported that patients required readmission to hospital in less than half of their visits.

Seven patients and carers surveyed stated they rarely had any problems, such as the cannula or tube coming out, or with the flow of the antibiotic or any infections related to the home pathway; however, the patient interviewed described some of the problems experienced:

> *'It was ok, it was safe. It was fine. I think the only part that was a bit difficult was that, having it for a long time, I believe, instead of using the cannula it would have been better if I had a line like what do I call it?* [midline]. *Yes, sometimes I'd have to take it off. There was a patch you could take it off and then put it back in. Sometimes I had help from my wife* [district nurse] *but other times I could do it on my own. Getting into the shower, having to lift your hand a bit, you know, just to make sure everything is well and then coming back to set it up again'* (Patient).

During interviews, clinicians also noted problems with cannulas and echoed the benefit of using different lines for patients who were on IV for a week or more. Community clinicians found that patients correctly identified problems with the home pathway. Community clinicians were mixed in how they rated four of the characteristics of using the elastomeric device—filling, use, emptiness of balloon and flow of fluid—from very easy to very difficult, while priming and handling the device were rated as easy, Table 4.

On the survey, all community clinicians reported that delivery of care was improved with the use of the home pathway.

In general, there were no issues with the availability of medication, but occasionally community clinicians had to wait for delivery from the pharmacy, as no medication had been sent from the hospital when the patient was discharged to Hospital at Home. Similarly, two (22%) had delays with delivery of the elastomeric device, and seven (78%) did not. Community clinicians stated during interviews that they tried to maintain a stock of elastomeric devices and medication to ensure there are no delays in treatment:

> *'Again, we keep a supply at each base, but sometimes that's limited so that we say if we've got somebody on 16 vials of Flucloxacillin, that might be our entire stock. So that's only one day'* (CC5).

Table 4: Community clinicians' ratings for the use of the elastomeric device.

Ease of	Very easy	Easy	Neutral	Difficult	Very difficult
Filling	2	1	2	3	1
Use	5	3	1	0	0
Priming	5	4	0	0	0
Handling	4	5	0	0	0
Emptiness	3	5	0	1	0
Fluid flow	3	3	0	2	1

Hospital at Home pharmacy is very quick to deliver medications, thus easing the risk of running out of supplies.

3.3.6. Delivery of Care With Remote Monitoring. Currently, there is a combination of manual and automatic readings being sent through remote monitors, but trials are in progress for fully automated readings.

On the survey patients and carers rated their communication with the remote monitoring hub highly, with four patients (67%) describing it as excellent and two (33%) as good. Similarly, when reporting concerns to the hub, four patients (57%) rated the experience as excellent, while three (43%) rated it as good.

From the perspective of remote monitoring clinicians surveyed, all reported an improvement in their ability to respond to patient concerns, adverse events, or device malfunctions. This enhanced responsiveness allowed clinicians to document and escalate issues more effectively as needed. However, opinions on the effectiveness of remote monitoring in detecting changes in patient conditions were mixed. Two clinicians (40%) believed the system was effective in this regard, while three (60%) were neutral. In interviews, clinicians noted that while monitoring equipment was easy to use, they observed that patients might face dexterity difficulties.

One remote monitoring clinician noted that while monitoring equipment generally worked well, there were technical or logistic challenges, but these were infrequent and did not significantly impact patient care. However, a surveyed remote monitoring clinician noted that the equipment tended to be inaccurate on occasions:

> *'Respiration monitoring is not accurate and can give wide range of figures from 0 to 500 respirations per minute'* (RM5).

All remote monitoring clinicians agreed that monitoring equipment was effective in supporting the home pathway and believed it enhanced the patient experience, likely due to the follow-up calls:

> *'I was supposed to like 10:00 AM because, I'll get a call like 10:05. Or the second one is at 4:00. Sometimes I'll get, like maybe 10 minutes past. I'm like, I just called to just check on if you've been you've done your OBS* [observations] *and*

it's all that helps with that having have someone calling and just to check up on you and that that was really very helpful' (Patient interview).

These follow-up calls from the remote monitoring hub also contribute to enhancing patient safety (see safety aspects below). Four (80%) remote monitoring clinicians surveyed found them effective, while one (20%) remained neutral in facilitating patient contact with the healthcare team. Views were mixed on whether additional support for patients was necessary beyond daily visits: three (60%) felt it was needed, while two (40%) remained neutral. Similarly, opinions on patients' ability to use monitoring equipment were divided: three (60%) considered it manageable, while two (40%) were neutral. This divide reflects the clinicians' experiences, as three (60%) believed patients found the system difficult, while two (40%) did not. A community clinician reported additional support was available for patients who experience difficulties.

3.3.7. Safety Aspects. During interviews, none of the respondents expressed any safety concerns regarding the home pathway. On the surveys, community clinicians showed varying levels of confidence in its impact on patient safety, with six (66%) feeling confident and three (33%) remaining neutral. Among patients and carers, six (86%) indicated that they never experienced infections related to the infusion or had concerns about infection control at home, while one (14%) stated that they rarely did. However, one community clinician mentioned that there were instances when precautions had to be taken:

'But sometimes that's a bit of a challenge. But over the last well, 20 years of me doing IVs in the community, I've kind of developed my ways around things and even using someone's kitchen. We've cleaned it with anti-bac wipes and things before. Now we just have to try and do what we can with what we're faced with' (CC1).

Five patients and carers reported on the survey that they never (71%) or rarely ($n = 2$, 29%) required additional care outside the usual visit to refill the elastomeric device. However, a surveyed remote monitoring clinician described an example that highlighted the effectiveness of remote monitoring:

'A patient admitted to remote monitoring while on IV elastomeric pathway but got Doccla kit for taking observations and the BP readings showed high reading for blood pressure, the BP trend noticed and prescribed antihypertensive to control the blood pressure' (RM1).

3.3.8. Potential Improvements. Most of the suggestions made by participants focused on improving the system supporting the home pathway. One recommendation for the elastomeric device was to alter its shape to oblong, allowing patients to dress while remaining connected to the IV. Clinicians noted that the spherical shape was heavy to carry, a point supported by the carer, who thought that wearing the device could be cumbersome and uncomfortable. The main improvement suggested for remote monitoring was better respiratory monitoring. Clinicians proposed several potential improvements to better support the home pathway, including:

- Self-administration options for patients.
- Provide instructions on how to use the devices supplied for remote monitoring.
- Increase the availability of bridging carers to support patients who are not confident in taking their observations.
- Shortening the length of the administration set between the cannula and the sensor.
- Use a CVP line rather than a peripheral cannula.
- Use different-sized vials of IV fluids.

Several participants emphasised the importance of improving general knowledge of the home pathway and ensuring that patients are fully informed before consenting to its use. As shown in the training section above, community clinicians expressed varying amounts of training and felt that there is a need for more 'hands-on' training. Most of the respondents believed the home pathway had the potential to be extended to other suitable IV medications and settings, such as care homes.

3.4. Economic Impact of the Pathway

3.4.1. Health Service Utilisation. The costs used to calculate the economic impact of the home pathway compared to the other three pathways are detailed in Table 5. Costs for clinicians were restricted to those with direct contact with patients to administer their medication to provide a like-for-like comparison of the pathways.

The total cost for the home pathway is £60,181.03, making it the most cost-saving option compared to £146,944.88 for the hospital pathway, £104,960.84 for the hypothetical pathway and £86,490.15 for the outpatient pathway. This translates into annual savings of £86,763.85 against the hospital pathway, £44,779.81 against the hypothetical pathway and £26,309.12 against the outpatient pathway. On a per-patient basis, the total cost of the home pathway is £2507.54, compared to £6122.70 for the hospital pathway, £4373.37 for the hypothetical pathway and £3603.76 for the outpatient pathway. This results in savings of £3615.16 per patient compared to the hospital pathway, £1865.83 compared to the hypothetical pathway and £1096.21 compared to the outpatient pathway, Table 6.

The costs associated with adverse drug events (ADEs) reflect underlying assumptions about the settings in which antibiotics are administered and devices are fitted. For the hospital pathway, the controlled environment of the hospital is assumed to minimise the likelihood of ADEs, resulting in no associated costs. Similarly, the outpatient pathway, which involves the fitting of devices in a clinical setting—also a sterile environment—is considered to provide a reduced risk

Table 5: Health service utilisation by the patients.

Resources/metric	Hospital pathway	Hypothetical pathway	Home pathway	Outpatient pathway
Antimicrobials				
Flucloxacillin				
Patients prescribed	10	10	10	10
Avg. duration per patient (days)	5.41	5.41	5.41	5.41
Frequency per day	4	4	1	1
Piperacillin/tazobactam (Tazocin)				
Patients prescribed	14	14	14	14
Avg. duration per patient (days)	5.08	5.08	8.71	8.71
Frequency per day	3	3	1	1
Device and consumables (per patient)				
Sodium chloride 0.9% 250 mL bottle	37.41	37.41	10.63	0.00
Elastomeric device (empty)	0.00	0.00	10.63	0.00
Elastomeric device—prefilled flucloxacillin 8 g	0.00	0.00	0.00	5.41
Elastomeric device—prefilled piperacillin/tazobactam 13.5 g	0.00	0.00	0.00	8.71
Elastomeric device—prefilled piperacillin/tazobactam 18 g	0.00	0.00	0.00	0.00
Other consumables	37.41	37.41	10.63	10.63
Service utilisation (per patient)				
Hospital stay (days)	10.63	0.00	0.00	0.00
Community clinician visits	0.00	36.88	10.63	0.00
Clinician travel time (one-way, hours)	—	1.09	1.09	—
Outpatient clinic visits	0.00	0.00	0.00	10.63
Remote monitoring escalations	0.00	0.00	0.58	0.00
Time per escalation (hours)	0.00	0.00	0.50	0.00
Adverse drug events (per patient)	0.00	0.13	0.13	0.00

Note: The total cost might not exactly match the product of the utilisation rate and unit costs, as costs were calculated individually for each patient and reflect marginal variations associated with time and quantity.

Table 6: Costs of home pathway compared to other pathways.

	Hospital pathway	Hypothetical pathway	Home pathway	Outpatient pathway
Total cost for 24 patients				
Antibiotics cost	£9457.21	£9510.31	£9510.31	£0.00
Device and consumables	£497.19	£1778.78	£7051.30	£21,060.66
Hospitalisation	£118,020.95	£0.00	£0.00	£32,397.91
Inpatient nursing	£18,969.53	£0.00	£0.00	£18,969.53
Travel time (community clinicians' visit to home)	£0.00	£22,919.32	£6508.27	£0.00
Outpatient nursing time	£0.00	£0.00	£0.00	£14,062.05
Nursing time at home	£0.00	£70,335.43	£20,040.94	£0.00
Remote monitoring nurses	£0.00	£0.00	£16,160.01	£0.00
Escalation at remote monitoring hub	£0.00	£0.00	£493.20	£0.00
Adverse drug events	£0.00	£417.00	£417.00	£0.00
Grand total	**£146,944.88**	**£104,960.84**	**£60,181.03**	**£86,490.15**
Total saving (home pathway compared to others)	**£86,763.85**	**£44,779.81**		**£26,309.12**
Per patient cost				
Antibiotics cost	£394.05	£396.26	£396.26	£0.00
Device and consumables	£20.72	£74.12	£293.80	£877.53
Hospitalisation	£4917.54	£0.00	£0.00	£1349.91
Inpatient nursing	£790.40	£0.00	£0.00	£790.40
Travel time (community clinicians' visit to home)	£0.00	£954.97	£271.18	£0.00
Outpatient clinic nursing time	£0.00	£0.00	£0.00	£585.92
Nursing time at home	£0.00	£2930.64	£835.04	£0.00
Remote monitoring nurses	£0.00	£0.00	£673.33	£0.00
Escalation at remote monitoring hub	£0.00	£0.00	£20.55	£0.00
Referred to hospital	£0.00	£17.38	£17.38	£0.00
Total cost	**£6122.70**	**£4373.37**	**£2507.54**	**£3603.76**
Total saving (home pathway compared to others)	**£3615.16**	**£1865.83**		**£1096.21**

Note: The Device and Consumables section includes all relevant items required for antibiotic preparation and administration. The cost of antibiotic vials is listed separately under antibiotic cost, while items such as water for injection, saline bags, infusion lines and giving sets are included under device and consumables cost. In the outpatient pathway, prefilled elastomeric devices containing the formulated antibiotic solution were used; hence, there is no separate antibiotic cost associated with this pathway.

of ADEs compared to home-based pathways and hypothetical pathways where antibiotics are administered outside controlled hospital or clinic settings. This results in a modest cost of £417 for the cohort of 24 patients, or £17.38 per patient in these pathways. These assumptions acknowledge the potential safety advantages of sterile conditions in reducing ADE risks while maintaining consistency in evaluating home-based pathways. ADEs associated with the different pathways reveal differences in safety outcomes.

3.4.2. Annual Cost Savings. Over a three-month period, 24 patients were managed through the home pathway, translating to 8 patients per month or 96 patients per year. The total yearly cost for the home pathway is £240,724.12, making it the most economical option compared to £587,779.53 for the hospital pathway, £419,843.36 for the hypothetical pathway and £345,960.59 for the outpatient pathway. Consequently, the home pathway yields annual savings of £347,055.41 compared to the hospital pathway, £179,119.24 compared to the hypothetical pathway and £105,236.47 compared to the outpatient pathway Table 7.

When capacity is increased by 10% annually, the total undiscounted savings amount to approximately £5.1 million compared to the hospital pathway, £2.6 million compared to home visits with IV infusion and £1.5 million compared to the OPAT pathway. Discounted savings (net present value—NPV) for the same scenario are approximately £4.9 million, £2.5 million and £1.5 million, respectively. A 20% annual capacity increase results in total undiscounted savings of approximately £6.6 million (hospital), £3.4 million (hypothetical) and £2.0 million (outpatient), with discounted savings reaching approximately £6.3 million, £3.3 million and £1.9 million. At the highest capacity increase of 30% annually, the total undiscounted savings are approximately £8.2 million, £4.2 million and £2.5 million, while the discounted totals are approximately £7.9 million, £4.1 million and £2.4 million. These results illustrate the financial advantages of scaling the home pathway, particularly when higher capacities are achieved, as it consistently delivers greater savings relative to hospital, hypothetical and outpatient pathways over time. The summarised information on the financial implications of scaling up is provided in Table 8 and Supporting Information (available here).

4. Discussion

The evaluation of the home pathway demonstrates that this approach is practical, acceptable and economically viable for administering IV antibiotics in the home setting.

Patient satisfaction was high because they felt safer and had freedom being at home. Other research found patients were around 90% satisfied with 24 h self-treatment [2], and this is supported by research elsewhere [6, 14]. Patients and carers were happy with their quality of life and could

Table 7: Annual cost savings of the home pathway compared to other pathways.

Costs	Hospital pathway	Hypothetical pathway	Home pathway	Outpatient pathway
Antibiotics cost	£37,828.84	£38,041.22	£38,041.22	£0.00
Device and consumables	£1988.75	£7115.12	£28,205.21	£84,242.64
Hospitalisation	£472,083.82	£0.00	£0.00	£129,591.64
Inpatient nursing	£75,878.13	£0.00	£0.00	£75,878.13
Travel time (community clinicians' visit to home)	N/A	£91,677.29	£26,033.08	N/A
Outpatient nursing time	£0.00	£0.00	£0.00	£56,248.19
Nursing time at home	£0.00	£281,341.73	£80,163.74	£0.00
Remote monitoring nurses	£0.00	£0.00	£64,640.05	£0.00
Escalation at remote monitoring hub	£0.00	£0.00	£1972.81	£0.00
Adverse drug events	£0.00	£1668.00	£1668.00	£0.00
Total cost	**£587,779.53**	**£419,843.36**	**£240,724.12**	**£345,960.59**
Total saving (home pathway compared to others)	**£347,055.41**	**£179,119.24**		**£105,236.47**

Table 8: Cost saving associated with home pathway compared to other pathways under different capacities in 10 years.

Capacity increase (%)	Savings type	Hospital pathway (£)	Home pathway (£)	Outpatient pathway (£)
10	Undiscounted	5,097,376.33	2,630,813.83	1,545,660.61
	Discounted (NPV)	4,931,115.09	2,545,004.52	1,495,245.77
20	Undiscounted	6,561,516.33	3,386,473.12	1,989,626.96
	Discounted (NPV)	6,344,010.20	3,274,215.73	1,923,673.29
30	Undiscounted	8,188,338.57	4,226,094.55	2,482,922.90
	Discounted (NPV)	7,913,893.66	4,084,450.42	2,399,703.87

complete functional activities, albeit with help from the clinicians or carers. A review also noted that differences in the results for quality of life using standard measurement tools, such as SF-36 for quality of life and Bartel for functional activities, were attributed to different health conditions being treated at home [14].

For clinicians the home pathway was acceptable because they felt patients were more comfortable in their own home, provided adequate support and safety nets are in place to ensure prompt action if any health problems arise. In general clinicians were comfortable with their responsibility to support patients, however, filling the elastomeric device was not easy and was time consuming, especially when numerous vials needed to be mixed. This has not been reported previously, however, a device is available to assist clinicians, but this was not used during the evaluation.

Concerns about the accuracy of the flow of antibiotic medication were raised and are supported by elsewhere [1, 15, 16]. Clinicians were unable to monitor the flow, and sometimes residual medication was left in the pump; however, this may be due to several reasons, such as the ambient temperature, type of antibiotic used or variations in the time clinicians visited rather than the pump itself. Likewise, the size, shape and weight of the device were considered negatively by clinicians, yet this is one of the smallest devices, and other research suggested patients preferred elastomeric devices because they were less cumbersome than electronic pumps [2]. Another disadvantage identified by clinicians was issues around cannulas used to deliver medication. These often became detached and were thought unsuitable for long-term use; however, although this has not been previously identified in research, this could be a problem for all elastomeric devices. The advantages are that cannulas can be inserted by a clinician at the patients' home, ensuring rapid administration of antibiotics and earlier discharge from hospital.

Discrepancies were noted on respiratory measurement via remote monitoring; however, it also highlighted a health problem that averted readmission to hospital. Other research shows remote monitoring saved over 300 hospital bed days for patients with urinary tract infections and reduced mortality of patients with heart disease [17]. Unusual readings may be due to patients inputting wrong data, or devices may be faulty. Adopting passive monitoring will reduce patient burden in the future. Standard operating procedures provide detailed information about patient care, and a proactive approach means patients are contacted when unusual vital signs appear and escalated to a doctor if required. Research on equipment failure is lacking; however, Doccla stated that six out of 270 respiratory monitor devices were replaced across the whole Hertfordshire Hospital at Home during the evaluation.

Overall, clinicians, patients and carers felt safe with the use of the elastomeric device. Adverse events (drug-related, pump-related and line-related) were not recorded during the evaluation, and few were reported in the surveys. Other research suggests a very low incidence of adverse events for this technology [18].

Most clinicians felt that patients needed more information and better training about the home pathway. Indeed, all participants considered communication throughout health and social care could be much improved, which is also reflected in other research [2, 6]. Likewise, a rapid review of remote monitoring devices highlighted the need for stakeholder engagement to ensure successful rollout of the technology [17].

Recent studies highlight that OPAT is more cost-effective than hospitalisation, with costs varying based on the model (outpatient clinic, nurse home visits and self-administered), medication and condition treated [3–6]. These studies support the economic evaluation findings herein, where costs for the Braun Easy Pump II pathway were compared with hospitalisation, outpatient clinic, and a virtual pathway of home visits using preprepared elastomeric devices; however, analyses were focussed on the four pathways rather than on different medications and health conditions.

To further improve acceptability, device developers are encouraged to consider clinician and patient feedback to enhance device recyclability, wearability and usability for daily activities. Expanding the pathway's adoption among paid carers, care homes and patients requiring extended IV treatments with midline cannulas could broaden its reach. Effective communication about the pathway, its support structures, and the transition process is essential to ensure patients and carers fully understand and accept the model. Including additional IV medications compatible with the pathway could further enhance its applicability, provided the stability and potential toxicity are monitored to ensure patient safety in the home environment.

Despite the positive outcomes, limitations should be acknowledged. The study was conducted in Hertfordshire, so findings may not generalise to other regions. Some cost estimates, particularly for remote monitoring and ADEs, were based on assumptions or expert opinion due to a lack of robust data, which may introduce variability. Additionally, small sample sizes, patient selection criteria and possible bias in survey responses (facilitated by remote monitoring staff) may have influenced results. Patients were carefully selected to ensure safe administration of antibiotics via the elastomeric device and may not have been fully briefed about the evaluation, and how questions are presented could influence responses positively. The cost comparison between the home-based model presented in this study and conventional hospitalisation should be interpreted with caution. NHS cost data reflect all hospital cases, including those with clinical complexities or severity that would preclude home management. In contrast, patients treated at home in this evaluation represent a selected group, introducing potential selection bias that may influence the cost analysis. Future research should address these limitations by investigating differences in device preparation times, reasons for remote hub responsiveness issues and workload concerns for monitoring staff. Collecting data on escalations to senior clinicians and adverse events will also allow for more comprehensive comparisons with other IV pathways. Research to explore the potential resource implications of staff training and supervision is useful, as these elements could pose a substantial burden in the implementation and long-term sustainability of the home pathway. Quantifying these costs more precisely would provide a more comprehensive understanding of the overall economic impact. Lastly, each research method used for the evaluation has limitations; however, using multiple methods improves trustworthiness and provides in-depth real-world experiences, which are invaluable for providing comprehensive appraisals of healthcare innovations.

5. Conclusion

The home pathway is acceptable, feasible and has an economic advantage over other IV pathways. The convenient, patient-centred approach, with safety measures, makes the home pathway valuable for enhancing outpatient care; however, thought should be given to difficulties preparing the IV antibiotics and filling the elastomeric device. As the NHS seeks innovative strategies to improve patient outcomes and experiences while managing healthcare costs, this pathway offers a promising means to advance public health goals and sustainability objectives.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. *(Supporting Information)*

Supporting Information 1: Checklist: SRQR.

Description of data in the Supporting file.

Eligibility criteria for patients accepted on the home pathway.

Patient survey results.

Community clinicians survey responses.

Remote monitoring clinicians survey responses.

Key assumptions of the economic model.

Cost inputs used in the economic model.

Financial consequences of scaling up use of B. Braun EasyPump II elastomeric devices with remote monitoring.

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