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SMARTPHONE-BASED FOLLOW-UP FOR LOWER LIMB PROSTHETIC USERS: A SIX-WEEK TELE-REHABILITATION MODEL

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Abstract

Background: *Rehabilitation of lower limb prosthetics involves long-term follow-up following the fitting of the prosthetic, but a significant number of users have barriers to travel, cost, mobility, and communication, which restrict access to timely care. Tele-rehabilitation using Smartphone can be used as an extension of regular follow-up that can substitute face-to-face prosthetic services.*

Purpose: *In this study, an effective smartphone-based follow-up model was developed and evaluated in lower limb prosthetic users.*

Approaches: *A pre-post developmental design compared to pre-intervention was employed. Fifty prosthetic users of lower limbs were screened and 40 eligible and 35 with a 6-week follow-up. The model adopted conventional smartphone applications, such as WhatsApp or video calls, SMS notices, workout instructions, activity, prosthetic care, messages of motivations and safety reporting instructions. Outcomes consisted of QUEST 2.0 satisfaction scores, weekly adherence, average daily steps, perceived effectiveness, participant feedback, and any safety concerns.*

Findings: *Barriers to traditional follow-up were reported by participants, typically due to distance to travel, travelling difficulty with a prosthesis, the cost of travelling, shortage of specialists, latent communication with clinicians, and cancellation or lateness of appointments. The mean QUEST score in the tele-rehabilitation condition rose to 4.20 opposed to no tele-rehabilitation condition, which rose to 3.00 to 3.40. Six weeks of tele-rehabilitation condition showed an increase of 3,200 on average daily steps to 4,800 and adherence rose as well by 62 to 89 percent. There were also high scores on perceived usefulness, particularly the willingness to recommend the model and better access to follow-up care.*

Conclusion: *There was evidence that a low-burden smartphone-based follow-up model was safe, acceptable, and supportive in lower limb prosthetic users. It should be placed in a supportive position to, not a substitute of face-to-face prosthetic and rehabilitation care.*

INTRODUCTION

Amputation of the lower limbs influences mobility, self-care, social activity, employment, self-confidence, and quality of life. Prosthesis is capable of producing a meaningful function yet the prosthesis alone is not adequate in providing a safe and sustainable mobility. The rehabilitation of prosthetics necessitates care of the residual limb, gait training, balance training, progressive

Frontier in Medical & Health Research
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strengthening, socket comfort testing, fall prevention, education of the user, and regular review. These needs are ongoing, as the use of prosthetics adjusts to the adjustment of the residual limb, activity levels improve, confidence grows or complications develop. International Classification of Functioning, Disability and Health describes the concept of disability as an interplay between body structures, activities and participation, as well as personal issues and environmental limitations, and is particularly applicable in the context of the prosthetic user who has the device at hand but cannot easily receive the support (World Health Organization, 2001).

The rehabilitation needs of the world are huge. Cieza et al. (2020) calculated that one in three individuals globally could at one point or another receive rehabilitation services during illness or injury. Assistive technology also takes pride of place in the sphere of independence and engagement, which, however, cannot be regarded as a blessing without assessment, fitting, training, maintenance, and aftercare (World Health Organization and United Nations Children Fund, 2022). Follow-up is thus not an administrative contact elective in lower limb prosthetic care. It is a process that helps to support functionality and early detect complications, reinforce self-management, and identify when a user must be reviewed in-person.

Conventional after-sales services may be challenging to use. Limb prosthetic users can experience long travel distances, transportation cost, reliance on caregivers, inability to travel with an uncomfortable prosthesis, missed work, wait, and a lack of rehabilitation professionals. These obstacles are grave in environments in which there are large urban centers that focus on prosthetic and rehabilitation services. It may not be addressed when pain, skin irritation, socket pain, fear of falling, ineffective gait patterns, lack of confidence, and lack of time spent in a prosthesis are not adequately addressed before they become part of the routine follow-up. The outcome may be avoidable loss of functionality and avoidable service dissatisfaction.

Tele-rehabilitation is an effective method of enhancing between-face visits continuity. It employs communication technology to provide rehabilitation assistance remotely and can involve the use of video consultation, telephone calls, messages, remote monitoring, exercise instructions, education and asynchronous feedback. Rehabilitation literature evidence supports that remote models can enhance access and has the potential to yield similar outcomes to traditional care under certain conditions of choice (Cottrell et al., 2017; Kairy et al., 2009). In amputee care, distance services can decrease the number of trips to the clinic and enable clinicians to look at challenges in the environment of the user at home (Webster et al., 2021). Models that deal with smartphones are particularly pertinent since smartphones integrate video, audio, messaging, reminders, cameras, and activity tracking into a well-known and relatively inexpensive mobile device.

Nevertheless, prosthetic rehabilitation requires needs that are not sufficiently represented by tele-rehabilitation research in general. The attention to residual limb skin, fit of sockets, pain, gait safety, care of the prosthetics, confidence of the balance, adherence to home exercise, and timely referral in case of hands-on assessment is needed by the users. Digital health guidance addresses the need to empower health services through technology as well as highlighting that technology is not an issue to substitute weak systems (World Health Organization, 2019). This study was thus aimed at designing and evaluating a viable smart phone-based tele-rehabilitation follow up model among lower limb prosthetics users. The research measured access barriers, usability, acceptability, and adherence, satisfaction, activity patterns, and safety monitoring, but regarded smartphone follow-up as an adjunct to, not a replacement of, clinical care of a prosthetic.

Methods

Study design. A descriptive developmental design with pre- and post-intervention comparison was used. The descriptive element found challenges faced by the users of lower limb prosthetic when receiving conventional follow-up rehabilitation. A

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smartphone-based follow-up model development system was developed and assessed against common communication tools by the developmental component. The design was appropriate since the intervention was service-delivery model as opposed to prosthetic fabrication or alignment procedure. Summary of quantitative results was conducted in a way that summarized the results and interpretation of usability and acceptability was carried out through open-ended feedback.

Setting and participants. The sample consisted of adult users of lower limb prostheses having a history of prosthetic rehabilitation therapy. Participants with below-knee or above-knee amputations, lower limb prosthesis, and able to make sense of follow-up instructions, could access a smartphone, and had willingness to adhere to the six-week remote follow-up were eligible to partake. The exclusion criteria included: did not use a lower limb prosthesis, no access to smartphones, was unable to communicate remotely, or needed emergency medical treatment as opposed to routine follow-ups. The model was not aimed to substitute emergency care, fabrication of the prostheses, molding of the socket, wound treatment, or clinical procedures, which presuppose direct examination.

Participant flow and sampling. Non-probability purposive sampling was employed to select participants as the study needed to have certain characteristics: participants had to be using a prosthetic, have access to a smartphone, and be willing to participate in remote follow-up. Lower limb prosthetic users: a total of 50 individuals who were prosthetic users were screened. Ten had to be excluded due to lack of inclusion criteria or they refused to participate. Forty of them were used in the follow up study, and 35 of them completed the six-week intervention and were enrolled in the final analysis. There were five lost to follow-up. The proportion of the eligible participants who completed the program was thus 87.5, which argues the practical usability of the model to those who fulfilled the access criteria.

Smartphone-based tele-rehabilitation model. The intervention lasted six weeks and was using well-known smartphone features. Elements encompassed WhatsApp / video appointments, SMS notifications, workout supervision, activity and mobility cues, prosthetic care messages, skin monitoring messages, encouragement messages, and safety reporting messages. Two to three messages per week were delivered, and they were aimed at informed behaviors regarding safe wearing of a prosthetic device, walking, strengthening and balance, checking and inspecting a residual limb, the sock comfort, early warning of pain, redness, sores, or difficulty walking. In cases where a participant had persistent or alarming symptoms, instructions were given and face to face evaluation was prescribed where necessary. The model was clearly positioned as an extension of regular rehabilitation, and not an alternative to face-to-face assessment.

Outcome measures. The satisfaction measure was done through the QUEST 2.0 based device and service items. QUEST 2.0 is a relatively well-known scale consisting of measures of satisfaction with assistive technology and related services (Demers et al., 2002). The satisfaction with device aspects discussed comfort, effectiveness, ease of use, durability and the satisfaction with the device. Service satisfaction was comprised of training, delivery, repair services, follow-up services and service satisfaction. The 5-point Likert scale was applied on items with higher scores showing increased satisfaction. The mobility related change was measured by number of average daily steps in a week in 6 weeks. The adherence to rehabilitation was measured every week with the help of reports about exercise practice, practice with propsittus, answers to the follow-up messages, and attendance at arranged remote communication. Perceived effectiveness and acceptability was determined by scores of increased access, enhanced clinician communication, increased confidence in the use of the prosthetic, the ability to easily report problems, to make less unnecessary visits, and a desire to recommend the model. The monitoring of safety documented pain, walking difficulty, residual limb redness/irritation, sores, socket pain, and manual assessment requirement.

Data collection and analysis. Baseline information included demographic and clinical characteristics,

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traditional follow-up barriers, baseline satisfaction, and baseline mobility. Smartphone logs and activity hours, adherence history, and safety reports were recorded during the intervention. After six weeks, satisfaction, adherence, activity, perceived effectiveness, and feedback of participants were re-assessed. It was analyzed using descriptive statistics. Frequencies and percentages were used to summarize categorical variables. The Likert-scale, satisfaction, adherence, and activity data were summarized as a means or or weekly trend. The results of pre- and post-follow-up of QUEST were compared across tele-rehabilitation and no tele-rehabilitation conditions descriptively. The manuscript dataset did not provide participant-level inferential information and, therefore, the results are disclosed as descriptive changes, rather than indicative causal estimates.

Ethical considerations. The Superior University, Lahore, institutional process was used to get the ethical approval. The study purpose, procedures, possible benefits, risks, confidentiality and voluntary participation were explained to the participants. Informed consent was informed in writing and the participants were free to withdraw without any repercussions. No names were used and instead use of participant codes. Communication though Smartphone was managed with a lot of caution since it was possible to compose messages, images, or report on symptoms, which may include personal health information. In-person clinical assessment was referred to participants who reported severe pain, open wounds, possible infection, frequent falls, and severe issues with the prosthetics.

Table 1
Participant flow and final analysis sample

Stage	Number	Description
Assessed for eligibility	50	Initial screening
Excluded	10	Did not meet inclusion criteria or declined
Allocated to follow-up study	40	Eligible participants
Lost to follow-up	5	Could not complete six-week follow-up
Included in final analysis	35	Final analysis sample

Results

Participant characteristics. The final analysis included 35 lower limb prosthetic users. Most participants were men (n = 26, 74.3%), while 9 were women (25.7%). The largest age group was 31-45 years (n = 15, 42.9%), followed by 46-60 years (n = 10, 28.6%), 18-30 years (n = 7, 20.0%), and above 60 years (n = 3, 8.5%). Below-knee amputation was more common (n = 24, 68.6%) than above-knee amputation (n = 11, 31.4%). Diabetes or vascular causes (n = 14, 40.0%) and trauma (n = 13, 37.1%) were the most common causes of amputation then infection (n = 5, 14.3%), and congenital or other causes (n = 3, 8.6%). Prosthetic use: 8 (22.9) of the respondents had not used a prosthesis more than six months, 12 (34.3) used it between six and 12 months, and 15 (42.8) used over 12 months.

Hurdles to conventional follow-up. There were various obstacles to face-to-face follow-up, reported by participants. Travel distance to the clinic (74.3%), difficulty travelling with a prosthesis (68.6%), cost of transportation (65.7%), low occurrence of specialists (60.0%), late communication with clinicians (57.1), and missed or delayed appointments (54.3) were most frequent. These significant findings suggest that the necessity to have remote follow-up was not a mere convenience issue; it was practical challenges that may postpone the rehabilitation instructions and reporting of problems.

Use of smartphone follow-up components. The participants utilized the smartphone model via video or WhatsApp calls, SMS notifications, and tracking activities. Three-fourths of the participants (70 percent) used WhatsApp or video

Frontier in Medical & Health Research
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sessions regularly, 22 percent occasionally, and 8 percent rarely. The percentage of those who found SMS reminders helpful was 83% with 11% of the respondents reporting some neutrality and 6% disagreement. The monitoring of activities encouraged the use of a prosthetic in three-quarters of the participants, 15 percent were neutral and 10 percent opposed. Digital challenges reported were unstable internet connection (40%), challenges in using smartphone features (23%), lack of access to mobile data (18%), and no significant challenge (19%). This trend justifies the acceptance but it also demonstrates that low data, elastic delivery is critical.

Satisfaction outcomes. The post-follow-up device satisfaction was high with the mean score of 4.18 in comfort, and 4.26 in effectiveness, ease of use, and durability, as well as overall device satisfaction at 4.22. The level of service satisfaction was also high as service training was rated 4.41, 4.33 on service delivery, 4.17 on service repairs, service follow-ups and the overall service satisfaction (4.30) respectively. The comparatively lower repair service score indicates that smartphone services can enhance reporting and guidance but not a substitute to actual repair or mechanical repair.

Comparisons between pre and post follow-ups indicated greater descriptive improvement in the tele-rehabilitation condition. Mean QUEST score was increased by 1.10 and a percentage change of 35. 5 which was 4.20 compared to 3.10. Under the no tele-rehabilitation condition, there was an increase in the mean QUEST score, between 3.00 and 3.40 with a mean of 0.40 and a percentage of change of 13.3%. The two sets of baseline scores were close and the difference of post-follow-up scores was in favor of the smartphone based model.

Trends in activities and adherence. The average daily steps in the tele-rehabilitation condition rose progressively, as measured in weeks 1 to 6, the average daily steps were 3, 200 and 4, 800, respectively. Steps in the no tele-rehabilitation condition only rose to 3,100-3,450. It is clinically significant that the tele-rehabilitation condition improves progressively, since the practice of gradual walking is less risky than rapid changes in activities among prosthetic users who can feel fatigued, experience residual limb pressure, or have a fear of balance. The adherence to rehabilitation was also similar in that it was 62% in week 1 to 89% in week 6 in the tele-rehabilitation condition. Comparatively, adherence in the no tele-rehabilitation condition was boosted by 58 to 64%. According to this trend, frequent reminders, feedback, and distance interaction facilitated habit development and reinforcing interaction.

Perceived effectiveness/safety. Participants gave a good rating to the model. The means scores were 4.42, 4.36, 4.25, 4.18, 4.30, and 4.44, respectively, on improved access to follow-up care, improved communication with clinicians, improved confidence in the use of the prosthetic, reduced unnecessary visits, easier problem reporting, and willingness to recommend the model, respectively. Safety checks showed that half of the participants (57.1%), had no problem. Reported incidences of residual limb redness or irritation (17.1), mild socket discomfort (14.3), temporary pain during walking (8.6), and one participant (2.9) received referral to in-person evaluation. Themes on feedback comprised better accessibility, increased confidence, earlier reporting of problems, convenience, and digital challenge.

Table 2
Demographic and clinical characteristics of participants (N = 35)

Variable	Category	n	%
Gender	Male	26	74.3
Gender	Female	9	25.7
Age group	18-30 years	7	20.0
Age group	31-45 years	15	42.9
Age group	46-60 years	10	28.6
Age group	Above 60 years	3	8.5

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

Amputation level	Below-knee	24	68.6
Amputation level	Above-knee	11	31.4
Cause	Trauma	13	37.1
Cause	Diabetes/vascular	14	40.0
Cause	Infection	5	14.3
Cause	Congenital/other	3	8.6
Duration of prosthetic use	Less than 6 months	8	22.9
Duration of prosthetic use	6-12 months	12	34.3
Duration of prosthetic use	More than 12 months	15	42.8

Table 3
Traditional follow-up barriers

Challenge	n	%
Travel distance to clinic	26	74.3
Difficulty travelling with prosthesis	24	68.6
Transportation cost	23	65.7
Limited availability of specialists	21	60.0
Delayed communication with clinician	20	57.1
Missed or delayed appointments	19	54.3

Table 4
Selected outcome trends

Outcome	Tele-rehabilitation	No tele-rehabilitation
QUEST mean score	3.10 to 4.20 (+35.5%)	3.00 to 3.40 (+13.3%)
Average daily steps	3,200 to 4,800	3,100 to 3,450
Adherence	62% to 89%	58% to 64%
Overall device satisfaction	4.22/5	Not separately reported
Overall service satisfaction	4.30/5	Not separately reported

Table 5
Perceived effectiveness and safety summary

Domain	Finding
Improved access	Mean score 4.42/5
Improved clinician communication	Mean score 4.36/5
Improved confidence in prosthetic use	Mean score 4.25/5
Easier problem reporting	Mean score 4.30/5
Would recommend the model	Mean score 4.44/5
No issue reported	20 participants (57.1%)
Residual limb redness/irritation	6 participants (17.1%)
Mild socket discomfort	5 participants (14.3%)

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

Temporary walking pain	3 participants (8.6%)
In-person referral	1 participant (2.9%)

Discussion

This paper constructed and evaluated a six-week, smartphone-based, tele-rehabilitation follow-up model in lower limb prosthesis patients. The results perceive that a straightforward, comfortable and systematic smartphone prototype can uphold continuity of care, enhance perceived access, augment satisfaction, obtain adherence, and provoke gradual mobility-associated change. These findings are also consistent with evidence of wider rehabilitation literature on the potential support of remote care on clinical workflows and accessibility by designing around patient requirements (Kairy et al., 2009; Peretti et al., 2017). They coincide with the new amputee-care literature that suggests that virtual rehabilitation can ease the travel burden, as well as, increase access to specialist guidance (Webster et al., 2021).

The obstacles described by the respondents reveal why regular follow-up may be challenging when using prosthetic users. The most common ones were travel distance, transportation cost and inability to travel with a prosthesis and delayed reporting by clinicians. These obstacles are not minor nuisances; they may have a direct impact on rehabilitation since pain and skin irritation, discomfort of the socket, fear of falling, and indecision may lead the user to limit the wearing of the prostitution or abandoning exercising at home. Previous research has established that physical capacity, psychosocial and rehabilitation support affects walking ability following lower limb amputation rather than the provision of a prosthesis (Sansam et al., 2009; van Velzen et al., 2006). Follow-up in this case is a component of the rehabilitation intervention.

The increase in QUEST satisfaction is specifically pertinent, as the smartphone intervention was used to change the service pathway, but did not change the physical prosthesis. QUEST 2.0 differentiates between satisfaction with the assistive technology and related services (Demers et al., 2002). Service satisfaction was quite high in the current study, particularly the case of training and follow-up services. This points to the fact that users cherished communication, education and ongoing support. The fact that the repair service score was lower is also vital: tele-rehabilitation is able to enable users to report problems sooner, yet it cannot offer socket adjustment, mechanical repair, or real-life prosthetic alignment. This affirms that follow-up via smartphone should be adopted as a hybrid service whereby an in-person care referral channel is explicit.

Practice trends and attendance patterns indicate that remote follow-up can assist users in turning the recommendation of clinics into everyday habits. Those who took part in tele-rehabilitation exhibited a progressive condition in the daily number of steps and significant improvement in much adherence in six weeks. This result is equally credible since the model had reminders, activity tracking, exercise instructions, and clinician contacts. Digital interventions can enhance compliance with home exercise in the short-term but it is still unclear whether it will be sustained in the long-term (Lang et al., 2022). In the case of prosthetic users, immediate compliance is desirable as initial activities of putting on, walking, checking the residual limb, and practice can play out the subsequent adjustment.

The positive result of the growth of walking activity should be taken cautiously but positively. The amounts of steps recorded on Smartphones may also be influenced by the positioning of their phones, type of devices, and the presence of the Smartphone during all the walk sessions. Nonetheless, the trend and direction of the six-week progress indicate that the participants did become more active with the help of some structured support. This has clinical significance as the core component of the rehabilitation of prosthetics is mobility. Interventions using gait training have the potential to enhance walking outcomes following lower limb amputation (Highsmith et al., 2016), and prompts online could be utilized to maintain walking behaviors between consultation sessions.

Frontier in Medical & Health Research

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Acceptability of the participants was high, and the willingness to recommend the model is the highest. It is important since the failure of digital rehabilitation is when it is technically in place, but unacceptable to customers. The analysis involved common platforms but not a dedicated application that was complex, which probably minimized technology load. Concurrently, electronic obstacles existed. Some of the participants experienced unstable internet, limited data and issues with mobile phone features. This observation aligns with that of the World Health Organization, which suggests that digital interventions need to empower health systems and yet be viable, equitable, and safe (World Health Organization, 2019). A viable framework would then incorporate the provision of SMS or voice, plain language, and support of the family as long as signed to it, and low-data communication choices.

One of the most significant findings is safety monitoring. The majority of demonstrators did not complain of significant problems, and some said they had redness, discomfort in the socket, or temporary walking pain, and one had to be evaluated in person. These reports indicate the triage worth of smartphones follow. Remote care has the ability to detect symptoms early on in their progression and instruct users to stop activity, examine the limb, reevaluate the socket, or consult a clinician. Nevertheless, it is not able to substitute direct examination when symptoms are still present or risky. This difference is critical to practicing ethics. Severe pain, open wounds, infection, frequent falls, sudden swelling, probable socket disparity, and mechanical prosthetic issues should be assessed face-to-face.

The results also substantiate the idea of post-limb-loss self-management. Lower-limb amputee patients have to decide daily on hygiene, socket comfort, prosthetic wearing, and progression of activities as well as reporting of the problem. The co-designed digital self-management interventions in people who have lost a lower limb have focused on their design centered on the consumer and their practical value (Esfandiari et al., 2024). The current model is on the same track that utilizes follow-up as continuous, brief, familiar and clinically connected. It is based on self management and does not transfer unsafe responsibility onto the patient.

A number of constraints need to be addressed. First, the design of the study was descriptive developmental with purposive sampling and thus the results cannot be used to determine causal effectiveness similar to randomized controlled trial. Second, the study sample was small, and it was only the participants that had followed six weeks of the analysis. This was not representative of users who lacked access to smart phones, those who were not digitally literate and those who required immediate care. Third, this manuscript could not have individual-level inferential statistics, and therefore present the results descriptively. Fourth, smartphone step count-based activity data could be inaccurate. Fifth, there was a limited intervention time and long-term compliance, prosthetic satisfaction, falls, skin outcomes, and cost-effectiveness were not evaluated.

In spite of these limitations, the study has a practical implication. One of its strengths is the pragmatic design. The intervention required no expensive sensors or proprietary software, or highly developed telehealth infrastructure; it relied on devices used by many patients and clinicians to communicate, already. This eases the model into a more realistic approach when it comes to daily rehabilitation centers and low-resource environments. The combination of the outcomes of satisfaction, adherence, activity, acceptability, and safety is another strength because it assists in taking a broader perspective of service value compared to mobility. With learning centers, a tiered follow-up pathway where routine education, reminders, adherence support and early symptom screen are provided remotely with complex issues referred to in-person review. When providing remote contacts to patients, clinicians should record the contacts, present clear instructions on safety, and control the response time to ensure that the patients know when they need remote support. Smartphone follow-up should be regarded by policymakers and rehabilitation managers as a cost-effective option to reach underserved users, particularly those who live a long distance away and may not have access to specialist services. Future studies must be able to test the model in a bigger randomized or controlled study, participant-level statistical study, analyse long-term results, and test the cost, safety and equity. The standardization of follow-up algorithms and formal reporting of adverse events in different clinical settings should also be included in future protocols.

Conclusion

Smartphone based tele-rehabilitation follow up model of six weeks was practical, tolerable, and helpful, when lower limb prosthetic patients had access to smartphone communication. Compared to the standard model, the model enhanced perceived access, clinician communication, satisfaction, adherence, and gradual mobility-related activity. It is strong in continuity, early reporting, education, and behavioral support. The model can come in handy especially in the initial adaptation phase, when the users are acquiring safe wearing habits, the control of confidence and other possible warning signs of the socket or the skin. It never should substitute in-person prosthetic care, but can significantly complement regular rehabilitation when facilitated by well-established referral policies, privacy protection, easy access to communication and oversight by clinicians.

Clinical Implications

Follow-up using a smartphone may be incorporated into the routine prosthetic rehabilitation as a structured supplementary follow-up between clinic visits. A do-not-resuscitate service must incorporate regular check-ins, low data reminders, exercise and walking instructions, residual limb and socket comfort messages, recorded concerns, and direct referral in case of red flags. The strategy is particularly useful to users who are geographically distant to specialist services or transport difficulties. To ensure safe implementation, the rehabilitation team must not consider the remote contact treatment as an alternative to the activity of adjusting the prosthetic, caring about the wound, making mechanical repairs or performing the assessment of the gait in detail when these procedures are clinically necessary.

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