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Primary Knee

A Remote Physical Therapy Program Demonstrates Similar Outcomes Compared to In-Person, Supervised Physical Therapy After Same-Day Discharge Total Knee Arthroplasty: A Randomized Clinical Trial

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ABSTRACT

Background: A growing number of total knee arthroplasty (TKA) patients are candidates for same-day discharge (SDD). Previous research has shown that internet-based remote physical therapy (RPT) can produce equivalent outcomes to supervised outpatient physical therapy (OPT) after TKA. We sought to compare outcomes between RPT and OPT in patients undergoing SDD TKA using an electronic remote perioperative management (ERPM) program.

Methods: Patients undergoing SDD TKA were enrolled in an ERPM program and randomized to ERPM + RPT or ERPM + OPT. Preoperative and 6-week functional assessments included knee range of motion, timed up and go, and 4-meter gait speed. Numerical Rating Scale pain scores were evaluated preoperatively, at 6 and 12 weeks, and satisfaction was assessed at 6, 12, and 52 weeks postoperatively. Participants completed the Veterans Rand 12 Item Health Survey and Knee Injury and Osteoarthritis Outcome Score preoperatively and at 6, 12, and 52 weeks postoperatively. OPT utilization was collected 90 days postoperatively.

Results: Of 197 initially randomized patients, 76 remained in the ERPM + RPT group and 95 in the ERPM + OPT group after withdrawals and crossovers. Baseline characteristics showed no differences between the 2 groups. No clinically relevant differences were observed in knee range of motion, Numerical Rating Scale pain, patient-reported outcomes, functional assessments, or satisfaction at any follow-up time. Participants in the ERPM + OPT group attended an average of 11.57 physical therapy sessions, incurring a total cost of $462.8 and 133 minutes of travel. Conversely, the ERPM + RPT group experienced no expenses or travel time.

Conclusions: Patients in the ERPM + RPT group had similar outcomes, lower costs, and saved time compared to patients in the ERPM + OPT group after SDD TKA. Further analysis is needed to determine predictive indicators for crossovers.

With the development of improved surgical techniques and multimodal rapid recovery protocols, there has been a marked reduction in the length of stay (LOS) after total knee arthroplasty (TKA). Outpatient TKA is expected to grow substantially over the next 5 years, with more than 50% achieving same-day discharge (SDD) [1,2]. In a value-based care era, there is a focus on reducing total episodic costs [3]. As such, there has been a recent interest in studying the efficacy of remote means of patient engagement, monitoring, and physical therapy (PT) [4].

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There is consensus that physical exercise focusing on knee range of motion (ROM), muscle strengthening, and gait mechanics is essential for optimal outcomes after TKA. At present, the available outpatient physical therapy (OPT) settings after TKA include (1) in-person supervised OPT, (2) in-person supervised at-home PT, (3) unsupervised at-home PT, and (4) remote supervised at-home PT (telerehabilitation). Several studies have demonstrated that unsupervised or remotely supervised home-based therapy programs are not inferior to and are less costly than formal supervised OPT after inpatient TKA [5]. However, there is limited information regarding the influence of remotely supervised home therapy on outcomes after SDD outpatient TKA (SDD TKA). We designed this study to investigate the influence of 2 different perioperative care paradigms on objective functional outcomes, patient-reported outcome measures, Numerical Rating Scale (NRS) pain scores, and patient satisfaction after SDD TKA performed in both hospital and ambulatory surgery center (ASC) settings. Study patients were enrolled in an electronic remote perioperative management (ERPM) program and prospectively randomized to receive postoperative remote physical therapy (RPT) through the ERPM program (ERPM + RPT) or postoperative PT with an in-person supervised OPT program (ERPM + OPT).

Materials and Methods

Study Participants and Enrollment

After local Institutional Review Board approval, all patients undergoing TKA by a single high-volume joint arthroplasty surgeon between August 27, 2019 and October 21, 2021 were recruited to enroll in this prospective, randomized single-institution study. The trial followed a parallel design with a 1:1 allocation ratio. All surgeries were performed in either a specialized ASC dedicated exclusively to hip and knee arthroplasty or in the neighboring hospital. Patients who had uncontrolled, modifiable risk factors (Table 1) were not allowed to schedule surgery until optimization thresholds were met. Contraindications to surgery in the ASC were limited only to patients who had an American Society of Anesthesia Score of 4, the presence of an automated internal cardiac defibrillator, a serum creatinine > 2.0, or those who had cardiac disease labeled high risk for cardiac complications by their cardiologist. All patients were discharged on the day of surgery (SDD) after a physical therapist ensured appropriate functional safety. Exclusion criteria included (1) requirement for revision knee arthroplasty implants; (2) bilateral knee arthroplasty in the same setting; (3) lack of a home care partner; and (4) lack of a valid, active e-mail address or home internet access.

Knee ROM was a primary outcome of the study. Based on a significance level of 5% and a power of 80%, assuming a standard deviation of 10° for knee ROM and a noninferiority margin of 3.4° [6], we calculated that 68 patients per group were needed (total of 136) (RStudio, Boston, Massachusetts). Assuming a 20% dropout rate, a total of 163 patients were needed to complete this study.

During the study period, a total of 1,030 (598 hospital and 432 ASC) patients underwent primary TKAs by the study surgeon. Of these, 833 (81%) declined to participate or did not meet inclusion criteria. A total of 197 patients enrolled and provided consent. All study patients were enrolled in an ERPM (Force Therapeutics TM, New York City, New York) designed to provide educational content, exercise instruction, direct messaging between patient and care team, and the collection of patient-reported outcome measures (PROMs). Patients were then randomized into 2 study groups through computer-generated sets of random allocations to receive ERPM before surgery and remotely supervised postoperative PT through the ERPM application (ERPM + RPT) or ERPM before surgery and in-person supervised OPT (ERPM + OPT). The preoperative ERPM programs were identical between groups. There were 95 patients randomized to ERPM + RPT and 102 to ERPM + OPT. After withdrawals and crossovers due to clinical indications or patient preference, 171 patients were available for final analyses, with 76 patients remaining in the ERPM + RPT group and 95 in the ERPM + OPT group. No funding was received for this study.

Table 1
Patient Demographics and Baseline Function Bivariate Analysis Comparing Electronic Remote Perioperative Management Program (ERPM) + Remote Physical Therapy (RPT) (ERPM + RPT) to ERPM + Outpatient Physical Therapy (OPT) (ERPM + OPT).

Baseline Demographic/Function	ERPM + RPT (n = 95)	ERPM + OPT (n = 102)	*P* Value
Demographic Data			
Age (mean ± SD [min-max])	70.2 ± 8.4 (36 to 84)	70.2 ± 8.0 (47 to 87)	.97
Laterality, % Right	66.32	55.88	.13
% Men	38.89	50.00	.09
BMI (mean ± SD [min-max])	30.4 ± 5.4 (18 to 40)	30.1 ± 4.7 (18 to 40)	.68
ASA Classification, n (%)			
Class I	1 (1.05)	2 (1.96)	.87
Class II	58 (61.05)	61 (59.80)	
Class III	35 (36.84)	39 (38.24)	
Class IV	1 (1.05)	0 (0.00)	
Preop Knee ROM (mean ± SD [min-max])			
Extension	1.4 ± 3.4 (−15 to 15)	2.8 ± 3.5 (−2 to 15)	.07
Flexion	111.8 ± 10.6 (85 to 125)	112.1 ± 10.5 (80 to 130)	.88
Preop Patient-Reported Outcomes (mean ± SD [min-max])			
KOOS, JR.	52.9 ± 15.4 (8 to 92)	51.4 ± 13.9 (0 to 80)	.49
VR-12 MCS	53.4 ± 11.2 (23 to 69)	52.9 ± 11.8 (22 to 72)	.77
VR-12 PCS	33.1 ± 10.0 (15 to 57)	31.7 ± 9.1 (16 to 56)	.30
Preop Functional Assessment (mean ± SD [min-max])			
TUG	10.6 ± 3.8 (5 to 27)	11.3 ± 4.6 (5 to 31)	.29
4-meter Gait	4.3 ± 1.6 (2 to 11)	4.3 ± 1.7 (2 to 13)	.78
NRS Pain (0 to 10)	4.7 ± 2.1 (0 to 10)	5.3 ± 2.2 (0 to 10)	.24

Bolded *P* values indicate statistical significant results.
SD, standard deviation; BMI, body mass index; ASA Classification, American Society of Anesthesiologists Classification; ROM, range of motion; KOOS, JR., knee injury and osteoarthritis outcome score; VR-12 MCS/PCS, veterans rand 12 mental and physical health component summary; TUG, timed up and go; NRS Pain, numeric pain rating scale; ERPM, electronic remote perioperative management program; RPT, remote physical therapy; OPT, outpatient physical therapy.

Surgical Procedure

All TKAs were performed without the use of a tourniquet via a medial parapatellar approach using manual instrumentation. All patients received a cemented, fixed-bearing cruciate retaining implant (DePuy Attune, Raynham, Massachusetts) with patellar resurfacing. After resection of the distal femur and proximal tibia, the extension space was evaluated with a spacer block to ensure full extension and appropriate ligament tension in the extension space. Rotational alignment of the femoral component was performed to create a balanced flexion space of equal magnitude to the extension space. Wound closure and immediate postoperative protocols were identical between the study groups.

Study Interventions

Prior to surgery, all patients were enrolled in the same preoperative ERPM program. Available by smartphone application or internet-connected computer, the preoperative program consisted of educational content, preoperative exercise instruction, Health Insurance Portability and Accountability Act compliant direct messaging between patient and care team, and the collection of baseline PROMs. All patients were introduced to the platform as part of the routine preoperative consultation and were provided with specific instructions on its use. In addition, all patients were required to attend a preoperative, in-person educational class to learn about expected recovery milestones. Study staff followed study participants preoperatively to ensure patient compliance and proper utilization of the ERPM program using a platform-based engagement tool.

Patients randomized to ERPM + RPT were enrolled in a postoperative TKA recovery program developed by our physical therapists that was delivered by the ERPM program without in-person supervision or assistance by a physical therapist. The program consists of instructional videos demonstrating proper PT exercise techniques that can be viewed at any time from any smartphone or personal computer with internet access. The program includes sequential phases based on time from surgery and milestone achievement. In sequence, the phases were as follows: (1) knee ROM, (2) swelling reduction and gait training, and (3) muscle strengthening. The RPT sessions were delivered to the patient on the ERPM program twice daily for 6 weeks. After 6 weeks, the patients were instructed on a knee maintenance program. Compliance with the program and achievement of recovery milestones were tracked in real-time. The postoperative recovery program in the ERPM application remained available for ERPM + RPT patients for a total of 3 months after surgery. Patients who were randomized to the ERPM + RPT group that could not comply with the program because of technical difficulty or failure to reach appropriate recovery milestones were evaluated in person and allowed to crossover to the traditional ERPM + OPT pathway if they preferred.

After completing the same preoperative ERPM program, patients randomized to the ERPM + OPT pathway received a prescription for evaluation and treatment by a licensed physical therapist of their choice 3 times per week for 6 weeks after surgery. Although the ERPM-based postoperative RPT program was not followed in the OPT group, the OPT group continued to use the ERPM program for communication with the care team, collection of postoperative PROMs, and recovery milestones. After 6 weeks, the OPT group was given the same maintenance program as the RPT group. Patients who failed to achieve 90° of flexion by 6 weeks postoperatively were designated as meeting the threshold for manipulation under anesthesia (MUA).

Outcomes

Knee ROM was a primary outcome of the study. Additionally, participants completed Veterans Rand 12 Mental and Physical (VR-12 MCS/PCS) and knee injury and osteoarthritis junior preoperatively and at 6, 12, and 52 weeks postoperatively. Timed up and go, ROM, and 4-meter gait were measured preoperatively and at 6 weeks after surgery. NRS pain scores were evaluated preoperatively, and at 6 and 12 weeks, while patient satisfaction was evaluated at 6, 12, and 52 weeks postoperatively. OPT utilization was collected 90 days postoperatively for both groups. A subanalysis was conducted to compare patients who underwent surgery in the hospital versus those in the ASC (Supplementary Table 1).

Data Analyses

The data analysis was conducted on an intent-to-treat basis. Additional analysis was conducted comparing intent-to-treat and as-treated outcomes (Supplementary Table 2). Likewise, the demographics of patients who either declined to enroll in the study or did not meet inclusion criteria were compared to those of the enrolled patients (Supplementary Table 3). Study data were compiled, and the results from the 2 study groups were statistically analyzed (α of 0.05) for the determination of statistically significant differences in functional outcomes, satisfaction, and PT visits. Demographics and baseline characteristics were listed as means with standard deviations for continuous variables or frequencies with percentages for categorical variables. Normality testing was performed on continuous data, and means were compared using 2-tailed *t*-tests. Categorical data were analyzed using *Chi*-square or Fisher's exact tests. All data were analyzed using Excel analytics (Microsoft, Redmond, Washington) and RStudio (Posit, Boston, Massachusetts). We adhered to the consolidated standards of reporting trials guideline as a checklist for reporting randomized trials [7].

Crossovers and Withdrawals

Of the 197 patients randomized between August 2019 and May 2021, 95 (48%) were assigned to the ERPM + RPT and the remaining 102 (52%) were randomized to receive ERPM + OPT. In total, 19 patients crossed over and 7 withdrew from the study. Of the withdrawals, 4 were from the ERPM + RPT group and 3 were from the ERPM + OPT group. There were 15 patients who crossed over from ERPM + RPT to ERPM + OPT, while 4 crossed over from ERPM + OPT to ERPM + RPT. Most of the crossovers to ERPM + OPT occurred on account of patient preference for OPT or to address concerns regarding ROM (Table 2). After withdrawals and crossovers, 171 patients remained in the study and completed the study protocol, with 76 subjects remaining in the ERPM + RPT group (44%) and 95 in the ERPM + OPT group (56%). Crossover and withdrawal data are summarized in Figure 1 and Table 2.

Results

At 52 weeks of follow-up, there were no significant differences in any outcomes except for VR-12 PCS; however, the difference did not meet the clinical significance threshold of 5.0 [8]. Furthermore, there were no significant differences in patient-reported outcomes (knee injury and osteoarthritis junior VR-12 MCS/PCS), functional assessments (4-meter gait, timed up and go), knee ROM (flexion and extension), pain (NRS pain), or patient satisfaction between the study groups at any other follow-up point. No patient in either group met the threshold for a MUA. Participants in the ERPM + OPT arm of the study attended an average of 11.57 sessions, resulting in

Table 2
Analysis of Patients who Crossed Over From ERPM + RPT to ERPM + OPT (n = 15).

Sex	Age	Preop Extension	Preop Flexion	6W Extension	6W Flexion	Reason for Crossover
W	76	10	100	5	90	ROM
W	63	0	90	5	90	ROM
W	61	0	120	5	105	ROM
W	80	5	100	0[a]	105[a]	ROM
W	71	0	120	0	95	ROM
W	74	5	120	0	115	Patient Preference
M	76	0	120	0	125	Patient Preference
W	63	0	120	0	120	Patient Preference
W	77	−10	100	−5	90	Patient Preference
M	74	0	85	0	115	Patient Preference
W	54	3	120	−2	120	Gait Deficient
W	76	0	120	0	110	Gait Deficient
M	82	0	120	0	120	Fall
W	78	0	120	0	130	Pain/Weakness
W	73	0	100	0[a]	95[a]	Medical

ERPM, electronic remote perioperative management program; RPT, remote physical therapy; OPT, outpatient physical therapy; 6W, 6 Weeks Postop; ROM, range of motion.
[a] Four weeks postop due to missing data.

an average of 133 minutes of patient travel time and incurring $462.8 dollars in out-of-pocket co-pays (based on an average $40 market price point in our region). In contrast, participants attending internet-based PT had no expenses or travel time. Outcome data are shown in Table 3. Furthermore, no significant differences in outcomes were observed between hospital and ASC patients or between intent-to-treat and as-treated analyses. However, the patients who either declined to enroll in the study or did not meet inclusion criteria consisted of fewer men and had a higher average body mass index compared to those who agreed to enroll.

Discussion

In this study, participants undergoing SDD TKA enrolled in an electronic remote patient monitoring program with remote postoperative PT (ERPM + RPT) demonstrated equivalent outcomes to those who underwent formal supervised outpatient therapy (ERPM + OPT) postoperatively. Patients in the ERPM + RPT group realized considerable cost and time savings.

While the need and benefit of PT are well established, the optimal rehabilitation setting and methodology remain under investigation. In their meta-analysis and systematic review, Zhao et al. [9] found no difference in patient-reported outcomes, functional assessments, ROM, MUA, or other adverse events between supervised outpatient therapy and home-based therapy only. However, the authors were unable to account for procedural LOS, and the specific methods in the home therapy group were broad (one-on-one in-person home PT, telerehabilitation supervision, and unsupervised) [9]. The LOS after surgery is an important variable as it allows time for in-person patient education and PT instruction.

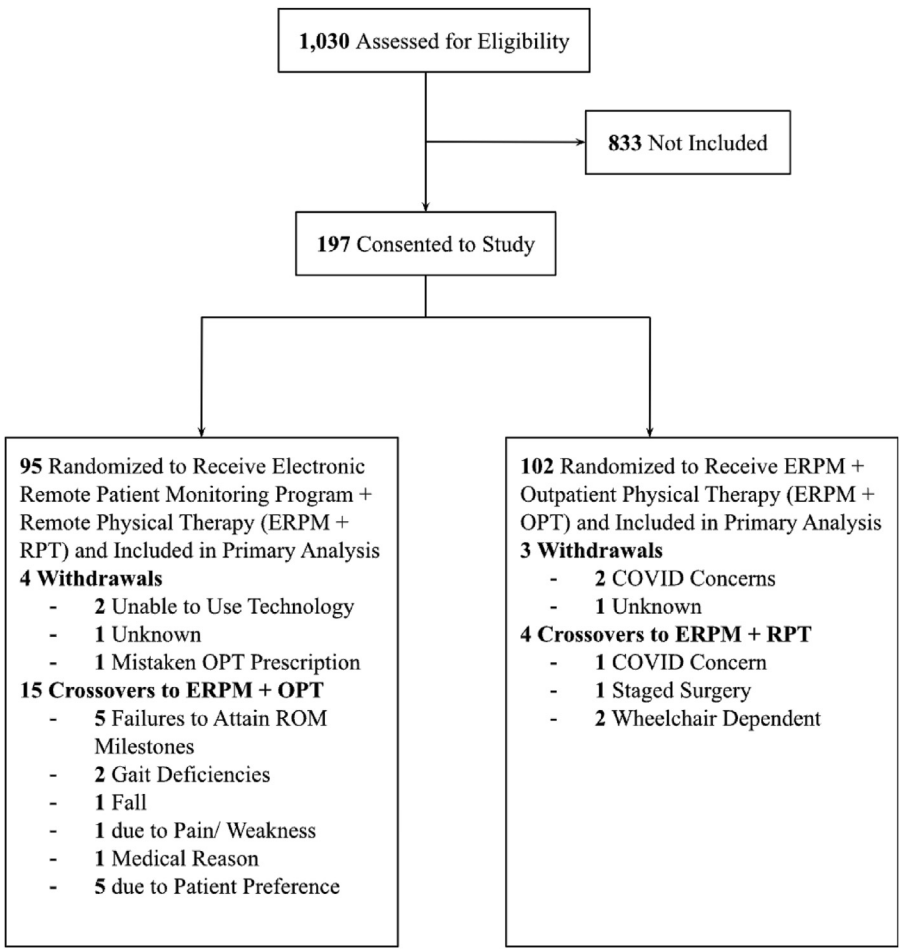

Fig. 1. This is a Consolidated Standards of Reporting Trials (CONSORT) flowchart showing patient recruitment, attrition, and retention.

Table 3
Results of Postoperative Outcomes Assessment.

Assessment	6 Wk		*P* Value	12 Wk		*P* Value	52 Wk		*P* Value
	ERPM + RPT	ERPM + OPT		ERPM + RPT	ERPM + OPT		ERPM + RPT	ERPM + OPT	
	(n = 95)	(n = 102)		(n = 95)	(n = 102)		(n = 95)	(n = 102)	
Postop Knee ROM (mean ± SD [min-max])									
Extension	0.48 ± 2.0 (−5 to 10)	0.82 ± 1.9 (−2 to 10)	.26	-	-	-	-	-	-
Flexion	116.2 ± 10.4 (90 to 135)	117.7 ± 8.5 (95 to 130)	.31	-	-	-	-	-	-
Postop Patient-Reported Outcomes (mean ± SD [min-max])									
KOOS, JR	67.4 ± 9.3 (40 to 85)	67.2 ± 11.0 (45 to 100)	.92	71.3 ± 10.4 (47 to 100)	72.4 ± 12.1 (50 to 100)	.50	79.2 ± 13.6 (50 to 100)	80.2 ± 13.6 (50 to 100)	.64
VR-12 MCS	53.3 ± 10.1 (29 to 71)	54.5 ± 8.8 (27 to 67)	.39	54.2 ± 9.3 (22 to 68)	54.4 ± 10.0 (28 to 70)	.93	55.4 ± 8.7 (30 to 67)	56.6 ± 6.8 (37 to 68)	.35
VR-12 PCS	38.2 ± 8.9 (17 to 55)	37.3 ± 9.5 (15 to 56)	.56	42.1 ± 8.7 (18 to 57)	40.9 ± 9.1 (17 to 56)	.35	**45.6 ± 9.3 (22 to 64)**	**42.4 ± 9.8 (15 to 58)**	**.03**
Postop Functional Assessment (mean ± SD [min-max])									
TUG	10.1 ± 4.7 (5 to 44)	9.9 ± 3.3 (5 to 21)	.79	-	-	-	-	-	-
4-meter Gait	3.8 ± 1.3 (0 to 11)	3.9 ± 1.4 (2 to 10)	.62	-	-	-	-	-	-
NRS Pain (0 to 10)	2.8 ± 1.8 (0 to 8)	1.9 ± 1.7 (0 to 7)	.25	3.4 ± 2.2 (0 to 10)	2.3 ± 2.0 (0 to 8)	.21	-	-	-
Patient Satisfaction	4.5 ± 0.70 (2 to 5)	4.7 ± 0.51 (3 to 5)	.08	4.6 ± 0.61 (3 to 5)	4.61 ± 0.72 (1 to 5)	.99	4.5 ± 0.90 (1 to 5)	4.71 ± 0.54 (3 to 5)	.12

Bolded *P* values indicate statistical significant results.
ERPM, electronic remote perioperative management program; RPT, remote physical therapy; OPT, outpatient physical therapy; SD, standard deviation; ROM, range of motion; KOOS, JR, knee injury and osteoarthritis outcome score; VR-12 MCS/PCS, veterans rand 12 mental and physical health component summary; TUG, timed up and go; NRS Pain, numeric pain rating scale.

Several investigators have compared unsupervised home PT and remote supervised PT (telerehabilitation) to in-person supervised outpatient PT after TKA. Fleischman et al. [5] demonstrated that at-home unsupervised PT using a web-based platform or printed paper manual was not inferior to conventional outpatient PT. However, these were not all SDD TKA cases, and LOS ranged from 0 to 5 days. Our study demonstrates similar outcomes in a different patient cohort, specifically, those undergoing SDD TKA.

The ERPM + RPT program investigated in this study offers several appealing features. First, ERPM + RPT provides a consistent rehabilitation schedule based on predetermined functional recovery milestones. Unlike traditional OPT, ERPM + RPT uses automated tracking and alerts tied to defined recovery milestones, ensuring a more standardized and closely monitored approach to rehabilitation. In addition, the ERPM + RPT program enables real-time monitoring of patient compliance and engagement throughout the recovery process. These continuous physiologic recovery data allow for immediate identification of the failure of a patient to meet milestones (ie, 4-week ROM milestones). As such, a struggling patient can be identified quickly and switched to a recovery protocol using more direct in-person supervision or MUA if needed. In contrast, OPT typically involves periodic evaluations rather than constant, real-time monitoring. The program also allows a Health Insurance Portability and Accountability Act-compliant direct line of communication with the physical therapists, nurses, and surgeons, which both arms of the study had access to. This method of communication allows patient questions and concerns to be addressed quickly by a multifaceted team, reducing patient anxiety and enhancing accessibility and support. Despite less direct human interaction in the ERPM + RPT group, we found that patient satisfaction was no different between the study groups. It is important to recognize that all patients in this study were required to attend a preoperative education class taught by our therapists and nurses. In the absence of such education, the ERPM + RPT group patients would have been more likely to feel anxious about the lack of in-person supervision.

This study is not without potential limitations. As the absence of a home care partner was an exclusion for study participation, the result of the study may not be applicable to those patients who do not have such support at home. Furthermore, 81% of patients either declined to participate or were excluded, indicating the potential presence of selection bias. The comparison of demographics between nonenrolled and enrolled patients revealed that those who did not enroll had similar American Society of Anesthesiologists scores but were more often male and had a higher body mass index. Study enrollment occurred during the COVID-19 pandemic. On account of concerns regarding in-person interactions, 2 patients withdrew from the ERPM + OPT group, and 4 patients opted to crossover from ERPM + OPT to ERPM + RPT. More important were the 15 patients who crossed over from the ERPM + RPT group to the ERPM + OPT group. Of those 15 patients, 5 demonstrated less than optimal motion at 6 weeks after surgery, but did not meet the MUA threshold. Interestingly, 3 of those 5 had major restrictions in motion prior to surgery. There were 5 patients who crossed over because of personal preference and 2 because of concerns regarding gait kinematics. In addition, of those who crossed over from ERPM + RPT to ERPM + OPT, 4 patients required the routine use of a cane and 7 reported a history of falls prior to surgery. Therefore, it makes sense that patients who have more important preoperative functional compromise will have a more reluctance to only use a remote-supervised PT program. In addition, 7 patients crossed over from ERPM + RPT because of concerns about achieving optimal ROM despite achieving appropriate objective ROM milestones. Although no patients in either group met the threshold for MUA, in-person assistance with ROM may have

provided benefit for those in the ERPM + RPT group who were apprehensive about their progress with motion. It is important to recognize the influence of surgical technique on ROM after TKA. The intraoperative use of spacer blocks provides a means of ensuring appropriate gap magnitudes. As such, the risk of limitation in ROM resulting from excessive ligament tension may be reduced.

Several patients were unsatisfied with ERPM + RPT and opted to crossover, while others failed to achieve the desired ROM independently. These results imply that not all patients are candidates for sole reliance on remote care. The authors believe that an ERPM + RPT program should be targeted toward higher-functioning patients who are capable and willing to participate. The OPT should be available for individuals who have limited functionality, limited technology skills, limited internet access, or anxiety related to a remote supervision program.

Conclusions

The ERPM + RPT program in this study is a viable, cost-effective rehabilitation strategy that offers improved convenience and an excellent means of postoperative patient monitoring for patients who are discharged on the same day after TKA. The authors encourage the utilization of ERPM + RPT for all patients who can use an internet-connected device, ambulate independently, and have an available care partner at home. However, supervised PT should be readily available for more frail patients needing more substantial postoperative support. Despite these encouraging results, further studies with larger sample sizes are needed to determine the ideal candidates for remote supervision.

CRediT authorship contribution statement

Thomas L. Bradbury: Writing – review & editing, Writing – original draft. **Mary Jane McConnell:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Deanna Whitacre:** Supervision, Project administration, Methodology, Investigation, Conceptualization. **Brandon H. Naylor:** Supervision, Methodology, Conceptualization. **Benjamin T. Gibson:** Supervision, Project administration, Methodology, Investigation. **Charles A. DeCook:** Supervision, Methodology, Conceptualization.

References

[1] Culliford D, Maskell J, Judge A, Cooper C, Prieto-Alhambra D, Arden NK, et al. Future projections of total hip and knee arthroplasty in the UK: results from the UK Clinical Practice Research Datalink. Osteoarthritis Cartilage 2015;23:594–600. https://doi.org/10.1016/j.joca.2014.12.022.

[2] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89:780–5. https://doi.org/10.2106/JBJS.F.00222.

[3] Burnett RA, Serino J, Yang J, Della Valle CJ, Courtney PM. National trends in post-acute care costs following total knee arthroplasty from 2007 to 2016. J Arthroplasty 2021;36:2268–75. https://doi.org/10.1016/j.arth.2021.01.021.

[4] Sambare TD, Bozic KJ. Preparing for an era of episode-based care in total joint arthroplasty. J Arthroplasty 2021;36:810–5. https://doi.org/10.1016/j.arth.2020.09.028.

[5] Fleischman AN, Crizer MP, Tarabichi M, et al. 2018 john N. Insall award: recovery of knee flexion with unsupervised home exercise is not inferior to outpatient physical therapy after TKA: a randomized trial. Clin Orthop Relat Res 2019;477:60–9. https://doi.org/10.1097/CORR.0000000000000561.

[6] Mehta SP, Barker K, Bowman B, Galloway H, Oliashirazi N, Oliashirazi A. Reliability, concurrent validity, and minimal detectable change for iPhone goniometer app in assessing knee range of motion. J Knee Surg 2017;30:577–84. https://doi.org/10.1055/s-0036-1593877.

[7] Schulz KF, Altman DG, Moher D. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. J Pharmacol Pharmacother 2010;1:100–7.

[8] Total knee arthroplasty outcomes. Cleveland clinic. https://my.clevelandclinic.org/departments/orthopaedics-rheumatology/outcomes/635-total-knee-arthroplasty. [Accessed 27 November 2023].

[9] Zhao B, Liu H, Du K, Zhou W, Li Y. Effectiveness and safety of outpatient rehabilitation versus home-based rehabilitation after knee arthroplasty: a systematic review and meta-analysis. J Orthop Surg 2023;18:704. https://doi.org/10.1186/s13018-023-04160-2.

Appendix

Supplementary Table 1
Comparative Analysis of Electronic Remote Patient Monitoring Program (ERPM) + Remote Physical Therapy (RPT) (ERPM + RPT) Versus ERPM + Outpatient Physical Therapy (OPT) (ERPM + OPT) in Hospital and Ambulatory Surgery Center (ASC) Patients.

Assessment	Hospital		*P* Value	ASC		*P* Value
	ERPM + RPT	ERPM + OPT		ERPM + RPT	ERPM + OPT	
	(n = 58)	(n = 55)		(n = 37)	(n = 47)	
Knee ROM (mean ± SD)						
Preop Extension	1.47 ± 4.05	2.43 ± 3.40	.18	1.17 ± 3.94	2.28 ± 3.62	.21
Preop Flexion	112.27 ± 10.71	113.58 ± 8.85	.49	111.17 ± 10.46	110.12 ± 12.12	.69
6 W Extension	0 ± 1.47	0.62 ± 1.93	.08	1.27 ± 2.59	1.08 ± 1.92	.74
6 W Flexion	116.26 ± 10.23	118.19 ± 8.04	.30	116.13 ± 10.78	117.13 ± 9.18	.68
Patient-Reported Outcomes (mean ± SD)						
Preop KOOS, JR.	51.19 ± 16.62	52.30 ± 11.82	.69	55.63 ± 12.86	50.33 ± 16.03	.10
6 W KOOS, JR.	67.30 ± 9.13	67.18 ± 11.72	.96	67.42 ± 9.70	67.18 ± 10.31	.92
12 W KOOS, JR.	71.43 ± 9.49	72.26 ± 11.37	.69	71.11 ± 11.79	72.62 ± 13.02	.59
52 W KOOS, JR.	77.57 ± 13.28	80.14 ± 14.54	.40	81.43 ± 13.99	80.25 ± 12.63	.72
Preop VR-12 MCS	53.05 ± 10.99	53.24 ± 11.99	.93	53.98 ± 11.68	52.53 ± 11.76	.58
6 W VR-12 MCS	54.22 ± 8.33	53.95 ± 9.75	.89	51.79 ± 12.31	53.95 ± 9.75	.41
12 W VR-12 MCS	54.47 ± 8.18	53.37 ± 11.64	.58	53.86 ± 11.10	55.43 ± 7.79	.49
52 W VR-12 MCS	54.42 ± 8.47	56.36 ± 7.38	.24	56.83 ± 8.87	56.74 ± 6.31	.96
Preop VR-12 PCS	33.90 ± 10.19	31.24 ± 8.17	.13	31.83 ± 9.83	32.16 ± 10.14	.88
6 W VR-12 PCS	40.05 ± 8.32	36.92 ± 9.63	.09	35.37 ± 9.16	37.83 ± 9.47	.26
12 W VR-12 PCS	42.24 ± 8.33	41.43 ± 8.72	.63	41.95 ± 9.33	40.32 ± 9.58	.45
52 W VR-12 PCS	45.57 ± 8.90	43.03 ± 10.52	.21	45.70 ± 10.02	41.72 ± 9.18	.07
Functional Assessment (mean ± SD)						
Preop TUG	10.60 ± 3.75	10.54 ± 3.60	.94	10.57 ± 4.07	12.42 ± 5.61	.12
6 W TUG	9.65 ± 2.63	10.02 ± 3.03	.52	10.55 ± 6.64	9.96 ± 3.71	.66
Preop 4-meter Gait	4.14 ± 1.72	4.05 ± 1.28	.23	4.03 ± 1.45	4.78 ± 2.18	.10
6 W 4-meter Gait	3.78 ± 0.92	4.05 ± 1.41	.28	3.80 ± 1.77	3.89 ± 1.30	.80
Preop NRS Pain (0-10)	5.40 ± 2.15	5.42 ± 1.93	.08	4.86 ± 1.97	5.70 ± 2.31	.97
6 W NRS Pain	2.38 ± 1.60	2.89 ± 2.05	.87	3.00 ± 1.95	3.08 ± 2.17	.18
12 W NRS Pain	1.85 ± 1.78	2.39 ± 2.17	.49	1.85 ± 1.73	2.23 ± 1.99	.29
6 W Patient Satisfaction	4.52 ± 0.54	4.67 ± 0.52	.18	4.31 ± 0.93	4.61 ± 0.72	.72
12 W Patient Satisfaction	4.60 ± 0.60	4.65 ± 0.73	.71	4.70 ± 0.68	4.57 ± 0.67	.67
52 W Patient Satisfaction	4.48 ± 0.92	4.74 ± 0.55	.11	4.66 ± 0.72	4.55 ± 0.83	.83

Bolded *P* values indicate statistical significant results.
SD, standard deviation; ROM, range of motion; 6 W, 6 weeks postop; 12 W, 12 weeks postop; 52 W, 52 weeks postop; KOOS, JR., knee injury and osteoarthritis outcome score; VR-12 MCS/PCS, veterans rand 12 mental and physical health component summary; TUG, timed up and go; NRS Pain, numeric pain rating scale; ERPM, electronic remote perioperative management program; RPT, remote physical therapy; OPT, outpatient physical therapy.

Supplementary Table 2
Comparative Analysis of Electronic Remote Patient Monitoring Program (ERPM) + Remote Physical Therapy (RPT) (ERPM + RPT) Versus ERPM + Outpatient Physical Therapy (OPT) (ERPM + OPT) with Intent-to-Treat Versus As-Treated Analysis.

	Intent-to-Treat		*P* Value	As-Treated		*P* Value
	ERPM + RPT (n = 104)	ERPM + OPT (n = 93)		ERPM + RPT (n = 79)	ERPM + OPT (n = 112)	
Knee ROM (mean ± SD)						
6 W Extension	0.48 ± 2.0	0.82 ± 1.9	.26	0.43 ± 1.83	0.84 ± 2.11	.19
6 W Flexion	116.2 ± 10.4	117.7 ± 8.5	.31	117.65 ± 8.93	116.57 ± 9.97	.47
Patient-Reported Outcomes (mean ± SD)						
6 W KOOS, JR.	67.4 ± 9.3	67.2 ± 11.0	.92	67.67 ± 9.02	66.88 ± 11.00	.61
12 W KOOS, JR.	71.3 ± 10.4	72.4 ± 12.1	.50	71.65 ± 10.51	71.99 ± 11.90	.84
52 W KOOS, JR.	79.2 ± 13.6	80.2 ± 13.6	.64	79.35 ± 13.93	79.98 ± 13.25	.78
6 W VR-12 MCS	53.3 ± 10.1	54.5 ± 8.8	.39	53.93 ± 9.32	53.80 ± 9.86	.93
12 W VR-12 MCS	54.2 ± 9.3	54.4 ± 10.0	.93	54.77 ± 8.76	53.84 ± 10.43	.52
52 W VR-12 MCS	55.4 ± 8.7	56.6 ± 6.8	.35	55.53 ± 8.31	56.60 ± 7.13	.41
6 W VR-12 PCS	37.3 ± 9.5	37.3 ± 9.5	.56	38.88 ± 9.13	36.93 ± 9.24	.17
12 W VR-12 PCS	42.1 ± 8.7	40.9 ± 9.1	.35	42.31 ± 8.96	40.81 ± 8.72	.26
52 W VR-12 PCS	**45.6 ± 9.3**	**42.4 ± 9.8**	**.03**	**46.03 ± 9.63**	**42.82 ± 9.59**	**.047**
Functional Assessment (mean ± SD)						
6 W TUG	10.1 ± 4.7	9.9 ± 3.3	.79	9.96 ± 3.08	10.18 ± 3.39	.59
6 W 4-meter Gait	3.8 ± 1.3	3.9 ± 1.4	.62	3.71 ± 1.02	4.01 ± 1.52	.13
6 W NRS Pain (0-10)	2.8 ± 1.8	1.9 ± 1.7	.25	2.70 ± 1.86	2.90 ± 2.02	.52
12 W NRS Pain	3.4 ± 2.2	2.3 ± 2.0	.21	1.90 ± 1.71	2.22 ± 2.08	.39
6 W Patient Satisfaction	4.5 ± 0.70	4.7 ± 0.51	.08	4.47 ± 0.72	4.58 ± 0.65	.28
12 W Patient Satisfaction	4.6 ± 0.61	4.61 ± 0.72	.99	4.64 ± 0.63	4.64 ± 0.67	.96
52 W Patient Satisfaction	4.5 ± 0.90	4.71 ± 0.54	.12	4.46 ± 0.97	4.71 ± 0.54	.07

Bolded *P* values indicate statistical significant results.
SD, standard deviation; ROM, range of motion; 6 W, 6 weeks postop; 12 W, 12 weeks postop; 52 W, 52 weeks postop; KOOS, JR., knee injury and osteoarthritis outcome score; VR-12 MCS/PCS, veterans rand 12 mental and physical health component summary; TUG, Timed Up and Go; NRS Pain, numeric pain rating scale; ERPM, electronic remote perioperative management program; RPT, remote physical therapy; OPT, outpatient physical therapy.

Supplementary Table 3
Patient Demographics Comparing Enrolled Patients Versus Patients who did not Meet Inclusion Criteria or Declined Enrollment in the Study.

Demographic Data	Enrolled Patients	Excluded/Declined Patients	*P* Value
Age (mean ± SD)	70.20 ± 8.14	71.16 ± 10.57	.179
% Men	**44.16**	**37.94**	**.019**
BMI (mean ± SD)	**30.24 ± 5.06**	**31.33 ± 6.82**	**.016**
ASA Score (mean ± SD)	2.37 ± 0.52	2.44 ± 0.53	.082

Bolded *P* values indicate statistical significant results.
SD, standard deviation; BMI, body mass index; ASA Score, American Society of Anesthesiologists Classification.

Reporting checklist for randomized trial

Based on the CONSORT guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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		Reporting Item	Page Number
Title and Abstract			
Title	#1a	Identification as a randomized trial in the title.	1
Abstract	#1b	Structured summary of trial design, methods, results, and conclusions.	2
Introduction			
Background and objectives	#2a	Scientific background and explanation of rationale.	3
Background and objectives	#2b	Specific objectives or hypothesis.	3
Methods			
Trial design	#3a	Description of trial design (such as parallel, factorial) including allocation ratio.	4
Trial design	#3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons.	N/A- no changes
Participants	#4a	Eligibility criteria for participants.	4
Participants	#4b	Settings and locations where the data were collected.	4
Interventions	#5	The experimental and control interventions for each group with sufficient details to allow replication, including how and when they were actually administered.	5 and 6
Outcomes	#6a	Completely defined prespecified primary and secondary outcome measures, including how and when they were assessed.	6
Outcomes	#6b	Any changes to trial outcomes after the trial commenced, with reasons.	N/A- no changes
Sample size	#7a	How sample size was determined.	4
Sample size	#7b	When applicable, explanation of any interim analyses and stopping guidelines.	6
Randomization - Sequence generation	#8a	Method used to generate the random allocation sequence.	5
Randomization - Sequence generation	#8b	Type of randomization; details of any restriction (such as blocking and block size).	5
Randomization - Allocation concealment mechanism	#9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned.	4
Randomization - Implementation	#10	Who generated the allocation sequence, who enrolled participants, and who assigned participants to interventions.	4
Blinding	#11a	If done, who was blinded after assignment to interventions (eg, participants, care providers, those assessing outcomes) and how.	N/A- impossible to blind
Blinding	#11b	If relevant, description of the similarity of interventions.	N/A- no blinding
Statistical methods	#12a	Statistical methods used to compare groups for primary and secondary outcomes.	7
Statistical methods	#12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses.	7
Results			
Participant flow diagram (strongly recommended)	#13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analyzed for the primary outcome.	7
Participant flow	#13b	For each group, losses and exclusions after randomization, together with reason.	7
Recruitment	#14a	Dates defining the periods of recruitment and follow-up.	7
Recruitment	#14b	Why the trial ended or was stopped.	N/A- not ended or stopped
Baseline data	#15	A table showing baseline demographic and clinical characteristics for each group.	Table 1
Numbers analyzed	#16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups.	7
Outcomes and estimation	#17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval).	Table 3
Outcomes and estimation	#17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended.	N/A
Ancillary analyses	#18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing prespecified from exploratory.	Figure 1 and Table 2
Harms	#19	All important harms or unintended effects in each group (For specific guidance see CONSORT for harms).	N/A- standard of care

(*continued on next page*)

(*continued*)

		Reporting Item	Page Number
Discussion			
Limitations	#20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses.	9 and 10
Generalizability	#21	Generalizability (external validity, applicability) of the trial findings.	10
Interpretation	#22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence.	8, 9, and 10
Registration	#23	Registration number and name of trial registry.	N/A- observational study
Other information			
Interpretation	#22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence.	8, 9, and 10
Registration	#23	Registration number and name of trial registry.	N/A
Protocol	#24	Where the full trial protocol can be accessed, if available.	N/A- unavailable
Funding	#25	Sources of funding and other support (such as supply of drugs), role of funders.	1