Prosthetic joint infections: new diagnostic and therapeutic strategies

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CHAPTER 3

Wound drainage after arthroplasty and prediction of acute prosthetic joint infection: prospective data from a multicenter cohort study using a telemonitoring app

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Abstract

Background

Differentiation between uncomplicated and complicated postoperative wound drainage after arthroplasty is crucial to prevent unnecessary resurgery. Prospective data about the duration and amount of postoperative wound drainage in patients with and without PJI are currently absent.

Methods

A multicenter cohort study was conducted to assess the duration and amount of wound drainage in patients after arthroplasty. During 30 postoperative days after arthroplasty, patients recorded their wound status in a previously developed wound care app and graded the amount of wound drainage on a 5-point scale. Data about prosthetic joint infection (PJI) in the follow-up period were extracted from the patient files.

Results

Of 1019 included patients, 16 patients (1.6%) developed a PJI. Minor wound drainage decreased from the first to the fourth postoperative week from 50% to 3%. Both moderate to severe wound drainage in the third week and newly developed wound drainage in the second week after a week without drainage were strongly associated with PJI. (OR 103.23, 95% CI 26.08 to 408.57, OR 80.71, 95% CI 9.12 to 714.52, respectively). The positive predictive value for PJI was 83% for moderate to heavy wound drainage in the third week.

Conclusion

Moderate to heavy wound drainage and persistent wound drainage were strongly associated with PJI. The positive predictive value of wound drainage for PJI was high for moderate to heavy drainage in the third week but was low for drainage in the first week. Therefore, additional parameters are needed to guide the decision to reoperate patients for suspected acute PJI.

Introduction

Total hip and knee arthroplasties are highly successful treatment modalities for advanced osteoarthritis, the most common joint disorder worldwide [1]. A prosthetic joint infection (PJI), which develops in approximately 1-2% of all arthroplasties, is a serious and devastating postoperative complication with a high impact on a patient's well-being[2,3]. Postoperative wound drainage is frequently reported as an important indicator for the presence of PJI [4-6]. Wound drainage may be an early symptom of a present PJI but may also be a risk factor for subsequent development of PJI [5,7]. Discrimination between infectious and non-infectious postoperative wound drainage is of crucial importance. When the prosthetic joint is infected, surgical debridement and protracted antimicrobial treatment is required. For 'noninfectious' serosanguinous drainage caused by intraoperative disruption of soft tissue and capillaries, only conservative wound management is indicated [4].

In 2013, the first International Consensus Meeting (ICM) on PJI advised that surgical management of persistent wound drainage should be performed without delay if wound drainage persists for five to seven days after index surgery [8]. According to the recently published EBJIS definition for PJI, an history of prolonged wound drainage (as a feature of wound healing problem) is a clinical sign included in the PJI likely category [9]. However, these recommendations were not backed up by research data about duration of postoperative wound drainage as summarized in a recent systematic review [4]. Collecting wound drainage data is challenging because most patients are discharged from hospital soon after surgery. The use of smartphone applications for distant telemonitoring of postoperative patients has been shown to be feasible and acceptable for both patients and surgeons [10-13]. In an earlier study, the use of a postoperative wound care app that was developed at Leiden University Medical Center, showed a high perceived usefulness and ease of use as reported by patients[14]. To assess the amount and duration of postoperative wound drainage after joint arthroplasty in patients with and without PJI, we conducted a nationwide cohort study using this smartphone application in which we collected detailed information regarding the condition and natural history of the postoperative wound.

Methods

A multicenter, prospective observational study was conducted in 11 Dutch academic and non-academic hospitals between November 1st, 2019 and October 1st, 2021. All patients aged 18 years and older who received a knee or hip arthroplasty, who were able to provide informed consent, owned an android or iOS smartphone and were able to read Dutch language, were eligible for inclusion. Patients were screened during or after preoperative visits by a local

nurse specialist or the coordinating study nurse. Informed consent was obtained via the woundcare app. Instructions how to use the app were provided to all patients by the local research coordinator. The nurses on the ward as well as the study coordinator were available for help with the use of the app during admission and throughout the study. All patients received routine postoperative medical care in the outpatient clinic as per local protocol in each participating hospital. Primary endpoint was the extent and duration of postoperative wound drainage in patients with and without PJI. Secondary endpoints were the association between presence of self-reported fever, redness and pain and PJI, and the validation of the designed algorithm for sending alert messages for suspected PJI. PJI was defined according to the criteria from the European Bone and Joint Infection Society.[9]

The use and function of the app has been described previously [14]. In short, for 30 days following joint arthroplasty patients recorded their wound status daily on their mobile app. Redness, pain (by visual analogue score, VAS), wound drainage and presence of fever were recorded, and a picture of the wound could be taken. Based on the questionnaires, an inbuilt algorithm created a daily risk score (see Appendix A). If this score exceeded a predefined threshold, which was based on expert consensus of participating clinicians, an alert message was issued that allowed patients to contact their treating physician via a push button in the app. It was for the attending clinicians to decide whether patients needed a clinical review or not. If wound drainage during the first 14 days was not reported, patients were allowed to stop using the app. They were instructed to resume using the app if new drainage or other complications arose. After both 30 and 90 days, all patients were asked to report postoperative complications in the app. After a minimum follow up period of 90 postoperative days, endpoint data were extracted both from the app as from the electronic patient files to enable comparison of patient-reported and physician-reported outcome. If discordant, the outcome reported by the attending orthopedic surgeon was regarded as the final outcome.

The study was conducted according to the principles of the Declaration of Helsinki. The study was approved by the ethics review committees and a waiver was obtained to use electronic instead of written informed consent. The use of the app for this study was approved by the Dutch Health Inspectorate (reference number VGR2O1 1434). The app was developed by software company Innovattic. This company was not involved in the setup, data-analysis and report of this study.

Quantification of wound drainage

The International Consensus Meeting (ICM) on PJI defined persistent wound drainage as >2 × 2 cm of drainage in the wound dressing beyond 72 hours after index surgery. However, this definition lacks a more detailed quantification of wound drainage [15]. Therefore, we used a proposed classification of persistent wound drainage which is currently used in another

Dutch wound drainage study (National Trial Registration 5960)[16]. On a daily basis, the patient had to enter the following drainage scores in the app: no drainage, minimal drainage, mild drainage, moderate drainage or heavy drainage (for exact definitions, see Table 1).

Table 1. Self-reported wound characteristics by patients in the wound care app.

Characteristic	Daily available scores for the patient after surgery
Fever	T < 38°C
	T 38-38.5°C
	T > 38.5°C
Wound drainage	No
	Minimal: <2x2cm on bandage
	Mild: >2x2cm on bandage
	Moderate: 1-2 bandages exchanged
	Heavy: >2 bandages exchanged
	Not judgeable (e.g., due to plaster/wound dressing)
Redness of wound	No
	Yes, less red than yesterday
	Yes, same as yesterday
	Yes, increased compared to yesterday
	Not judgeable (e.g., due to plaster/wound dressing)
Pain score (Visual Analogue Score)	Score 0-10 (via a slider in the app)

Statistical analysis

Descriptive statistics were used for baseline characteristics. To address missing values of wound drainage, the most recent drainage score was carried forward if data were missing after the first 14 days but only if the most recent drainage score was 'no drainage'. The cut-off of 14 days was based on the recommendation of the app to stop using the app after 14 days and only reuse it if any new complications arose. Odds ratios, sensitivity, specificity, and negative and positive predictive values were calculated to examine the strength of the association between mild or moderate to heavy wound drainage and PJI and between duration of wound drainage and PJI. Median duration of wound drainage was compared between patients with and without PJI using Mann Whitney U Test. All statistical analyses were performed with SPSS (IBM SPSS Statistics version 25.0, Armonk, USA).

Data flow and management

Privacy-sensitive data entered into the app by patients were pseudonymized with trusted real-time encryption. Encryption keys and a list of investigators who were allowed for de-encryption were stored by a Trusted Third Party (ZorgTTP). The encryption code and the data entered in the app were sent to a research database and were only decrypted to review the physician-reported outcome. Data files used for analysis will be stored on a local safe network storage facility.

Results

Of all patients eligible for inclusion during the study period, 1019 patients were included (total hip arthroplasty 46%, total knee arthroplasty 54%). Baseline and outcome characteristics are summarized in Table 2. During the first two postoperative weeks, the app was used by more than 80% of patients per day (Figure 1). The app use declined during the third and fourth week from 80% to 30%, consistent with the advice that use of the app beyond two weeks was only needed if new drainage or other complications would occur.

Table 2. Baseline and outcome characteristics of 1019 patients as entered in the app#

	Reported by patient in app	Definite report by study team
Baseline characteristics		
Age (median, range)	65 (18-90)	n/a
BMI (mean, SD)	29.1 (11.0)	n/a
Type of joint arthroplasty		
Knee	467 (46%)	n/a
Hip	547 (54%)	n/a
Other (shoulder, ankle)	2 (0.2%)	n/a
Tumour prosthesis (n, %)	10 (1%)	n/a
Past medical history		
Diabetes mellitus	73 (7%)	n/a
Rheumatoid arthritis	60 (6%)	n/a
Report of outcome		
Prosthetic joint infection	16 (1.5%)	16 (1.6%)
Surgery for suspected PJI, appeared to be no PJI	5 (0.5%)	3 (0.3)
Superficial wound infection, resolved after antibiotic treatment	5 (0.5%)	6 (0.6%)
Superficial wound infection, spontaneously resolved	22 (2.2%)	2 (0.2%)
No data available	176 (17.5%)*	39 (3.8%)^
I don't know	121 (11.9)	-
No complication (if data available)	674/843 (80.0%)	956/980 (97.6%)

#Outcome checked until three months postoperative

*179 patients did not fill out the outcome after 30 and 90 days.

^From one study center, data from the 39 included patients could not be retrieved from the local researcher.

n/a: not applicable

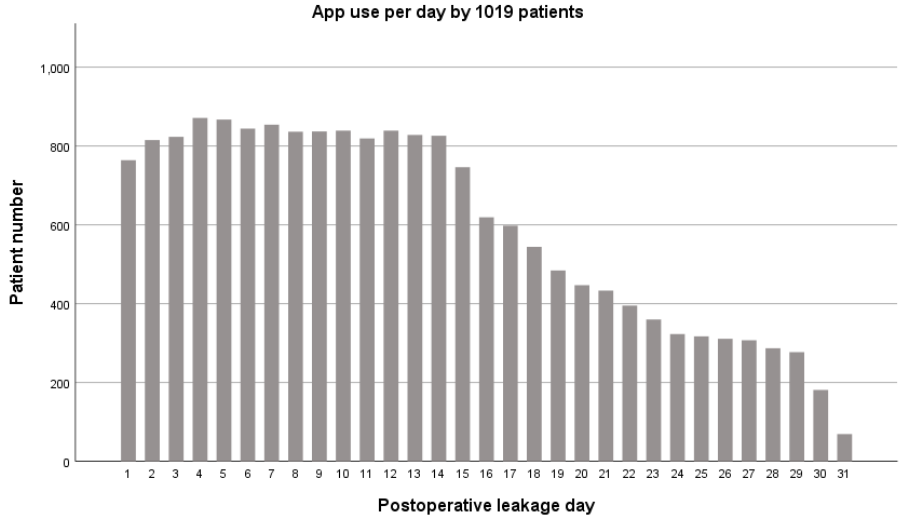


Figure 1. Daily wound care app use by patients during postoperative period

The incidence of postoperative wound drainage in patients with and without PJI is reported in Table 3 and Figure 2. During the first, second, third and fourth postoperative week, any form of wound drainage was present in 50%, 12%, 8% and 3% of patients without PJI and in 63%, 88%, 64% and 25% of patients with PJI. The high proportion of drainage in the first week was predominantly caused by minimal leakage (defined as <2x2cm on gauze) occurring in 87% (424/489) of patients without PJI. In this group, 51 patients (5%) had moderate to heavy wound drainage in the first week, decreasing to 1%, 1% and 0.1% in the next weeks. Moderate to heavy wound drainage of patients with PJI occurred in 25%, 38%, 46% and 0% of patients during four weeks. Reported redness (10%), fever (5%) and high pain scores (VAS >7, 11%) were mainly reported during the first week and declined thereafter. Proportions of wound drainage in patients without PJI varied depending on the type of joint, BMI and the presence of diabetes (Table 4).

Sixteen (1.6%) patients developed a PJI during the follow up period. Fourteen patients experienced an early postoperative PJI after a median of 14 days (IQR 10-18days). Two patients developed an early chronic PJI on postoperative day 71 and 77 (Table 5). Three patients were reoperated for a suspected PJI that was subsequently not confirmed (e.g. hematoma). Six patients (0.6%) received a short course of antibiotics for a presumed superficial wound infection but did not develop a PJI. The strongest risk factors for PJI were any wound drainage in the second week (OR 50.83, 95% CI 11.41-226.51), moderate to heavy drainage in the second (OR 51.22, 95% CI 15.84-165.65) or third week (OR 103.23, 95% CI 26.08-408.57). New onset drainage in the second week after a week without

Table 3. Reported postoperative wound drainage in all patients with and without prosthetic joint infection.

	1st week	
	No PJI	**PJI**
App use per week (n patients)	978	16
Wound drainage		
No wound drainage at all during week	416 (43%)	5 (31%)
Any wound drainage anywhere during week	489 (50%)	10 (63%)
Minimal (<2x2cm on gauze)	424 (87%)	8 (80%)
Mild (>2x2cm on gauze)	181 (37%)	7 (70%)
Moderate (1-2 gauzes exchanged)	41 (8%)	4 (40%)
Heavy (>2 gauzes exchanged)	10 (2%)	-
New onset drainage after 1week no drainage	-	-
> 4 days of wound drainage during week	82 (8%)	3 (19%)
Drainage not assessable*	165 (17%)	1 (6%)
Redness		
Any wound redness during week	100 (10%)	3 (19%)
Increased redness	32 (32%)	1 (33%)
Fever		
Fever during postoperative period	53 (5%)	-
Pain		
VAS > 5 anytime during week	360 (37%)	5 (33%)
VAS > 7 anytime during week	107 (11%)	0 (0%)
Alerts		
Any alerts during week	415 (42%)	8 (53%)
Number of alerts per week per patient		

*Patients with or without any drainage who could not assess wound drainage during one or more days during week due to gauzes in situ.

drainage (OR 80.71, 95% CI 9.12-714.52) and more than 5 cumulative wound drainage days during the first three postoperative weeks (OR 9.20, 95% CI 3.37-25.14) were also strongly associated with development of PJI (Table 6). Drainage for more than five days during the first three weeks predicted PJI with sensitivity of 63% and specificity of 87%, while drainage for more than 10 days predicted PJI with sensitivity of 27% and specificity of 97% (Appendix B). No wound drainage at all was reported by 467 patients (46%). Of them, only one patient developed a PJI resulting in a negative predictive value of no wound drainage as indicator for recovery without PJI of >98% (Table 6). The positive predictive value of any amount of wound drainage for PJI was low during the four postoperative weeks (2%, 11%, 8% and 4%, respectively) and increased for moderate-heavy wound drainage, especially in the third postoperative week (8%, 35%, 83%, 0%, respectively). Over the 4-week postoperative period, the average number of alerts per patient was not higher for patients with PJI compared to

2nd week		3rd week		4th week	
No PJI	PJI	No PJI	PJI	No PJI	PJI
950	16	999	11	999	4
789 (83%)	2 (13%)	903 (90%)	4 (36%)	973 (97%)	3 (75%)
115 (12%)	14 (88%)	76 (8%)	7 (64%)	25 (3%)	1 (25%)
98 (85%)	12 (86%)	65 (86%)	3 (43%)	24 (96%)	1 (100%)
25 (22%)	5 (36%)	19 (25%)	3 (43%)	4 (16%)	1 (100%)
10 (9%)	6 (43%)	1 (1%)	5 (71%)	1 (4H%)	-
2 (2%)	2 (14%)	-	-	-	-
28 (5%)	2 (13%)	25 (5%)	2 (50%)	4 (1%)	1 (25%)
31 (3%)	4 (25%)	11 (1.1%)	1 (9%)	4 (0,4%)	1 (25%)
50 (5%)	-	23 (2%)	-	1 (0.1%)	-
45 (5%)	3 (19%)	37 (4%)	3 (19%)	20 (2%)	0 (0%)
20 (44%)	2 (66%)	9 (24%)	0 (0%)	6 (30%)	0 (0%)
21 (2%)	1 (6%)	12 (1%)	2 (18%)	5 (0,5%)	1 (25%)
114 (12%)	1 (7%)	47 (5%)	1 (13%)	41 (4%)	-
19 (2%)	0 (0%)	8 (0,8%)	0 (0%)	6 (0,6%)	0 (0%)
250 (26%)	6 (40%)	101 (10%)	0 (0%)	66 (7%)	0 (0%)

patients without PJI (OR 1.37 (0.39-4.87). Of the 18420 days of app use, an alert was sent 2589 (14%) times to 498 patients. In total, 141 (6.6%) annotations could be obtained from the electronic patient files confirming that patients had contacted the hospital based on the sent alert. This led to a change of treatment in 61 (43%) patients as summarized in Appendix C. Of the 16 patients who developed a PJI, an alert was sent in the preceding period to six patients which resulted in earlier outpatient evaluation or hospital admission in three patients.

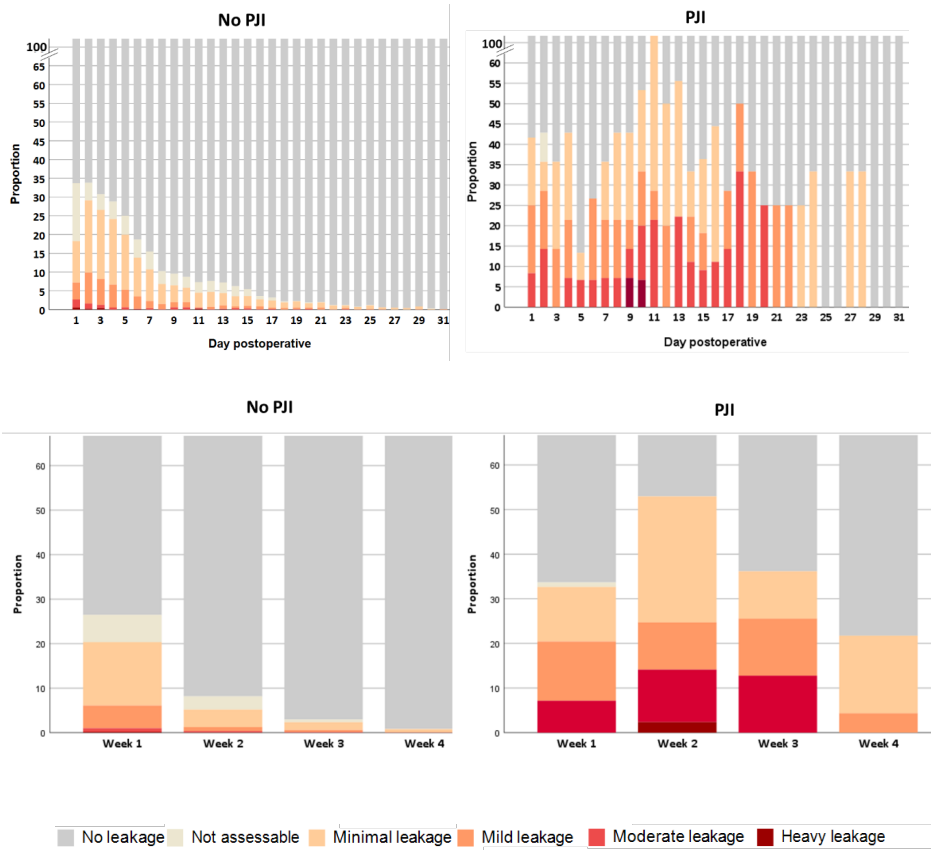


Figure 2. Reported extent and duration of postoperative wound drainage in patients with and without PJI.

Discussion

Principal findings

In the current study, a detailed overview of self-reported wound characteristics in the first month after arthroplasty while using a mobile wound care app provided important clinical insights. Complete absence of wound drainage during the first postoperative month was a sensitive and specific predictor of recovery without PJI. From the second week onward, wound drainage was strongly associated with the occurrence of PJI, but the positive predictive value remained low. Generation of an alert by the algorithm did not adequately identify patients with PJI.

Strengths and weaknesses

A major strength of this study is the unbiased prospective and daily information of exactly defined postoperative wound characteristics as provided by patients with an easy-to-

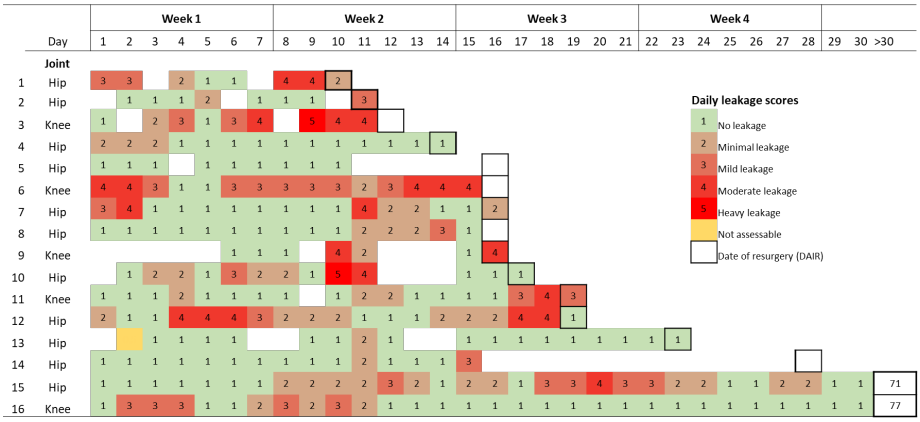
use smartphone application. Another strength is the large number of included patients without PJI that enabled us to create infographics of uncomplicated wound drainage for several subgroups of patients (Table 4).

Table 4. Percentage of postoperative wound drainage in 1003 patients without PJI during the postoperative course.

	Any wound leakage				Mild to heavy wound leakage				
	Hip		Knee		Hip		Knee		
	BMI < 30	BMI ≥ 30	BMI < 30	BMI ≥ 30	BMI < 30	BMI ≥ 30	BMI < 30	BMI ≥ 30	
DM	22%	30%	25%	72%	0%	10%	15%	38%	Week 1
No DM	40%	47%	62%	65%	12%	18%	27%	33%	
DM	11%	10%	19%	24%	0%	0%	10%	10%	Week 2
No DM	11%	16%	9%	9%	4%	8%	6%	4%	
DM	11%	0%	9%	24%	0%	0%	0%	14%	Week 3
No DM	5%	9%	7%	11%	1%	3%	3%	5%	
DM	0%	10%	0%	7%	0%	0%	0%	7%	Week 4
No DM	2%	2%	3%	6%	0%	2%	2%	1%	

Legend. BMI, Body Mass Index; DM, diabetes mellitus

Table 5. Drainage scores in 16 patients who developed a prosthetic joint infection



On verification in the patient files, *Patient 5* appeared to have stopped using the app on day 11 and subsequently developed wound drainage, redness and pain in the next three days without recording it in the app. On day 15, this patient was admitted with PJI. For *Patient 14*, no drainage data between day 14 and 28 could be retrieved from the patient notes.

This study has several limitations. The COVID-19 pandemic led to a temporary suspension of inclusions between March and May 2020 and continued to have a huge impact on the number of inclusions in the following year. The mean age of study participants (62.7 years for THA and 64.6 years for TKA) in our cohort was lower than the reported mean age in the Dutch Arthroplasty Registry involving all arthroplasties in The Netherlands (69.9 years for THA and 68.4 years for TKA in 2021), indicating that elderly may have been less willing to use the app. The relatively low number of patients with PJI in the study may have had an impact on the outcome. An even larger study would increase the precision of the results. Remarkably, patients who developed a PJI reported a relatively low proportion of wound redness and fever. We hypothesize that some patients with PJI symptoms may have visited their orthopedic surgeon without registering their symptoms in the app, but this remains speculative.

Table 6. Comparison of risk factors for failure in patients with and without PJI

	No PJI (n=1003)	PJI (n=16)	OR (95% CI)	Sens (%)	Spec (%)	PPV (%)	NPV (%)
Any drainage							
1st week	489/978	10/16	1.67 (0.60-4.62)	63	50	2	99
2nd week	115/950	14/16	50.83 (11.41-226.51)	88	88	11	100
3rd week	76/999	7/11	21.25 (6.09-74.22)	64	92	8	100
4th week	25/999	1/4	12.99 (1.31-129,24)	25	97	4	100
Moderate-heavy drainage							
1st week	47/978	4/16	6.60 (2.05-21.25)	25	95	8	99
2nd week	11/950	6/16	51.22 (15.84-165.65)	38	99	35	99
3rd week	1/999	5/11	103.23 (26.08-408.57)	45	100	83	99
4th week	1/999	0/4	-	0	100	0	100
New drainage after first week without drainage							
2nd week	28/480	5/6	80.71 (9.12-714.52)	83	94	15	100
3rd week	25/512	3/5	29.22 (4.67-182.85)	60	95	11	100
4th week	4/512	1/3	63.50 (4.74-850.04)	33	99	20	100
>5 cumulative leaking days during day 1-21							
2nd - 4th week	123/1003	9/16	9.20 (3.37-25.14)	56	88	7	99
Moderate to heavy drainage and/or fever and/or redness							
1st week	164/978	6/16	2.98 (1.07-8.31)	38	83	4	99
2nd week	68/950	7/16	10.09 (3.65-27.92)	44	93	9	99
3rd week	47/999	6/11	21.00 (6.21-70.99)	55	95	11	99
4th week	23/999	1/4	14.15 (1.42—141.17)	25	98	4	100
>2 alerts based on algorithm*							
1st week	141/978	3/16	1.37 (0.39-4.87)	19	86	2	98
2nd week	128/950	1/16	0.43 (0.06-3.27)	6	87	1	98
3rd week	69/999	0/11	-	0	93	0	99
4th week	47/999	0/4	-	0	95	0	100

Legend: PJI, prosthetic joint infection; OR, odd ratio; sens, sensitivity; spec, specificity; PPV, positive predicted value; NPV, negative predicted value.

* Algorithm is defined in Appendix A.

The short follow up of at least three months is a limitation of this study, in which we focused on the relation between wound drainage and early postoperative PJI. For late acute hematogenous PJI, initial wound drainage is probably not relevant because bacteremia is mostly the source of PJI. However, some patients with a chronic PJI will have been missed in our study and these patient may have had prolonged initial wound drainage providing a route for Coagulase-negative staphylococci to reach the implant and cause late chronic PJI. This would have resulted in an even stronger reported association between wound drainage and PJI than reported in this study. This needs to be further investigated in a follow up study.

Implications of our findings

This study has three important implications. First, moderate to heavy wound drainage in the third week strongly predicted PJI with a number needed to operate to diagnose one PJI of 1.2 patients. Although this predictor was only derived from a small subset of patients with PJI, moderate to heavy drainage was nearly absent in patients without PJI. Therefore, these patients need urgent clinical assessment of the postoperative wound to decide whether the patient should be operated for a suspected PJI or not.

Second, persistent wound drainage and wound drainage in the second and third postoperative week was strongly associated with development of PJI. However, positive predicted values were low due to the many patients with wound drainage during those weeks who did not develop PJI. If all patients with any form of drainage during the second postoperative week were regarded as suspected PJI, ten patients would need to be operated to find one PJI. This indicates that, even with a strong association between drainage and PJI, wound drainage alone is not an accurate predictor for presence of PJI in this group. The strength of the association did not increase significantly when fever and wound redness were added to wound drainage as risk factors, which may relate to the earlier mentioned low proportion of these symptoms reported by patients.

Third, wound drainage in the first postoperative week was not indicative of PJI. The high proportion of reported wound drainage during this week (Table 3, Figure 4) is explained by several factors: (1) drainage was recorded from the very first day postoperative day (not from discharge from hospital), (2) minimal wound drainage could have occurred during only one day of this week to be counted as wound drainage and (3) drainage was minimal (defined as <2x2cm on the gauze) in 87% of the patients with drainage in the first week (424/489 patients). Only 5% (n=51) of patients in this group had moderate to heavy wound drainage. In the second postoperative week wound drainage dropped down to 12%, again with minimal drainage (<2x2cm on gauze) in most (85%) of these patients.

This study confirmed that in patients without any wound drainage, an early postoperative PJI is very unlikely. With mobile health applications, this subgroup of patients can be easily identified during follow up and fewer outpatient visits may be needed during follow up which may reduce costs. The postoperative use of bandages during the first weeks to cover the postoperative wound may have resulted in underreporting of wound drainage. However, the impact was estimated to be similar in patients with and without PJI as the use of bandages was identical for all patients. We also assessed whether the closing technique (use of either glue or staples) was associated with duration of postoperative wound drainage after hip arthroplasty during the first two weeks, which was not the case (staples 3.2 days, glue 2.9 days, $p = 0.52$).

Only one out of the 16 patients with a PJI received more than two alerts prior to the PJI, indicating that the used algorithm was inadequate for predicting PJI. This may be explained by the low threshold in the algorithm for sending alerts secondary to pain and mild wound drainage. Many alerts were sent for minimal wound drainage or relatively mild pain scores not related to PJI. Unfortunately, a low number of alert-based treatment adaptations could be retrieved from the patient files making evaluation of the alerts send by the application speculative. Patients apparently made the right decision not to call their physician as no PJI occurred in 98% of them. The predictive value of the algorithm may be improved by using a machine learning algorithm, making iterative changes when the number of data increases thus allowing an automated update of the algorithm. Adding parameters like an increase in C-reactive protein may also increase the yield of the algorithm. Further, based on the current study, no "at-risk" points should be given for minimal wound drainage and low pain scores.

Conclusions

Detailed knowledge of the extent and duration of wound drainage after arthroplasty is vital for orthopedic surgeons who consider to reoperate patients with postoperative wound drainage for a suspected PJI. In this study, in which a mobile health application was used to monitor patients after arthroplasty, PJI was very unlikely in patients without any wound drainage. From the second week onward, wound drainage was strongly associated with the occurrence of PJI, but the sensitivity and positive predictive value of wound drainage as a single predictor for PJI was low. Due to the limited follow up of three months, some patients with a late chronic PJI may have been missed. The insights from this study may help clinicians evaluate postoperative patients who present with a leaking wound. Future research should focus on optimizing the algorithm, thereby improving the predictive value of the alert function.

Author contributions

Conceptualization: HS, RN, LV, MB, CL. Formal analysis : HS, MB, RZ. Software: RZ. Funding acquisition: HS, MB, RN. Investigation: RM, BE, WZ, TG, JL, RW, RP, MS, PJ, KB. Original draft preparation: HS. Review and editing: HS, BE, RM, WZ, TG, JL, RW, RP, MS, PJ, KB, RN, LV, MB. Supervision: MB, LV, RN

Ethical statement

The study was conducted according to the principles of the Declaration of Helsinki. The study was approved by the ethics review committee of Leiden University Medical Center and a waiver was obtained to use electronic instead of written informed consent(P18.220). The use of the app for this study was approved by the Dutch Health Inspectorate (reference number VGR2O1 1434).

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Competing interests

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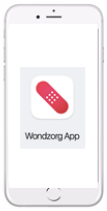
Appendices

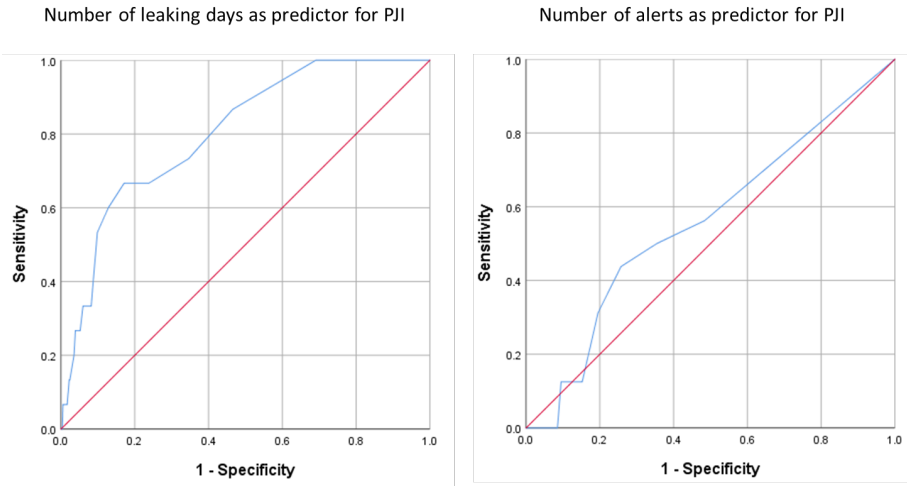
Appendix A. Calculated scores from the app and algorithm for sending alert to patients

Daily review	Answers	Points
1. Fever?	T <38^{o}C	0
	T 38-38.5^{o}C	2
	T 38-38.5^{o}C (>2days)	5
	T >38.5^{o}C	5
2. Wound leakage?	No	0
	Minimal(<2x2cm on bandage)	1
	Mild (>2x2cm on bandage)	2
	Moderate (1-2 bandages exchanged)	3
	Severe (>2 bandages exchanged)	4
	Not judgeable (e.g. plaster/dressing)	0
3. Redness of wound?	No/unchanged	0
	Increased redness compared to yesterday	2
4. VAS score	VAS ≤ 5	0
	VAS >3 (>3days)	3
	VAS >2pts increase in 1 day	3
	VAS 6 or 7	3
	VAS >7	4
	Total amount of points:	☐



Score is calculated daily. Alert sent if: ≥ 5 points *or*
≥ 4 points 2 consecutive days *or*
≥ 3 points 3 consecutive days

Appendix B. ROC using duration of leakage days or number of sent alerts as cutoff value for detecting PJI.



Appendix C. Actions taken on algorithm-based alerts generated by the app from 18437 daily reports

	All	No PJI (n=1013)	PJI (n=16)
Total alert count	2590 (14%)		
Alerts received (n patients)	498/1019 (48.9%)		
Alert 1st week postoperative (n patients)	423/498 (84.9%)		
Alert 2nd week postoperative (n patients)	232/498 (46.6%)		
Alert 3rd week postoperative (n patients)	97/498 (19.5%)		
Alert 4thweek postoperative (n patients)	68/498 (7.0%)		
Alerts per individual patient (median)	3		
Reported patient-physician contact based on alerts	141/2124 (6.6%) *	135 (13%)	6 (40%)
Outcome of patient-physician contact			
No action needed	51 (36%)	51	0
Adjust pain medication	34 (24%)	34	0
Earlier outpatient evaluation	24 (17%)	22	2
Admission to hospital	3 (2%)	2	1
Other	29 (21%)	26	3

* From 466 alerts, patient files could not be checked for placed phone calls

^

$ Practical wound management advice, Deep Venous Thrombosis excluded, patient not yet discharged