Submaximal cardiopulmonary exercise testing to evaluate aerobic capacity in patients with knee osteoarthritis scheduled for total knee arthroplasty: *a feasibility study*

Master thesis

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Name student:	A.C.M. (Anke) Kornuijt
Student number:	6639941
Date:	27 July 2021
Internship supervisors:	Dr. R.G.J. Marcellis, Dr. B.C. Bongers and Prof. dr. A.F. Lenssen
Internship institute:	Department of Physical Therapy, Maastricht University Medical Center (MUMC+), Maastricht, The Netherlands
Lecturer/supervisor Utrecht University:	Dr. M.F. Pisters

“ONDERGETEKENDE

Anke Caroline Mireille Kornuijt,

bevestigt hierbij dat de onderhavige verhandeling mag worden geraadpleegd en vrij mag worden gefotokopieerd. Bij het citeren moet steeds de titel en de auteur van de verhandeling worden vermeld.”

Examiner

Dr. M.F. Pisters

Assessors:

Prof. dr. A.F. Lenssen

Prof. dr. C. Veenhof

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ABSTRACT

Background

Higher aerobic capacity before surgery possibly is prognostic for a better and faster recovery in patients with knee osteoarthritis (OA) scheduled for total knee arthroplasty (TKA). Cardiopulmonary exercise testing (CPET) is the gold standard to evaluate aerobic capacity; however, until now no studies have investigated the feasibility of submaximal CPET using cycle ergometry in this population.

Aim

To investigate the feasibility of submaximal CPET in patients with knee OA scheduled for TKA surgery in three domains: 1) recruitment rate of participants who are representative of the target study population; 2) feasibility of a submaximal CPET procedure; and 3) acceptability and suitability. Furthermore, this study aimed to assess the aerobic capacity of participants using submaximal CPET indicators and to compare these results with normative values.

Methods

In this cross-sectional multi-centre feasibility study, participants with knee OA scheduled for primary unilateral TKA surgery performed a submaximal CPET following preoperative screening, three to six weeks before surgery. To examine their experiences, participants completed a questionnaire and one week later they were contacted by telephone. CPET feasibility was assessed against five criteria: 1) recruitment rate ≥20%; 2) CPET performance rate ≥90%; 3) ≥90% of participants reached the ventilatory anaerobic threshold (VAT); 4) no serious adverse events; and 5) ≥80% of participants had a positive attitude towards CPET. Aerobic capacity was evaluated using the oxygen uptake (VO_2) at the VAT and oxygen uptake efficiency slope (OUES) .

Results

All feasibility criteria were met: 14 representative participants were recruited (recruitment rate: 53.8%), all were able to perform the test, reached the VAT, were positive towards CPET and no serious adverse events occurred. The median VO_2 at the VAT was 12.82 $ml.kg^{-1}.min^{-1}$ (IQR 11.29–13.63). The median OUES was $23.09.kg^{-1}$ (IQR 20.23–28.90), and 109.5% and 113.0% of predicted.

Conclusion and key findings

Submaximal CPET using cycle ergometry is feasible in patients with knee OA scheduled for TKA surgery to evaluate aerobic capacity. Based on these results, the exercise test can be used preoperatively to identify patients with a reduced aerobic capacity.

Trial registration: NCT04773262.

Keywords: Osteoarthritis, Knee, Cardiopulmonary Exercise Testing, Feasibility.

INTRODUCTION

Patients with end-stage osteoarthritis (OA) of the knee experience increasing pain and are progressively restricted in their activities of daily living.[1,2] As part of usual care before their total knee arthroplasty (TKA) procedure, patients are screened for risk factors for a delayed postoperative recovery by measuring preoperative physical functioning.[3,4] Various practical performance-based tests are used during screening, such as measuring handgrip strength, and the Timed-Up-and-Go test (TUG)[5] and the De Morton Mobility Index (DEMMI)[6] as measures for functional mobility. Evaluating preoperative aerobic capacity might have added value, but is never part of the standard preoperative screening. Cardiopulmonary exercise testing (CPET) is the gold standard for objectively measuring aerobic capacity.[7]

There is uncertainty whether it is feasible to perform a submaximal CPET prior to TKA surgery using cycle ergometry in patients with knee OA. Submaximal CPET is considered more suitable for this population compared to the usual maximal exercise test. In patients with knee OA, peak exercise is more likely limited due to musculoskeletal symptoms (joint pain, muscle pain, or muscle fatigue) rather than generalized fatigue or dyspnoea.[8] In the few studies which examined maximal aerobic capacity using CPET prior to TKA surgery, the minimum threshold values indicative of a maximal exercise response (in these studies defined as ≥80% of age-predicted maximum heart rate (220 minus age) and a respiratory exchange ratio at peak exercise of ≥1.0) were not achieved in 11–28% of the patients,[8,9] due to musculoskeletal limitations.[8] Furthermore, approximately 40% of the patients could not cycle due to a restricted knee flexion range of motion or pain, possibly leading to selection bias.[8–11] One study reported recruitment difficulties since eligible patients did not volunteer because of fear of inability to perform the CPET.[8]

Instead of measuring the highest oxygen uptake achieved during the test (VO_2 peak), submaximal exercise responses can be evaluated as indicators for aerobic capacity,[12] like VO_2 at the ventilatory anaerobic threshold (VAT) and the oxygen uptake efficiency slope (OUES). Studies have shown a strong correlation ($r \geq 0.80$) between these two submaximal parameters and VO_2 peak.[13,14] Patients with end-stage knee OA show severe deconditioning, reflected with a reduced VO_2 peak of 12.8 $ml.kg^{-1}.min^{-1}$ compared to 17.6 $ml.kg^{-1}.min^{-1}$ in patients without OA ($p < 0.0005$).[9] In addition, deconditioning was more prominent in patients with more severe knee OA.[10]

In patients undergoing non-cardiopulmonary thoraco-abdominal surgery, a higher aerobic capacity is a valid predictor of lower perioperative morbidity and mortality.[15] A higher aerobic capacity prior to joint replacement surgery is assumed to be prognostic for a better and faster postoperative recovery. This is supported by the feasibility study of Pilot et al.,[16] in which CPET was performed before and after total hip arthroplasty. Preoperative well-conditioned patients had a better postoperative VO_2 peak value compared to patients with a poor preoperative condition,[16] possibly influencing postoperative recovery. In patients with a reduced aerobic capacity prior to TKA, physical therapy might improve their preoperative aerobic capacity ('prehabilitation'), which may lead to better postoperative functioning.

First, it is necessary to have a feasible exercise test, which can be used preoperatively to identify patients with a reduced aerobic capacity. Feasibility can be assessed in different ways, for example by examining recruitment rate, appropriateness of CPET using cycle ergometry and patients' acceptability.[17] We hypothesized that evaluating aerobic capacity with submaximal CPET is feasible in patients with knee OA scheduled for TKA. Therefore, the primary objective of this study was to investigate this feasibility in three domains, as defined by Orsmond et al.[17]: 1) recruitment rate of participants who are representative of the target study population; 2) feasibility of CPET procedure; and 3) acceptability and suitability of CPET. Secondly, this study will explore the aerobic capacity of the study population using submaximal parameters and compare these results with normative values.

METHODS

Study design and setting

This cross-sectional multi-centre feasibility study was performed in May and June 2021 at the Maastricht University Medical Center (MUMC+), Maastricht, the Netherlands and St. Anna Hospital, Geldrop, the Netherlands. MUMC+ was responsible for the integrity and conduct of the study. The study protocol was approved by the Medical Ethics Committee of the academic hospital Maastricht and Maastricht University (METC azM/MU, approval number 21-009) and was registered in ClinicalTrials.gov[18] (ID number NCT04773262).

Study participants

One of the participating orthopaedic surgeons referred all patients scheduled for TKA for a standard preoperative screening by a physical therapist. Potential patients for this study received verbal and written information about the study by the surgeon and, if interested, contacted the investigator who gave them further verbal information. Written informed consent was given face-to-face by the patient and investigator prior to participating in any study-related activities, after which the investigator assessed the eligibility criteria. Inclusion criteria were: scheduled for primary unilateral TKA surgery at the MUMC+ or St. Anna Hospital; diagnosis of knee OA; CPET that can be planned three to six weeks before TKA surgery following the preoperative screening; and sufficient mastery of the Dutch language. Exclusion criteria were: scheduled for revision arthroplasty, bilateral TKA or hemi-arthroplasty surgery; contraindications for CPET according to the American Thoracic Society (ATS) Statement on CPET[12] or following the American Heart Association/American College of Sports Medicine (AHA/ACSM) Health/Fitness facility pre-participation screening questionnaire[19]; unable to get on and off a stationary bike; complete dependence on a wheelchair; serious comorbidities (e.g. malignancy, stroke); cognitive impairments and; unable to sign informed consent.

Study procedure

Recruited patients were first subjected to the preoperative screening with the physical therapist. Participants' demographic data, including the use of walking aids, smoking status and degree of comorbidities, using the American Society of Anesthesiologists (ASA) classification[20] and Charnley classification,[21] were collected (Table 1). Subsequently, the participants performed a submaximal incremental CPET on an electronically braked cycle ergometer (Lode Corival CPET, Lode B.V. Groningen, the Netherlands), supervised by a trained clinical exercise physiologist. Participants were pre-instructed to continue their regular medication, but avoid caffeine, alcohol and cigarettes on the day of testing and eating a large meal in the two hours before the test.[7] Participants were also advised to abstain from high-intensity physical activity the day before the test and test day itself. Seat height was adjusted to the participant's leg length and it was assessed whether the participant could pedal the bicycle. During the test, participants breathed through a facemask, enabling measurement of minute ventilation, oxygen uptake, and carbon dioxide production. Heart rate was measured by continuous 12-lead electrocardiography. The test included a resting measurement of three minutes, followed by three minutes of unloaded cycling and then cycling with a constant work load which increased per minute. The increase in work load per minute (7.5, 10, 12.5 or 15 $W.min^{-1}$) depended on the patient's subjective physical fitness level. A pedal rate between 60 and 80 revolutions per minute (rpm) was maintained. Participants were instructed to cycle until they felt unable to continue due to cardiovascular and/or musculoskeletal complaints (which were registered) or until they wanted to stop volitionally. They could stop the test whenever they felt the need to do so, while the exercise physiologist would stop the test if the participant rated the effort as 'hard' on the Borg Rating of Perceived Exertion (RPE) 6–20 scale (value of ≥15). This instrument measures the subjective perception of effort during exercise[22] and 95% of the patients reach the VAT with a RPE-value of <15.[23] Each minute and after test completion, the participant was asked to indicate the effort on the Borg RPE scale, which had been explained before the CPET performance. The test ended with unloaded cycling to recover.

Shortly after the exercise test, acceptability and suitability of the CPET were examined by a questionnaire to explore the subjective experiences and perceptions of participants. The questions were drafted by the research team according to the ATS Statement[12] and four constructs of the theoretical framework of acceptability, namely 'affective attitude' (feelings), 'burden' (amount of effort), 'self-efficacy' (confidence) and 'intervention coherence' (understanding of CPET)[24] (Appendix I). The construct 'perceived effectiveness' was evaluated by the investigators whether the participants had reached the VAT. Two constructs, 'ethicality' and 'opportunity costs', were not evaluated. Included items of the questionnaire were the reason to stop cycling and the perceived willingness of participants to perform future CPET. Measurement of pain pre and post exertion, motivation, burden, self-efficacy, and the extent of being well informed about the aim, performance and possible side effects of the CPET were recorded, using the numeric rating scale-11 (NRS-11). The pain NRS is a reliable and valid pain measurement with a minimal detectable change of 1.3 in patients with knee pain due to OA.[25] One week after the exercise test, the investigator called the participants to inquire if any CPET-related physical complaints had occurred, to evaluate reasons of willing or not willing to perform the CPET again and if items could be improved during the entire process (Appendix II).

Study outcomes

The primary outcome in the present study was the feasibility of CPET operationalized with five feasibility criteria, specifically: 1) recruitment rate ≥20%; 2) performance rate ≥90%; 3) success rate ≥90%; 4) 0% of participants experienced serious adverse events; and 5) ≥80% of participants had a positive attitude towards CPET. Recruitment rate was defined as the percentage of patients recruited among those eligible. Performance rate was assessed by the percentage of recruited participants performing CPET. They were able to pedal the bicycle with at least 60 rpm and cycling was not hindered by restricted knee flexion. Success rate was defined as the percentage of participants who reached the VO_2 at the VAT during CPET performance. Safety was assessed by recording any unexpected serious adverse events that occurred during or after the test. Finally, a positive attitude towards CPET was defined as willing to perform the exercise test again at a later moment. The feasibility targets for success were defined a priori by the research team and were consensus-based.

The secondary outcome was the aerobic capacity of the study population, using VO_2 at the VAT and the OUES, presented both at group and individual level. VO_2 at the VAT in absolute ($ml.min^{-1}$) and relative value ($ml.kg^{-1}.min^{-1}$) was non-invasive determined by CPET software (SentriSuite). Verification was done by two trained independent investigators (BB, AK), using both the ventilatory equivalents method[26] and the V-slope method.[27] A previous study showed high agreement in determining the VAT in a large cohort of asymptomatic volunteers with an intraclass correlation coefficient (ICC) of 0.95 (95% CI 0.95–0.96) and a mean difference of 5 $ml.min^{-1}$ (95% limits of agreement ±161 $ml.min^{-1}$).[28] Work rate and heart rate were also recorded at this threshold. The OUES was determined from the linear relationship of VO_2 versus the logarithm of ventilation during exercise using all test data (since the start of the work rate increments), in absolute value and normalised for body mass ($OUES.kg^{-1}$).[13] High intratest reliability has been found in healthy subjects with ICCs ranging from 0.89–0.99 between submaximal (OUES calculated at 70% or 90% of total exercise time) and maximal derived values of OUES. The test-retest reliability coefficient of OUES was 0.93.[29] In addition, values of OUES were compared with normative values.[30,31] Variables that may affect aerobic capacity were recorded during the preoperative screening (e.g. body mass, comorbidity, smoking) and prior to CPET performance by measuring forced expiratory volume in one second (FEV_1) and registration of beta blockers usage.

Sample size justification

Sample size estimation was based on justification[32] that the feasibility study was large enough to provide useful information about the participants' experiences with the exercise test and their attitude towards submaximal CPET. With a sample size of 12 participants, the 90% confidence interval of reaching the VAT in ≥90% of the participants will be +/-14%, which is considered acceptable. The continuous variables of aerobic capacity can be described with sufficient precision about the mean and variance with at least 12 participants.[33,34]

Analysis

During the analysis, it was determined whether the feasibility criteria for success had been met. Descriptive statistics were used to evaluate primary and secondary outcomes and characteristics of the study population.[35] Categorical variables were presented as numbers and proportions. For continuous variables normality was assessed visually (histograms, boxplots) and through the Shapiro-Wilk test. Normally distributed data were described as mean and standard deviation (SD), while median and interquartile range (IQR) were used for non-parametric data.[36] The OUES values of the participants were expressed as percentages of predicted values from two studies of relative healthy persons.[30,31] To examine the representativeness of the study population, age and sex were compared between participants and all patients screened during the study period. The percentage females was allowed to deviate by a maximum of +/-20%. Age had to be within one SD using the mean, or within the IQR using the median, according to distribution type. Furthermore, reasons for non-participation in the study were also explored. Statistical analysis was performed using the statistical software package SPSS® (version 25.0).

RESULTS

During the study period, only patients from the St. Anna Hospital were included since no TKA surgeries were performed in the MUMC+ due to COVID-19 measures. Of a total of 34 patients with knee OA scheduled for TKA, there were 26 eligible patients (76.5%) of which 14 were included (recruitment rate: 53.8%). A flow diagram including reasons for non-participation of 12 eligible patients is presented in Figure 1.

The characteristics of participants are summarized in Table 1. Participants age and sex were in agreement with age and sex of all patients screened during the study period.

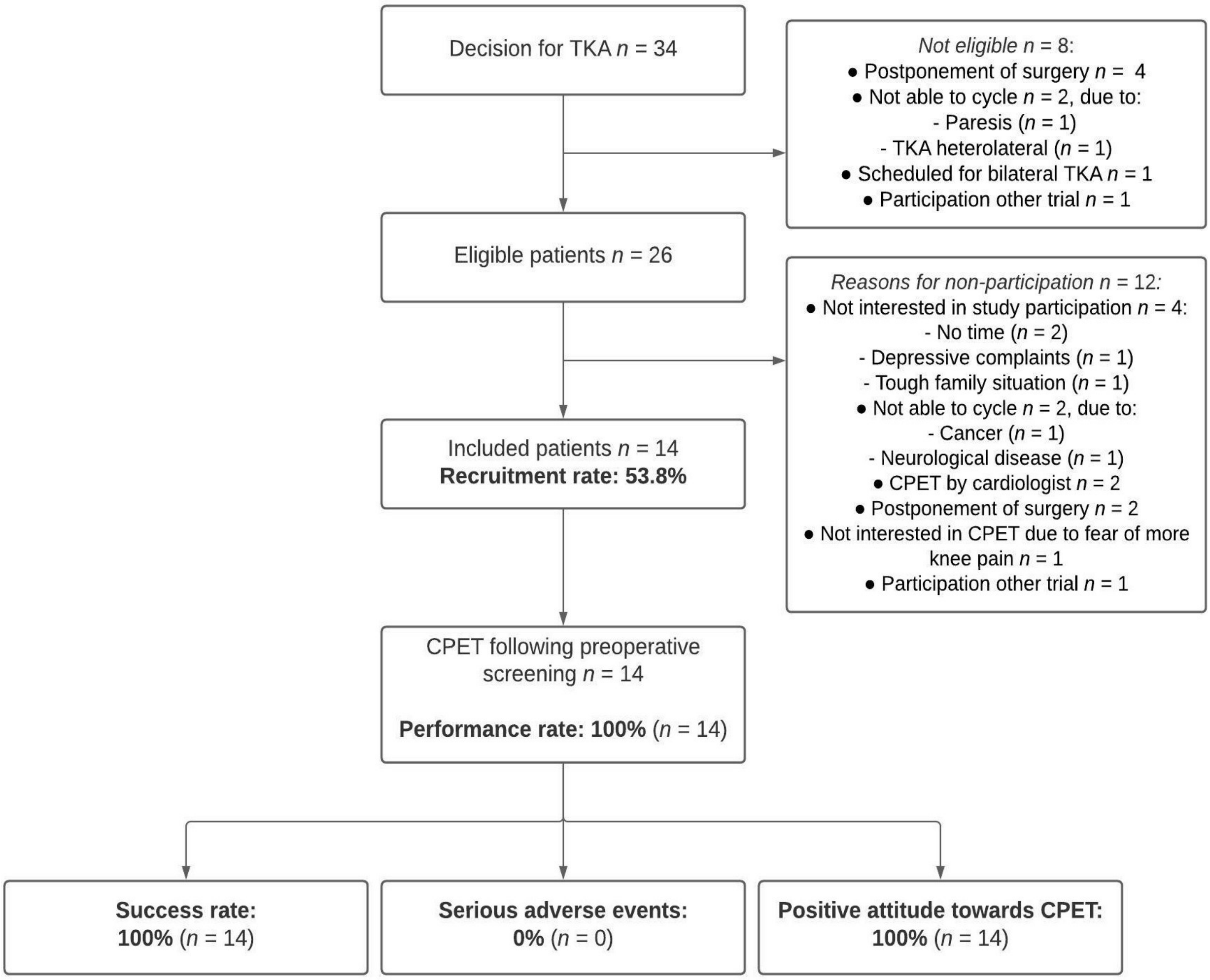
Table 1

Characteristics of study participants (n = 14)

Characteristics	Outcome
Age (years), median (IQR)	73.5 (65.8–82.3)*
Female, *n* (%)	9 (64.3)*
Body mass (kg), mean (SD)	83.7 (15.9)
Body height (cm), mean (SD)	164.6 (9.8)
Body mass index (kg/m^2), mean (SD)	30.7 (4.2)
Surgery side right knee, *n* (%)	9 (64.3)
Use of beta blockers, *n* (%)	3 (21.4)
Smoking status, *n* (%)	
Current smoker	0 (0.0)
Previous smoker	6 (42.9)
Never smoked	8 (57.1)
Comorbidities	
ASA classification[a], *n* (%)	
I	1 (7.1)
II	10 (71.4)
III	3 (21.4)
IV	0 (0.0)
Charnley classification[b], *n* (%)	
A	2 (14.3)
B	10 (71.4)
C	2 (14.3)
Use of a walking aid, *n* (%)	
In house	0 (0.0)
Outside	2 (14.3)[c]

Note. ASA, American Society of Anesthesiologists; IQR, interquartile range; *n*, number; SD, standard deviation; [a] Higher score indicates less fit for surgery[20]; [b] Indication of the function of the knee with regard to the ability to walk, with C less favourable[21]; [c] One patient used crutches, one patient used a walker outside. *Representative characteristic; all screened patients (*n* = 34) had a median age of 69.9 years (IQR 62.8–77.9) and 58.8% (*n* = 20) was female.

Figure 1 *Flow diagram*



Note. **bold**; feasibility criteria; CPET, cardiopulmonary exercise testing; *n*, number; TKA, total knee arthroplasty.

All criteria for feasibility were met (Figure 1). Reasons for participants to perform the CPET in the future were not requiring maximal effort and perceiving it as a relevant experience to get more information about their health. Results regarding acceptability and suitability of CPET are summarized in Table 2. Participants perceived the effort during exercise testing as 'hard' (median Borg RPE score of 15, min–max 13–17). The exercise physiologist stopped the test in 10 participants (71.4%), all due to achieving a Borg RPE score of ≥15. Four participants (28.6%) stopped the exercise test themselves because of knee pain (*n* = 1), dyspnoea (*n* = 1), both pain and dyspnoea (*n* = 1) or to prevent the occurrence of knee pain (*n* = 1).

They rated their pain at three moments with a median NRS score of 5.0 (IQR 4.8–6.0) during the past week, 4.5 (IQR 2.0–5.3) after cycling and 6.0 (IQR 5.0–7.0) during the week after cycling. Participants were well informed, motivated (both median NRS 10.0, IQR 9.0–10.0) and most were confident in performing the exercise test with their OA knee (median NRS 8.0, IQR

6.5–8.3). Only wearing the facemask was experienced somewhat burdensome (median NRS 4.5, IQR 2.0–7.3). An item for improvement was the text size of the Borg RPE scale, since participants had to indicate their perceived exertion during the test without wearing their glasses.

Table 2

Results from questionnaire and telephone call regarding acceptability and suitability of CPET

Experiences of participants (*n* = 14)	Outcome
Borg RPE scale after test completion, median (IQR)	15 (15–15)
Knee pain NRS-11, median (IQR)	
Pre exertion (past week)	5.0 (4.8–6.0)
Post exertion	4.5 (2.0–5.3)
Follow-up one week	6.0 (5.0–7.0)
Occurrence complaints, *n* (%)	
Immediately after CPET	3 (21.4)
Dizziness	1 (7.1)
Pain heterolateral knee joint	2 (14.3)
Follow-up one week[a]	7 (50.0)
More pain in the knee scheduled for surgery	4 (28.6)
Muscle strain (1-3 days)	2 (14.3)
Fatigue on exercise day or day after	2 (14.3)
Motivation NRS-11, median (IQR)	10.0 (9.0–10.0)
Burden NRS-11, median (IQR)	
Use of facemask	4.5 (2.0–7.3)
Use of electrocardiogram electrodes	0.0 (0.0–2.3)
CPET performance following preoperative screening	0.0 (0.0–1.0)
Other, *n* (%)	0 (0.0)
Self-efficacy NRS-11, median (IQR)	8.0 (6.5–8.3)
Well informed about CPET NRS-11, median (IQR)	10.0 (9.0–10.0)
Positive attitude: willing to perform CPET again, yes, *n* (%)	
Immediately after CPET	14 (100)
Follow-up one week	14 (100)

Note. Borg RPE scale, Borg Rating of Perceived Exertion scale 6-20, 6 perceiving 'no exertion at all' to 20 perceiving a 'maximal exertion' of effort; CPET, cardiopulmonary exercise testing; IQR, interquartile range; *n*, number; NRS-11, numeric rating scale; for knee pain and burden, 0 indicates the best score and 10 indicates the worst score. In contrast, for motivation, self-efficacy and well informed about CPET, 0 indicates the worst score and 10 indicates the best score.
[a] One participant experienced two complaints.

Table 3 displays the aerobic capacity of the study population. The median VO_2 at the VAT was 989.50 $ml.min^{-1}$ (IQR 876.50–1168.75) and 12.82 $ml.kg^{-1}.min^{-1}$ (IQR 11.29–13.63). The median OUES was 1923.25 (IQR 1586.38–2558.25) and 23.09.kg^{-1} normalised for body mass (IQR 20.23–28.90). The OUES values combined were higher than predicted OUES values, regardless of used reference values, respectively 109.5%[30] and 113.0%.[31]

Table 3

Results of exercise testing of the study population (n = 14)

Measure	Outcome
Resting heart rate (bpm), mean (SD)	79 (12.5)
FEV_1 (% of predicted), median (IQR)	96.0 (80.5–106.3)
Participants performing CPET, *n* (%)	14 (100)
Participants achieving VAT, *n* (%)	14 (100)
VO_2 achieved at VAT, median (IQR)	
Absolute, $ml.min^{-1}$	989.50 (876.50–1168.75)
Relative, $ml.kg^{-1}.min^{-1}$	12.82 (11.29–13.63)
Work rate at VAT (watts), mean (SD)	55 (17.1)
Heart rate at VAT (bpm), mean (SD)	108 (12.0)
OUES, median (IQR)	
Absolute, OUES	1923.25 (1586.38–2558.25)
Relative, OUES.kg^{-1}	23.09 (20.23–28.90)
OUES (% of predicted)[a]	109.5
OUES (% of predicted)[b]	113.0
Exercise duration with increasing load (s), median (IQR)	549 (429–677)
Stop reason[c], *n* (%)	
Borg RPE ≥15	10 (71.4)
Dyspnoea	6 (42.9)
Knee pain	3 (21.4)
Preventing knee pain	1 (7.1)

Note. bpm, beats per minute; CPET, cardiopulmonary exercise testing; FEV_1, forced expiratory volume in one second; IQR, interquartile range; *n*, number; OUES, oxygen uptake efficiency slope; RPE, Rating of Perceived Exertion; s, seconds; SD, standard deviation; VAT, ventilatory anaerobic threshold; VO_2, oxygen uptake.

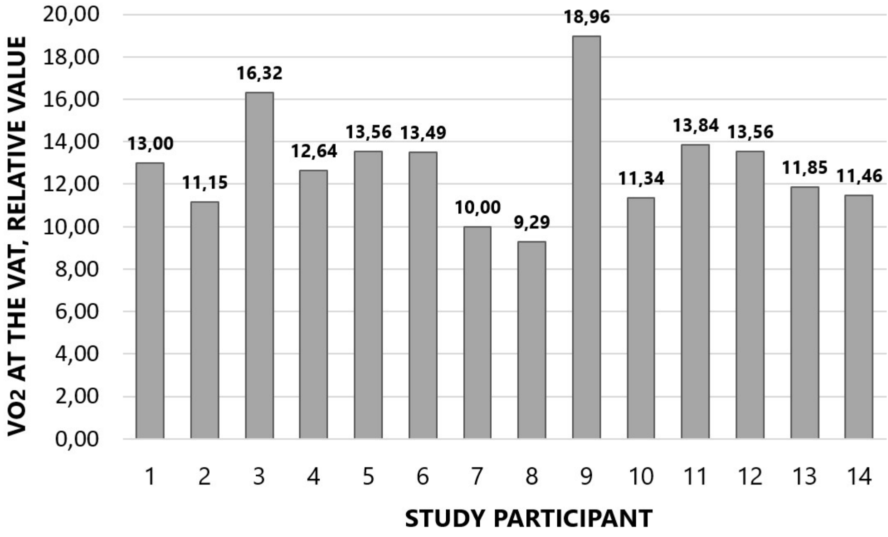
[a] Reference values calculated according to Barron et al.,[30] using the variables sex, age, height, weight, beta blocker intake, smoking status and FEV_1.

[b] Reference values calculated according to Hollenberg et al.,[31] using the variables sex, age, body surface area, FEV_1 and smoking status.

[c] Some participants had >1 stop reason.

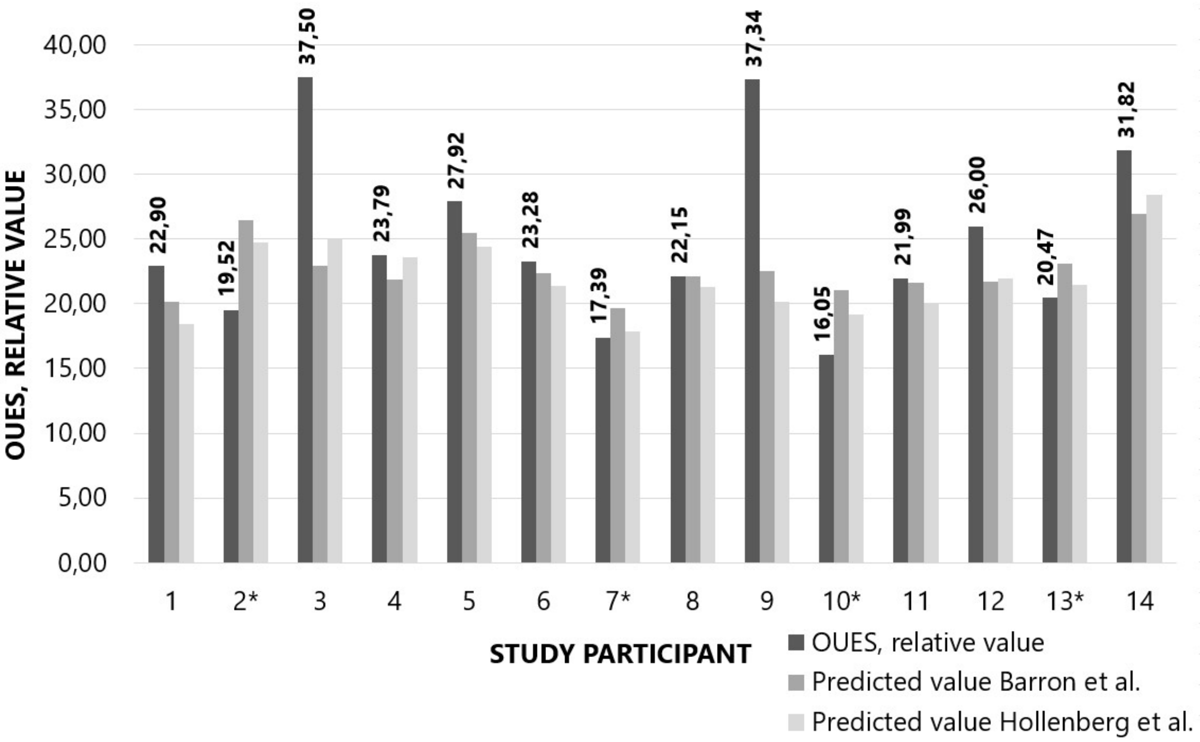
The individual values of VO_2 at the VAT and OUES of the patients are presented in Figure 2 and 3. Two patients (14.3%) have a VO_2 at the VAT of less than 11 $ml.kg^{-1}.min^{-1}$ and four patients (28.6%) have a OUES value which is less than predicted.

Figure 2 *Oxygen uptake at the ventilatory anaerobic threshold per participant*



Note. VAT, ventilatory anaerobic threshold, VO_2, oxygen uptake in $ml.kg^{-1}.min^{-1}$.

Figure 3 *Oxygen uptake efficiency slope and predicted values per participant*



Note. OUES, oxygen uptake efficiency slope in $OUES.kg^{-1}$. Predicted values according to the studies of Barron et al.[30] and Hollenberg et al.[31] * Patient scores less than predicted.

DISCUSSION

This study aimed to investigate the feasibility of submaximal CPET in patients with knee OA scheduled for TKA surgery. The main results show that a fairly high percentage of representative patients volunteered to participate in this study, of which all could perform the exercise test and reached the VAT, indicating the feasibility of the CPET procedure. Also, the acceptability and suitability were affirmed as no serious adverse events occurred and all participants indicated they would perform the CPET again. Therefore, submaximal CPET seems suitable to evaluate aerobic capacity in this population, using the VO_2 at the VAT and OUES.

Half of the participants experienced some CPET-related mild complaints in the week after the CPET, like muscle strain (*n* = 2, 14.3%), fatigue (*n* = 2, 14.3%) or more pain in the knee scheduled for surgery (*n* = 4, 28.6%). At group level the median NRS score of 5.0 pre exertion increased only one point to a median NRS score of 6.0 during the week after cycling, which is not clinically relevant[25] (median NRS difference of 0.0, IQR -1.0–2.0). Thereby, most patients with knee OA experience weekly fluctuations in pain.[37] Despite these mild complaints, all participants had a positive attitude towards CPET. This may be due to the pre-given extensive information about the CPET, in which possible physical responses on the exercise were indicated.

To our knowledge, this is the first study that explicitly investigated the feasibility of a submaximal exercise test which evaluated aerobic capacity with submaximal parameters in a population of only patients with knee OA prior to TKA surgery. In accordance with results from previous studies in which patients were subjected to maximum exercise testing, no serious adverse events occurred and all patients reached the VAT.[9–11,38] The positive attitude towards CPET in our study was also seen in the study of Roxburgh et al.[38] Remarkable is that all included patients could perform the CPET and were not hindered by restricted knee range of motion or pain, which was previously observed in approximately 40% of the patients.[8–11] This may be partly due to one of the inclusion criteria for being able to get on and off a stationary bike, although no patients were excluded for this reason. Besides, cycling is a very familiar mode of exercise in Dutch patients.[39] Two eligible patients (7.7%) were excluded because they were not able to cycle, but this was unrelated to their knee symptoms.

In terms of aerobic capacity, most studies focused on maximal exercise responses[8–11,40] and often only described that the VAT was reached.[9–11] Two studies reported on submaximal parameters in patients with hip and knee OA combined, scheduled for surgery.[8,38] One study (*n* = 37) showed a median VO_2 at the VAT of 10.6 $ml.kg^{-1}.min^{-1}$ (IQR 8.5–12.3)[8] and a recent study (*n* = 15) reported a mean VO_2 at the VAT of 10.7 $ml.kg^{-1}.min^{-1}$ (SD 2.9) and a mean OUES of 21.52.kg^{-1} (SD 5.9).[38] Our study population is healthier, which is reflected in higher values for both OUES (which were 109.5%[30] and 113.0%[31] of predicted) and VO_2 at the VAT. Although the characteristics of the study population correspond well with these previous studies,[8,38] none of the participants smoked or used any walking aids in house and only two participants (14.3%) made use of a walking aid outside. The better aerobic capacity can also be explained by the fact that all patients were advised by the orthopaedic surgeon to stay as active as possible before the surgery to advance recovery postoperatively. The general recommendation was aerobic training of moderate-intensity of at least 30 minutes per day for at least 5 days a week, according to Dutch and international physical activity guidelines.[41,42]

In addition to the median aerobic capacity at group level, individual values of aerobic capacity can be important to identify patients with a reduced aerobic capacity, possibly at risk for a delayed postoperative recovery. The VO_2 at the VAT was lowest for participant 7 and 8, while participant 2, 7, 10 and 13 showed OUES values less than predicted. Using both measures is probably the best method to distinguish patients with a sufficient or good aerobic capacity from patients with a reduced aerobic capacity. If we apply cut-off values reported earlier in literature for patients scheduled for major colorectal surgery (OUES: $<20.6.kg^{-1}$ and VAT: ≤ 11.1 $ml.kg^{-1}.min^{-1}$)[14], the same participants with a reduced aerobic capacity are found.

A strength of this study was the assignment of a central role to the patients, exploring their experiences and perceptions of performing submaximal CPET at two different moments. Also, representative patients with knee OA were included, no data was missing and the study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement.[43] Some limitations must be considered. First, although this study focused on a submaximal performance and the exercise physiologist would stop the test if the participant rated the effort with a Borg RPE score of ≥15, two participants may have delivered a (near) maximal effort. Both participants had a heart rate at the end of exercise of >95% of predicted peak heart rate (208 – (0.7 × age in years)). A respiratory exchange ratio at peak exercise ≥1.10, also indicative of maximal exercise,[14] was not achieved by any participant. Secondly, patients from the MUMC+ could not be included due to COVID-19 measures, which may affect the generalizability of the study results. Lastly, acceptability and suitability of CPET were studied quantitatively. By using qualitative methods we could have explored the subjective experiences of the participants on a more detailed level.

Since this study has demonstrated the feasibility of submaximal CPET, this instrument can be used in patients with knee OA to investigate the association of preoperative aerobic capacity with postoperative recovery after TKA. Risk thresholds may be defined, as seen in other populations undergoing a surgical procedure,[14,15,44] which may be used in operative decision-making in patients undergoing more complex or high-risk surgical procedures.

CONCLUSION

This study demonstrated the feasibility of submaximal CPET using cycle ergometry in patients with knee OA scheduled for TKA surgery to evaluate preoperative aerobic capacity using the VO_2 at the VAT and OUES. All participants were able to perform the test, reached the VAT and were willing to perform the CPET again. The study population demonstrated a median VO_2 at the VAT of 12.82 $ml.kg^{-1}.min^{-1}$ (IQR 11.29–13.63). The median OUES was 23.09.kg^{-1} (IQR 20.23–28.90), and 109.5% and 113.0% of predicted. The exercise test can be used preoperatively to identify patients with a reduced aerobic capacity. Future studies can safely investigate the effect of preoperative aerobic capacity on postoperative recovery using submaximal CPET.

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APPENDIX I

Dear sir/madam,
You have just performed a bicycle test. We are curious about your experience. The questionnaire will discuss various topics, like the perception of effort during exercise, possibly occurring complaints to your knee and your motivation.

Borg RPE-scale

The Borg scale, a scale for the subjective perception of effort during physical exercise.

Rate your perceived exertion. The perception of effort depends mainly on the level of exertion, muscle fatigue and the feeling of shortness of breath. View the scores on the scale. Indicate a score from 6 to 20, circle your score. A rating of 6 means that you perceived 'no exertion at all' and a rating of 20 means that you perceived a 'maximal exertion' of effort.

Scale	Perceived exertion
6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Reason to stop cycling

Can you indicate why you stopped cycling?

Numeric Pain Rating Scale

Pain in the knee scheduled for surgery prior to the bicycle test
Select the number that best describes the severity of your pain.
How severe was your pain (on average) in the past week (7 days), before performing the bicycle test?

0	1	2	3	4	5	6	7	8	9	10
no pain										**most imaginable pain**

Pain in the knee scheduled for surgery after the bicycle test
Select the number that best describes the severity of your pain.
How severe was your pain after performing the bicycle test?

0	1	2	3	4	5	6	7	8	9	10
no pain										**most imaginable pain**

Other complaints

Do you experience other complaints to your body after the bicycle test?

- ○ Yes, specifically: ____
  ____
- ○ No

Motivation

On a scale of 0 to 10, to what extent were you motivated to perform the bicycle test?

0	1	2	3	4	5	6	7	8	9	10
not motivated					**somewhat motivated**					**very motivated**

Equipment

On a scale of 0 to 10, to what extend did you find the facemask burdensome?

0	1	2	3	4	5	6	7	8	9	10

not burdensome | **somewhat burdensome** | **very burdensome**

On a scale of 0 to 10, to what extend did you find the electrodes on your torso burdensome?

0	1	2	3	4	5	6	7	8	9	10

not burdensome | **somewhat burdensome** | **very burdensome**

Did you find other things burdensome?

- ○ No
- ○ Yes, specifically:____

On a scale to 0 to 10, to what extend did you find the above item burdensome?

0	1	2	3	4	5	6	7	8	9	10

not burdensome | **somewhat burdensome** | **very burdensome**

Bicycle test

On a scale of 0 to 10, to what extend did you experience the bicycle test together with the other tests of the physical therapist as too much?

0	1	2	3	4	5	6	7	8	9	10

not too much | **somewhat much** | **very much**

Self-efficacy

On a scale of 0 to 10, how confident were you that you could perform the bicycle test with your knee problem?

0	1	2	3	4	5	6	7	8	9	10

not confident   **somewhat confident**   **very confident**

Information

On a scale of 0 to 10, to what extent were you well informed about the bicycle test?

0	1	2	3	4	5	6	7	8	9	10

not informed   **somewhat informed**   **very well informed**

Bicycle test in the future

Are you willing to perform the bicycle test again at a later moment?

○ Yes

○ No, because ____

____

- End of the questionnaire -

Thank you for completing

APPENDIX II

Have you experienced past week any complaints due to the bicycle test?

○ Yes, specifically:____

○ No

Numeric Pain Rating Scale

Pain in the knee scheduled for surgery

How severe was your pain (on average) in the past week (7 days)?

0	1	2	3	4	5	6	7	8	9	10
no pain										**most imaginable pain**

Bicycle test in the future

After the bicycle test, you indicated that you would not / would like to perform the test again. Do you still have this opinion?

○ No, because ____

○ Yes, because ____

Process

Is there anything we can improve?

○ Yes, item for improvement: ________________________________

○ I have no item(s) for improvement

○ I do not know

Additional information / comments: ________________________________