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Economic Evaluation of the Dr. Bart Application in Individuals With Knee and/or Hip Osteoarthritis

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Objective. To evaluate the cost-utility and cost-effectiveness of the dr. Bart app compared to usual care in people with osteoarthritis (OA) of the knees and hips, applying a health care payer perspective.

Methods. This economic evaluation was conducted alongside a 6-month randomized controlled trial that included 427 participants. The dr. Bart app is a stand-alone eHealth application that invites users to select pre-formulated goals (i.e., "tiny habits") and triggers for a healthier lifestyle. Self-reported outcome measures were health care costs, quality-adjusted life years (QALYs) according to the EuroQol 5-dimension 3-level (EQ-5D-3L) descriptive system, the EuroQol visual analog scale (QALY VAS), patient activation measure 13 (PAM-13), and 5 subscales of the Knee Injury and Osteoarthritis Outcome Score/Hip Disability and Osteoarthritis Outcome Score. Missing data were multiply imputed, and bootstrapping was used to estimate statistical uncertainty.

Results. The mean ± SD age of the study participants was 62.1 ± 7.3 years, and the majority of participants were female (72%). Health care costs were lower in the intervention group compared to the group who received usual care (€–22 [95% confidence interval €–36, –3]). For QALY and QALY VAS, the probability of the dr. Bart app being cost-effective compared to usual care was 0.71 and 0.67, respectively, at a willingness-to-pay (WTP) of €10,000 and 0.64 and 0.56, respectively, at a WTP of €80.000. For self-management behavior, symptoms, pain, and activities of daily living, the probability that the dr. Bart app was cost-effective was >0.82, and the probability that the dr. Bart app was cost-effective in the areas of activities and quality of life was <0.40, regardless of WTP thresholds.

Conclusion. This economic evaluation showed that costs were lower for the dr. Bart app group compared to the group who received usual care. Given the noninvasive nature of the intervention and the moderate probability of it being cost-effective for the majority of outcomes, the dr. Bart app has the potential to serve as a tool to provide education and goal setting in OA and its treatment options.

INTRODUCTION

Osteoarthritis (OA) is a chronic disease mainly affecting the knees and hips, resulting in pain, stiffness, and functional disability (1,2). Apart from this health burden, the financial annual burden of OA was 1.4% of the total health care expenditure in The Netherlands in 2017 (€1.2 billion). Costs attributable to OA among patients in secondary care (i.e., orthopedic surgeon, rheumatologist, or physician assistant) are 8.6 times higher (€629 million versus €73 million) than costs spent in primary care (e.g., general practitioner or physical therapist) (3). Due to an aging population and an increase in obesity rates, it is expected that the (economic) burden of OA will increase dramatically in the near future (1,4).

First-choice nonsurgical treatments for knee/hip OA comprise education, lifestyle advice, and healthy behaviors (5,6). Since OA is a chronic disease, a key element in nonsurgical disease management is self-management (7,8). Compared to usual care, traditional self-management programs show small benefits

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SIGNIFICANCE & INNOVATIONS

- This is the first study that performed an economic evaluation of a stand-alone electronic self-management tool for people with osteoarthritis (OA) of the knees and hips.
- The present economic evaluation shows, from a health care payer perspective, that an electronic self-management tool for knee/hip OA has moderate probabilities of being a cost-effective method.

on self-management skills, pain, function, and symptoms (9). In The Netherlands, conservative treatment modalities (i.e., information, analgesics, physical therapy, and weight management) are coordinated in primary care, in which the general practitioner functions as a gatekeeper for OA patients. In the event that these conservative treatments fail, patients are referred to secondary care (10). Despite recommendations about the content of nonsurgical treatment options in OA, quality of care is suboptimal in various European countries, including The Netherlands; lack of time results in underutilization of nonsurgical treatment options and unnecessary referrals to secondary health care for people with knee/hip OA (11).

Due to the considerable costs related to OA, there is a need for cost-effective interventions in the treatment of people with knee/hip OA. Electronic health (eHealth) technologies (e.g., applications, more commonly known as "apps") offer the possibility to provide self-management 24/7 at lower costs compared to traditional interventions. Electronic health interventions can be divided in blended interventions that combine face-to-face consultations with eHealth and in eHealth applications without therapeutic guidance. By using interventions without therapeutic guidance, the burden of OA on health care would be lessened not only for providers, but for patients as well as patients do not need to travel and can apply such interventions at their own pace (12). By providing education and self-management interventions without therapeutic guidance, eHealth interventions can provide high-reach, low-cost, accessible, and scalable solutions with scarce resources. Despite the high potential of these apps, the majority of apps have not proven their efficacy and cost-effectiveness in trials with people who have OA (13). Within mental health care and cardiac rehabilitation, blended interventions have been found to be cost-effective (14,15), whereas one study on people with knee/hip OA showed that a blended intervention was not cost-effective compared to usual physiotherapy (16). Conversely, previous reviews have shown that eHealth interventions have the potential to reduce treatment costs in musculoskeletal conditions (17,18). However, high-quality evidence is lacking when it comes to economic evaluations of stand-alone electronic apps being implemented without therapeutic guidance for people with knee/hip OA.

Given the huge potential of eHealth technologies, we developed the dr. Bart app to enhance self-management in people with knee/hip OA. The dr. Bart app is based on the Fogg model for behavioral change, augmented with reminders, rewards, and self-monitoring to reinforce app engagement (19). We hypothesized that use of the dr. Bart app would result in better self-management (and thus reduction of secondary health care consumption) and improvement in pain and functioning. However, in our assessment of the dr. Bart app, we did not find changes in health care utilization over 6 months between the control group and intervention group. Instead, the dr. Bart app had small but positive effects on pain, symptoms, and activities of daily living in people with knee/hip OA (20). Given how scarce health resources are for this area of medicine and the growing economic burden of OA as a consequence of the rising prevalence of this disease, as well as the fact that prior studies did not assess joint uncertainty around cost and effects, it is important to conduct an economic evaluation together with this trial. Moreover, to be implemented on a larger scale, insight into the cost-effectiveness of this eHealth app is warranted. Therefore, the present study describes, from a health care payer perspective, the incremental cost-utility and cost-effectiveness analyses of the dr. Bart application compared to usual care in people with knee/hip OA over a period of 6 months.

PATIENTS AND METHODS

Design overview. We conducted the present economic evaluation together with a randomized controlled trial evaluating the effectiveness of the dr. Bart app on health care use and clinical outcomes over 6 months, which was carried out at Sint Maartenskliniek Nijmegen, The Netherlands, between January 2018 to January 2019 (19,20). This economic evaluation was based on the general principles of cost-utility analysis and cost-effectiveness analysis, from a health care payer perspective, and compared the use of a fully automated eHealth app to usual care. Details on the trial design and the development of the dr. Bart app have been published previously (19). Ethical approval for the present study was requested and then waived by the local Medical Research Ethics Committee at the Radboud University Medical Centre, Nijmegen (CMO Arnhem-Nijmegen; protocol no. 2017-3625). The present study has been reported according to the Consolidated Health Economic Evaluation Reporting Standards statement (21).

Study participants. Participants were recruited via newspapers and campaigns on social media (e.g., Facebook and LinkedIn). Potential participants were invited to visit the website at www.drbart.eu to see if they were eligible for study enrollment. Participants were included if they met the following criteria: 1) self-reported OA of the knee and/or hip (i.e., experiencing pain in the knees and/or hips for >15 days in the past month, morning stiffness of <30 minutes in 1 or both knees, and/or morning stiffness of <60 minutes in 1 or both hips; 2) age ≥50 years; 3) having

an email address; 4) possession of smartphone or tablet and willingness to download the dr. Bart app on ≥1 devices; and 5) ability to read, write, and sufficiently communicate in Dutch.

Participants were excluded from study participation if they required a wheelchair, had a diagnosis of another inflammatory rheumatic disease or diseases, had undergone knee and/or hip replacement surgery, and if they had been scheduled for knee and/or hip joint arthroplasty in the subsequent 6 months (19).

Participants who fulfilled a baseline assessment were allocated to either the intervention group (dr. Bart app) or control group (usual care) at a 1:1 ratio performed with CastorEDC by a researcher (TP). Further details regarding the study population can be found in our previous work (19,20).

Ethical approval and consent to participate. Ethical approval for this study was requested by the local Medical Research Ethics Committee at Radboud University Medical Centre, Nijmegen, The Netherlands (protocol no. 2017-3625). The Committee concluded that the study fell outside the remit of the law for Medical Research Involving Human Subjects Act. All participants provided digital consent to participate in the present study.

Intervention group (dr. Bart app). We developed the dr. Bart app to enhance self-management and to actively involve people with OA in managing their disease. Participants allocated to the intervention group received an email with information to access the dr. Bart app. The dr. Bart app is a fully automated eHealth app, and its main function is to set goals for a healthier lifestyle based on the Fogg model for behavioral change (22). The dr. Bart app is augmented with reminders, rewards, and self-monitoring to reinforce app engagement and health behavior. The dr. Bart app proposes goals for a healthier lifestyle on the basis of machine learning techniques that use data collected from the personal profile and previous choosing behavior of the user. Further details regarding the applied theoretical framework and development of the dr. Bart app have been published previously (19).

Control group (usual care). Half of the study participants were allocated to the usual care group and received no active treatment. Participants allocated to the control group received an email that they were assigned to the control group. After completing the last follow-up questionnaire, participants in the control group were also offered the dr. Bart app.

Outcome and utility measures. Study participants were assessed at baseline, 3 months, and 6 months, and demographic data were collected at baseline. We measured health-related quality with the EuroQol 5-dimension 3-level (EQ-5D-3L) descriptive system (23). The questionnaire differentiates between 245 health states (23). These health states were converted into utility units by using Dutch tariffs (24). We calculated utility scores on a scale anchored at 0 ("The worst health you can imagine") to 1 ("The best health you can imagine"). Moreover, the EuroQol visual analog scale (VAS) was used to indicate health-related quality of life on a vertical line ranging from 0 ("The worst health you can imagine") to 100 ("The best health you can imagine"). We transformed the VAS score into a utility score using the following formula (25): transformed VAS = $(1 - [1 - \text{VAS}/100])^{1.61}$. Quality-adjusted life years (QALYs) for each participant were determined with the trapezoid method (26).

Clinical outcome measures. Knowledge, skills, and confidence to cope with one's health were assessed with the patient activation measure 13 (PAM-13) questionnaire (27,28). We used the Knee Injury and Osteoarthritis Outcome Score (KOOS) or Hip Disability and Osteoarthritis Outcome Score (HOOS) where applicable to assess pain, symptoms, activities of daily living, quality of life, and physical functioning in sport and recreation on a 0–100 scale, with higher scores indicating fewer symptoms (29,30).

Cost outcome measures. Costs included health care costs related to knee/hip OA during the study. We opted for a health care perspective as we assumed that health care cost would be the main cost drivers in the current study. Self-assessed direct medical costs were assessed at baseline and at 3 months and 6 months during follow-up.

Health care costs. Participants received online cost questionnaires at baseline, 3 months, and 6 months during follow-up. Health care costs included in the current study were those related to knee/hip OA health care resource utilization during a 6-month study period (assessed with a 3-month recall period). Resources comprised the number of consultations with all relevant health care providers (Supplementary Table 1, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24608). We assessed the number of consultations with a rheumatologist, orthopedic surgeon, or physician assistant completed in secondary care. Moreover, we assessed the costs of outpatient care days, hospitalization, and surgery in secondary care. For primary care, we assessed the number of consultations with a general practitioner, physical therapist, occupational therapist, exercise therapist, and dietician. The value of health care utilization was measured in Dutch standard cost prices of 2014 (31), converted to 2018 price levels using the Dutch price index rate (i.e., 1.041) (31,32). To determine health care costs, we multiplied the number of visits with the accompanying price per resource. To estimate costs of knee/hip OA–related surgery, we obtained pricing of surgical operations from the Dutch Health Authority (www.nza.nl). For intervention costs, we did not take development costs of the eHealth intervention into account in this economic evaluation.

Statistical analysis. All statistical analyses were performed using Stata 13.1 (www.stata.com). Statistical analyses were performed according to the intention-to-treat principle. Descriptive statistics were used to present group characteristics. Missing data were managed according to the recommendations of the specific questionnaire. For the PAM, we also calculated a total score when a maximum of 2 items on the questionnaire were missing, although the PAM recommends to only calculate a total score if not a single item is missing on its questionnaire. For this, we calculated the mean score of the answered questions in the PAM questionnaire and multiplied this by 13.

Multiple imputation by changed equation was used to estimate missing cost and utility data. A total of 20 imputed data sets were predicted based on available data. The imputation model included variables related to the outcomes and all available cost and effect measure values at baseline and during follow-up. For the cost-utility analysis, we drew bootstrap samples from each of the multiply imputed data sets and estimated the difference in net benefit between the treatment groups in each bootstrap sample, given a willingness-to-pay (WTP) threshold per QALY. The proportion of bootstrap samples in which the net benefit is positive represents the probability that the treatment is cost-effective for each multiply imputed data set. This probability is then

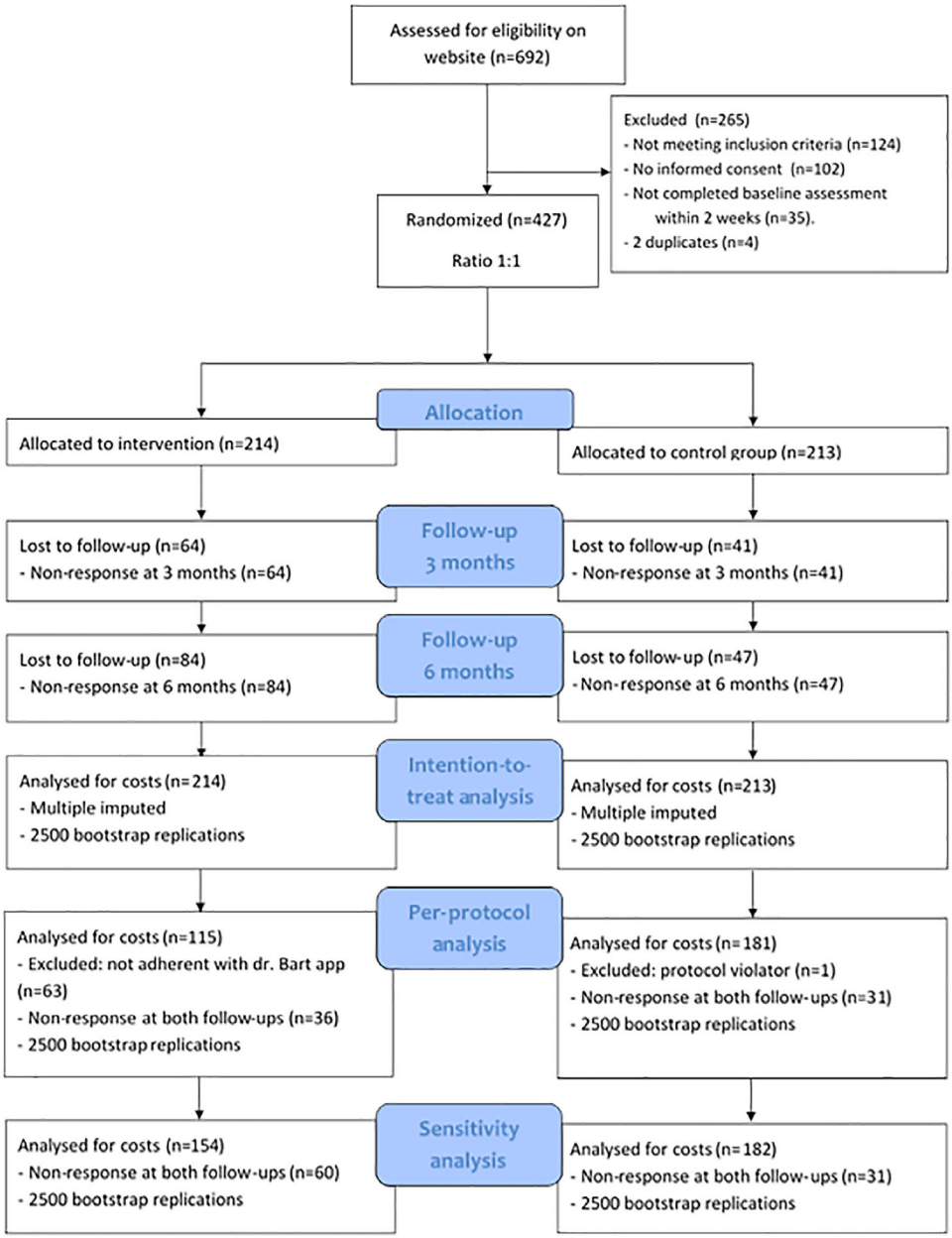

Figure 1. Flow chart of the study.

averaged across all multiply imputed data sets (33). Multiple imputed data sets were analyzed using Rubin's rules for combining multiply imputed data sets (Stata command: "mi estimate") (34).

We used longitudinal linear mixed-effects models with random intercept but without random slopes to evaluate the effectiveness of the dr. Bart app on clinical outcomes, with adjustment for values at baseline. Our primary analysis focused on the costs and effects over 6 months of follow-up. Differences in mean fitted predicted values were used to indicate group differences.

For the cost-utility and cost-effectiveness analyses, we reported the incremental net monetary benefit (iNMB) because this measure is easier to interpret than the incremental cost-effectiveness ratio when differences are small and around 0. The iNMB was calculated with the following formula: iNMB = WTP × (incremental effect) – incremental costs (35). Uncertainty (95% confidence interval [95% CI]) around costs and effects were estimated by percentile bootstrap intervals with 2,500 replications. Bootstrapped incremental cost-effect pairs were plotted on cost-effectiveness planes (36). Moreover, we plotted cost-effectiveness acceptability curves to indicate the probability of the dr. Bart app being cost-effective compared to usual care at different WTP values (€0 to €80,000) (37). Results presented in tables and figures are based on a society's willingness to pay €10,000.

Sensitivity analyses. We performed 2 sensitivity analyses. First, we performed a per-protocol analysis, excluding 1 participant from the control group (protocol violator), whereas in the intervention group, 63 participants were considered nonadherent to the dr. Bart app (i.e., individuals who did not choose at least 1 goal within the app) and were therefore excluded. For the second sensitivity analysis, we imputed missing data on health care utilization with a 0 when a study participant was not lost to follow-up, and we also imputed missing utility measures according to the last observation carried forward principle. Data sets used and/or analyzed in the present study are available from the corresponding author upon reasonable request.

RESULTS

Study participants. In total, 427 participants were included in this economic evaluation, with 214 allocated to the intervention with dr. Bart app group and 213 allocated to the usual care group (Figure 1). Baseline characteristics were similar for both groups, with an overall mean ± SD age of 62.1 ± 7.3 years, a majority of female participants (71.7%), and the presence of symptoms predominantly in the knees (73.3%). Almost 60% of participants had experienced OA symptoms for <5 years (Table 1). The response rates for the follow-up questionnaires were 75.4% (n = 150 in the intervention group and n = 172 in the control group) and 69.3% (n = 130 in the intervention group and n = 166 in the control group) at 3 and 6 months, respectively.

Utility measures in the economic evaluation. We found no differences in utility measures between the usual care group and the dr. Bart app group (mean group difference QALY of 0.00 (95% CI –0.00, 0.01) and QALY VAS of –0.00 (95% CI –0.00, 0.00) (Table 2).

Effects and health care costs. Except for self-management behavior, no significant differences were seen in clinical outcomes after 6 months between the dr. Bart app group and the usual care group after bootstrapping with 2,500 replications (Table 3). The estimated mean ± SE health care costs during follow-up were €503 ± €79 and €462 ± €80 for the control group and dr. Bart app group, respectively (Table 2). Over a period of 6 months, the estimated difference between groups was lower for the dr. Bart app group (€–22 [95% CI €–36, €–3]).

Cost-utility analysis. The primary economic evaluation of the present study was the cost-utility analysis that compared the differences between the dr. Bart app group and the control group in health care costs to the difference in QALY and QALY VAS, obtained with the EQ-5D-3L. Since both costs and QALYs were favorable for the dr. Bart app group (i.e., intervention with the dr. Bart app dominates the control group), the iNMB was also in favor of the dr. Bart intervention, regardless of society's WTP threshold (Table 3 and Figure 2). We found an iNMB of €53 (95% CI €11, €94) at a WTP threshold of €10,000. Accordingly, the cost-effectiveness acceptability curve (CEAC) for QALYs

Table 1. Baseline characteristics of 427 total study participants in the dr. Bart app intervention group and the control group*

Characteristic	Intervention group (n = 214)	Control group (n = 213)
Age, mean ± SD years	62.1 ± 7.7	62.1 ± 7.0
Female sex	147 (68.7)	159 (74.7)
Body mass index, mean ± SD kg/m^2	27.8 ± 5.1	27.3 ± 4.8
Level of education ≤12 years	56 (28.0)	36 (18.6)
Main osteoarthritis of the knee	157 (73.4)	156 (73.2)
Duration of symptoms		
<5 years	129 (60.3)	117 (54.9)
≥5–10 years	85 (39.7)	96 (45.1)
Self-management behavior	40.8 (5.3)	40.2 (5.7)
Symptoms	57.7 (16.3)	57.0 (18.9)
Pain	57.5 (15.5)	58.2 (17.8)
Activities of daily living	58.5 (19.7)	59.4 (20.2)
Activities	32.6 (23.9)	32.5 (23.1)
Quality of life	38.0 (17.5)	38.3 (17.1)

* Except where indicated, values are the no. (%) of patients. The following characteristics were assessed with either the Knee Injury and Osteoarthritis Outcome Score or the Hip Disability and Osteoarthritis Outcome Score: symptoms, pain, activities of daily living, activities, and quality of life.

Table 2. Utility scores and average health care costs per patient during follow-up for the intervention group and control group*

	Intervention group (n = 214)	Control group (n = 213)	Mean group difference (95% CI)
Utility measures			
QALY score, 0.0–0.5	0.36 (0.07)	0.36 (0.07)	0.00 (−0.00, 0.01)
QALY VAS score, 0.0–0.5	0.42 (0.05)	0.42 (0.04)	0.00 (−0.00, 0.00)
Total health care costs during follow-up, €†	462 (80)	503 (79)	−22 (−36, −3)
Total health care costs during follow-up, €‡	489 (104)	505 (80)	−8 (−25, 15)
Total health care costs during follow-up, mean ± SD €§	439 (1,294)	496 (1,240)	−31 (−66, 3)

* Except where indicated, values are the mean ± SE. Mean group differences and 95% confidence intervals (95% CIs) were obtained from bootstrapping with 2,500 replications using a longitudinal linear mixed-effects model adjusted for baseline value. Values in the intervention group and control group are raw estimates. QALY = quality-adjusted life year; VAS = visual analog scale.
† Missing data were multiply imputed.
‡ Calculated by per-protocol analysis.
§ When not loss to follow-up, missing data were imputed with zero cost.

showed probabilities of 0.71 and 0.64 for the dr. Bart app intervention being cost-effective at WTP thresholds of €10,000 and €80,000, respectively.

For QALY VAS, we found an iNMB of €29 (€−2, €60). At a WTP threshold of €10,000, we found a 0.67 probability of the dr. Bart app being cost-effective (Table 3 and Supplementary Figure 1, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24608). At higher WTP thresholds, this probability decreased. The net benefit between groups did not reach statistical significance.

Cost-effectiveness analysis. Since both costs and self-management behavior were in favor of the dr. Bart app group, the iNMBs were also in favor of the dr. Bart app intervention, regardless of society's WTP thresholds (Table 3 and Supplementary Figure 1, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24608). The CEAC showed a 0.99 probability of the dr. Bart app being cost-effective, irrespective of society's WTP threshold.

For symptoms, pain, and activities of daily living, we found iNMBS of €20,000–€30,000 at a WTP of €10,000, with none reaching statistical significance (Table 3 and Supplementary

Table 3. Differences in predicted mean costs and effects between the dr. Bart app group and control group*

Outcome	ΔC ∞, €	ΔE ∞, points	iNMB ∞, WTP threshold €10,000	iNMB ∞, WTP threshold €80,000	Cost-effectiveness distribution plane, %†			
					SE	NE	SW	NW
QALY, 0–1	−22 (−36, −3)	0.00 (−0.00, 0.01)	53 (11, 94)	274 (−25, 573)	62.5	0.3	36.2	1.0
QALY VAS, 0–1	−22 (−36, −3)	0.00 (−0.00, 0.00)	29 (−2, 60)	79 (−131, 292)	54.1	0.6	44.6	0.7
PAM	−22 (−36, −3)	1.2 (0.3, 2.2)	12,468 (3,115, 22,195)	99,593 (24,826, 177,381)	98.0	1.4	0.6	0.0
Symptoms	−22 (−36, −3)	2.6 (−0.8, 5.8)	25,856 (−8,001, 58,342)	206,695 (−64,204, 466,589)	92.1	1.1	6.6	0.2
Pain	−22 (−36, −3)	3.0 (−0.2, 6.1)	30,422 (−2,008, 60,726)	243,225 (−16,217, 485,562)	95.6	1.3	3.0	0.1
ADL	−22 (−36, −3)	1.9 (−2.3, 6.1)	19,017 (−22,782, 61,215)	151,984 (−182,503, 489,496)	80.8	0.8	17.8	0.5
Activities	−22 (−36, −3)	−0.7 (−5.1; 3.8)	−7,343 (−50,573, 37,943)	−58,899 (−404,788, 303,379)	36.4	0.2	62.2	1.2
QoL	−22 (−36, −3)	−0.7 (−4.8; 3.2)	−7,194 (−47,927, 31,992)	−57,706 (−383,505, 255,851)	35.4	0.3	63.2	1.0

* Positive numbers in the iNMB categories indicate that the dr. Bart app intervention was cost-effective compared to usual care at the willingness-to-pay thresholds of €10,000 or €80,000, after 2,500 bootstrap replications. Costs are expressed in 2018 Euros. ∞ = control group as reference. ADL = activities of daily living; iNMB = increment Net Monetary Benefit; PAM = patient activation measure; QALY = quality-adjusted life year; QoL = quality of life; VAS = visual analog scale; WTP = willingness-to-pay.
† In the cost-effectiveness distribution plane, the southeast (SE) quadrant shows that the dr. Bart app is more effective and less costly than usual care; the northeast (NE) quadrant shows that the dr. Bart app is more effective and more costly than usual care; the southwest (SE) quadrant shows that the dr. Bart app is less effective and less costly than usual care; and the northwest (NW) quadrant shows that the dr. Bart app is less effective and more costly than usual care.

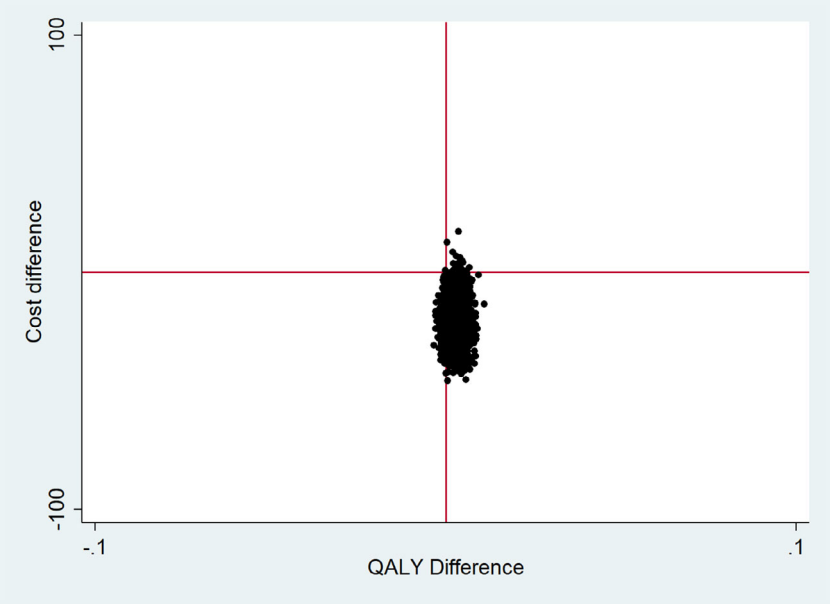

Figure 2. Cost-effectiveness plane for quality-adjusted life years (QALYs). Color figure can be viewed in the online issue, which is available at http://onlinelibrary.wiley.com/doi/10.1002/acr.24608/abstract.

Figures 2–4, available at http://onlinelibrary.wiley.com/doi/10.1002/acr.24608). Accordingly, the CEAC showed that the probability of the dr. Bart app being cost-effective compared to usual care was 0.93, 0.97, and 0.82 at different WTP thresholds for symptoms, pain, and activities of daily living, respectively.

For activities and quality of life, assessed with either the HOOS or KOOS, we found iNMBS of €7,000 in favor of the control group (Supplementary Figures 5 and 6). The CEAC showed that the probability of the dr. Bart app being cost-effective was 0.37 and 0.36, respectively, for activities of daily life and quality of life. At higher WTP thresholds, this probability remained about the same.

Sensitivity analyses. Our first sensitivity analysis (per-protocol analysis) provided similar results (Table 2 and Supplementary Tables 2 and 3, available on the *Arthritis Care & Research* website at http://onlinelibrary.wiley.com/doi/10.1002/acr.24608) as our primary analysis. Additionally, we performed a second sensitivity analyses (in which we imputed missing cost data with a 0) and found results comparable to those from our main analysis (€–31 [€–66, €3]) (Table 2 and Supplementary Tables 2 and 4).

DISCUSSION

We performed an economic evaluation of intervention with the dr. Bart app versus usual care in patients with knee/hip OA from a health care payer perspective. We found small differences in health care costs in favor of the dr. Bart app intervention group. Our analyses showed that both utility measures resulted in dominance for the dr. Bart app intervention group, irrespective of the WTP threshold. Furthermore, 4 of 6 clinical outcomes showed a chance of >0.80 that the dr. Bart app was cost-effective at WTP thresholds between €10,000 and €80,000.

Regardless of the limited clinical outcomes (20), we considered it important to conduct an economic evaluation as these analyses are necessary to implement interventions on a larger scale. In addition, an important aim of self-management interventions is to actively involve people with OA to manage their disease, including skills navigating the health care system (i.e., making optimal use of primary and secondary health care options) (38). In the current economic evaluation, we found no differences in utility measures between both study groups over 6 months, which is in line with 2 systematic reviews on traditional self-management interventions in OA (9,39), indicating that these interventions are not cost-effective when measured with QALYs (39). Alternatively, we found that the dr. Bart app had high chances of being cost-effective (>0.80) in 4 of 6 clinical outcomes. This finding might suggest that for nonpharmacologic conservative treatments in OA, clinical outcomes are more responsive to change over time than utility measures. Taken together, there appears to be some inconsistencies over a range of utility measures and clinical outcomes. Overall, our findings seem to be indicative of moderate-to-high chances of the dr. Bart app being a cost-effective intervention, albeit a modest one.

Although we a found moderate-to-high probability of the dr. Bart app being cost-effective for the majority of outcomes, differences in costs were small. The small differences in costs might be explained by the fact that the 6-month follow-up was too short to appropriately investigate whether the dr. Bart app reduces secondary health care costs in the long term. It is conceivable that the

"tiny habits" (22) will be incorporated in daily life by participants, resulting in larger health benefits and changes in patterns of health care use over time. Further, one could hypothesize that differences in costs over time will rise because orthopedic surgery might be necessary or patients will become impaired and have loss of productivity, leading to higher net cost savings. This is underlined by 2 studies that showed that nonpharmacologic conservative treatment programs can postpone and thus reduce the number of total joint replacements after 5 years (40,41). The relatively small net savings observed in the present study could be of importance given the high prevalence of OA and its burden on society. Further research should be undertaken to investigate the long-term efficacy and cost-effectiveness of nonpharmacologic conservative treatment interventions, including self-management.

The growing prevalence of OA will result in an additional demand on health care services. Therefore, there is a need for cost-effective interventions in the nonpharmacologic conservative treatment of OA. At present, evidence about the cost-effectiveness of stand-alone eHealth applications to enhance self-management in people with OA is absent. As a consequence, no proper comparison of our economic evaluation with other studies is possible. Currently there is limited evidence for cost-effectiveness of a blended web-based option in OA (16), as well as in telemedicine for other chronic conditions (e.g., diabetes mellitus). Nevertheless, these studies show that telemedicine has the potential to be cost-saving when appropriately executed (17,18). Therefore, more high-quality or intensive self-management interventions accompanied with economic evaluations are necessary to expand our understanding of the cost-effectiveness of eHealth applications that enhance self-management in chronic conditions, especially in OA.

The present study is the first that performed an economic evaluation of a stand-alone electronic self-management application for people with knee/hip OA. A potential limitation of this study is the self-reported nature of health care use; self-reports are susceptible to underreporting and recall bias. However, we used the same cost questionnaire for the intervention and control groups, which would suggest that under reporting would be similar in both groups. To minimize recall bias, we chose a recall period of 3 months. In our opinion, there is no better alternative to assess health care use as OA does not require continuous supervision by a physician, as is the case with other chronic conditions (diabetes mellitus and chronic obstructive pulmonary disease, among others), and thus verifying data from other sources is not possible (42,43).

A second potential limitation of the present study is the missing data on health care costs. We performed multiple imputations, which is considered highly appropriate to account for missing data. Third, this economic evaluation was conducted alongside a clinical trial and the required sample size was based upon the primary outcome of the randomized controlled trial. Since costs have a larger variation and skewness than clinical outcome measures, the current study may be underpowered (44,45). Fourth, one should keep in mind that we applied a health care payer perspective in the present economic evaluation. Thus, productivity losses were not considered. We assumed that secondary health care costs would be the main driver in the present study. This is underlined in a cost-effectiveness study on a blended intervention in knee/hip OA, in which two-thirds of costs emerged from direct health care costs. Another potential limitation might be that we used the EQ-5D-3L rather than the EQ-5D-5L descriptive system, as the 5L was developed to improve the sensitivity of the 3L. Last, it should be mentioned that we recruited individuals for participation in a study on eHealth, which may have affected the selection of participants in the sense that individuals with knee/hip OA who had an interest in using contemporary technologies may have been more likely to participate in the study compared to those with knee/hip OA who did not have a similar openness to using eHealth software. Thus, generalizability is restricted to people with knee/hip OA who have an interest in using modern technologies to manage their disease. A strength of the present study is that we performed not only a cost-utility analysis based on 2 different utility measures, but we also used 6 different clinical outcomes to estimate cost-effectiveness, which enabled trade-off among a range of benefits.

Considering the above-mentioned results and limitations, this economic evaluation from a health care payer perspective shows moderate probability that an eHealth application, such as the dr. Bart app, to enhance disease self-management in people with knee/hip OA can be considered cost-effective. In view of the prevalence of OA and the fact that inducing difficult lifestyle changes is the cornerstone of OA management—and therefore a potential long-term investment—we believe the magnitude of effects attributable to the dr. Bart app are worthwhile. Thus, the app could be applied as a primary approach to deliver useful information and support self-management in people with knee/hip OA, specifically for patients who are interested in eHealth.

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AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be submitted for publication. Drs. Pelle and van den Ende had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study conception and design. Pelle, Bevers, van den Hoogen, van der Palen, van den Ende.

Acquisition of data. Pelle.

Analysis and interpretation of data. Pelle, van der Palen, van den Ende.

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