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Original article

Medium-term patient's satisfaction after primary total knee arthroplasty: enhancing prediction for improved care

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INFO ARTICLE

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ABSTRACT

Background. – Patient-reported satisfaction after total knee arthroplasty (TKA) is low compared to other orthopedic procedures. Although several factors have been reported to influence TKA outcomes, it is still challenging to identify patients who will experience dissatisfaction five years after surgery, thereby improving their management. Indeed, both perioperative information and follow-up questionnaires seem to lack statistical predictive power.
Hypothesis. – This study aims to demonstrate that machine learning can improve the prediction of patient satisfaction, especially when classical statistics fail to identify complex patterns that lead to dissatisfaction.
Patients and methods. – Patients who underwent primary TKA were included in a Registry that collected baseline data and clinical outcomes at different follow-ups. The patients were divided into satisfied and dissatisfied groups based on a satisfaction questionnaire administered five years after surgery. Satisfaction was predicted using linear statistical models compared to machine learning algorithms.
Results. – A total of 147 subjects were analyzed. Regarding statistics, significant differences between satisfaction levels started emerging only six months after the intervention, and the classification was close to random guessing. However, machine learning algorithms could improve the prediction by 72% soon after the intervention, and an improvement of 178% was possible when including follow-ups up to one year.
Discussion. – This study demonstrates the feasibility of a registry-based approach for monitoring and predicting satisfaction using ML algorithms.
Level of evidence. – III.

1. Introduction

Total knee arthroplasty (TKA) surgery is widely recognized as an effective procedure. However, patient-reported satisfaction rates remain around 80%, with peaks of dissatisfied patients reported as high as 30% [1–3], which is a poor result compared to other orthopedic procedures. Interpreting patient satisfaction after TKA is not straightforward, as numerous factors may influence it [4]. However, it is crucial for better patient care and for the optimization of therapeutic strategies. Several systematic reviews have analyzed factors that influence satisfaction, such as pain reduction from preoperative levels [5], postoperative function [6], demographic factors [7], depression, and anxiety [8,9]. However, most postoperative satisfaction assessments lack mid- to long-term follow-ups. A thorough literature search resulted in only few studies that have monitored satisfaction after TKA with a follow-up of more than 1 year [10–12]. Therefore, there is a need to improve the understanding of satisfaction after TKA with longer follow-ups to enhance care models and maximize outcomes [11,13].

The impact of TKA on patients' lives can be measured through Patient Reported Outcome Measures (PROMs) by administering questionnaires at progressively longer intervals [14]. Although PROMs can be systematically collected in electronic registries [15], data collection and statistical analysis can impose a significant burden on orthopedic activities [16]. The benefit of collecting PROMs at multiple follow-ups may not justify the effort, as they have

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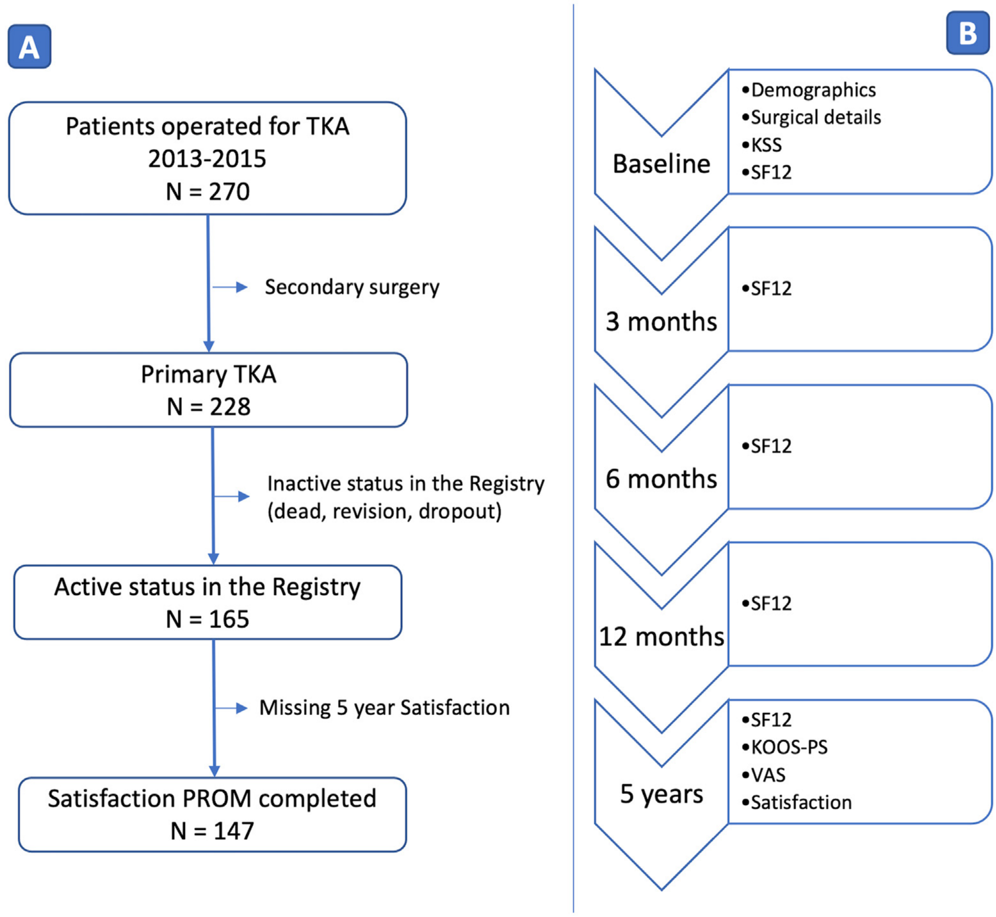

Fig. 1. Panel A: patient selection flowchart. Panel B: protocol.

been found to lack significance in statistical models [17]. Furthermore, recent studies question the ability of some widely used PROM scores to predict patients' satisfaction and functional outcome both in TKA and in unicompartimental knee arthroplasty [12,18]. Instead, a concurrent hypothesis could be that the usefulness of statistical models should be questioned when dealing with complex phenomena, such as mid-term satisfaction. Machine learning (ML) techniques could be the appropriate tool, as already proven in predicting short-term satisfaction [19].

Against this background, the research questions that have emerged are as follows:

- Q1. Are ML models better than statistics in predicting mid-term satisfaction?
- Q2. Are post-operative follow-ups useful in improving prediction?

Hence, the aim of this study is to determine the effectiveness of registry-based monitoring for predicting patients' satisfaction at medium-term after TKA, with the hypothesis that ML models may be able to identify important predictors despite their elimination in a linear model due to a lack of statistical significance (Q1) and that follow-up programs provide informative data for satisfaction prediction (Q2).

2. Patients and methods

2.1. Patients

Patients included in this study were enrolled in the Institute's Registry and underwent primary unilateral TKA for degenerative osteoarthritis only performed by the Ortopedia Ricostruttiva Articolare della Clinica Ortopedica (ORACO) team between 2013 and 2015. The exclusion criteria for this study were: (1) patients who were undergoing revision surgery or had any previous knee surgery, such as, knee osteotomy, meniscectomies, high tibial osteotomy or ligamentoplasty and (2) patients who did not complete the five-year Satisfaction questionnaire. The selection process of patients is illustrated in Fig. 1A.

Before the surgery, all patients provided informed consent for the secondary use of their data to enhance patient care (EC 82/INT/2015).

2.2. Methods of assessment

The data collected by the Registry is summarized in the Table 1, *Variable* column. It includes various components such as patients' demographics, surgical details, clinical questionnaires, PROMs, information on implanted devices, and radiological analysis.

The questionnaires and PROMs were administered according to the protocol outlined in Fig. 1B. They encompassed the following assessments: the Knee Society Score (KSS) in both objective and subjective forms [20], the Short Form 12 with its Physical (SF12-P) and Mental (SF12-M) sections [21], the Knee Injury and

Table 1
Sample characterization.

Variable	Satisfied (n = 96)	Neutral (n = 34)	Dissatisfied (n = 17)	Hypothesis testing p-value
Demography				
Sex	Female = 70 Male = 26	Female = 27 Male = 7	Female = 13 Male = 4	0.745[a]
Pre-operative BMI	29.75 ± 4.34	29.81 ± 5.04	27.75 ± 5.82	0.136[b]
Age at surgery	72.0 ± 7.5	72.29 ± 8.25	74.0 ± 6	0.335[b]
Intervention-related details				
Hospital stay	5 [5;6]	5.5 [5;6]	5 [5;6]	0.853[c]
American Society of Anesthesiologists (ASA) class	1 = 4, 2 = 77, 3 = 15	1 = 2, 2 = 26, 3 = 6	1 = 1, 2 = 15, 3 = 1	0.821[a]
Radiological measurements				
Tibia angle	0 [-1;1]	0 [-1;1.75]	0 [-1;2]	0.846[c]
Femur angle	5 [4;8]	5.5 [3.25;6.75]	7 [5;8]	0.199[c]
Kellgren-Lawrence	2 = 6, 3 = 24, 4 = 65, 1 missing	2 = 4, 3 = 9, 4 = 21	2 = 1, 3 = 4, 4 = 12	0.667[a]
Deformity degrees	8 [5;10]	5 [3;9.75]	4 [2;10]	0.074[c]
Varus/valgus	Varus = 70 Neutral = 5 Valgus = 20 1 missing	Varus = 21 Neutral = 6 Valgus = 7 1 missing	Varus = 7 Neutral = 2 Valgus = 8	**0.024**[a] post hoc: non-significant
Prosthesis characteristics				
Tibia size	3 [2.5;3]	3 [2.5;3]	2.5 [2.5;3]	0.483[c]
Patella presence	Yes = 24, No = 72	Yes = 25, No = 9	Yes = 2, No = 15	0.457[a]
Insert size	10 [10;12.5]	10 [10;10]	10 [10;10]	0.820[c]
Femur size	3 [2.5;4]	3 [2.5;4]	3 [2.5;3]	0.610[c]
Tibial slope	4 [2.0;4.0]	3.5 [1;5]	4 [2.0;3.5]	0.254[c]
Tibial slope presence	Yes = 89, No = 7	Yes = 26, No = 8	Yes = 17, No = 0	0.096[a]
Pre-op questionnaires				
SF12-P	32.0 ± 5.12	33.11 ± 6.38	32.1 ± 5.04	0.637[b]
SF12-M	43.8 [39.95;46.25]	42.75 [40.17;48.52]	42.3 [40.0;46.9]	0.984[c]
KSS-C	46.0 [37.0;50.0]	43.50 [35.0;49.0]	46.0 [37.0;58.0]	0.359[c]
KSS-F	50.0 [35.0;50.0]	50.0 [31.25;50.0]	40.0 [35.0;50.0]	0.866[c]
3-months questionnaires				
SF12-P	53.6 [52.1;55.7]	52.70 [50.10;55.30]	52.2 [50.1;52.9]	0.097[c]
SF12-M	60.7 [57.9;60.8]	58.80 [57.60;60.75]	57.6 [57.6;58.8]	0.073[c]
6-months questionnaires				
SF12-P	55.3 [52.1;56.6]	53.60 [51.10;56.60]	51.6 [46.4;53.6]	**0.026**[c] Post hoc satisfied-neutral: 0.817; **satisfied-diss.: 0.022**; neutral-diss.: 0.475
SF12-M	59.1 [57.9;60.8]	58.80 [57.60;60.75]	58.5 [56.9;60.7]	0.275[c]
12-months questionnaires				
SF12-P	55.70 [53.60;56.60]	55.70 [52.55;56.60]	52.20 [48.73;55.23]	**0.032**[c] Post hoc: satisfied-neutral: > 0.999; **satisfied-diss.: 0.031**; neutral-diss.: 0.082
SF12-M	60.70 [58.10;60.80]	60.70 [56.75;60.80]	58.30 [51.62;58.73]	**0.035**[c] Post hoc: satisfied-neutral: > 0.999; **satisfied-diss.: 0.024**; neutral-diss.: 0.186
5-years questionnaires				
SF12-P	46.4 [34.7;52.3]	41.85 [31.35;48.25]	34.8 [28.8;44.7]	**0.019**[c] Post hoc: satisfied-neutral: 0.189; **satisfied-diss.: 0.043**; neutral-diss.: > 0.999
SF12-M	50.35 [43.7;56.6]	49.35 [40.70;53.10]	46.7 [35.8;57.4]	0.316[c]
KOOS-PS	27.5 [14.8;37.0]	37.8 [29.7;51.2]	54.4 [42.0;71.8]	**< 0.001** Post hoc: **satisfied-neutral: < 0.001;** **satisfied-diss.: < 0.001;** **neutral-diss.: 0.016**
VAS	0 [0;3]	5 [2.5;7]	7 [5;9]	**< 0.001** Post hoc: **satisfied-neutral: < 0.001**; **satisfied-diss.: < 0.001**; neutral-diss.: 0.160

Statistically significant results in bold.
[a] Fisher test (frequency count).
[b] one-way Anova (mean ± standard deviation).
[c] Kruskal-Wallis test (median [quartiles]).

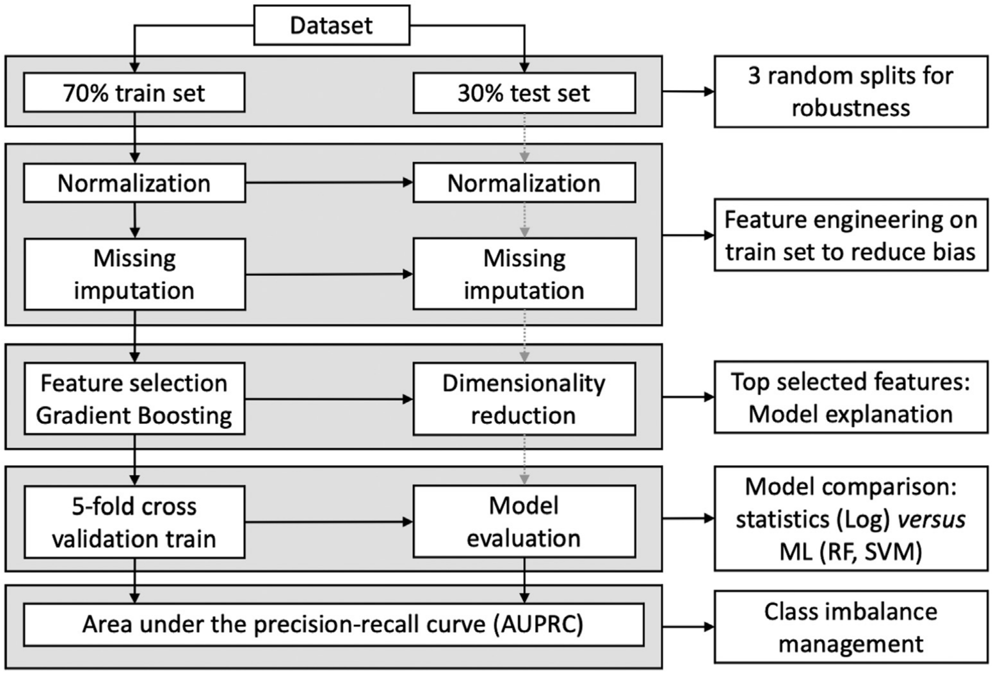

Fig. 2. Procedure for assessing predictive performance of statistical and ML models. Grey boxes explain the main steps.

Osteoarthritis Outcome Score Physical Functioning (KOOS-PS) [22], the Visual Analogue Scale (VAS) [23], and a 5-point Likert-scale Satisfaction questionnaire.

Regarding the radiological analysis, both anteroposterior (AP) and lateral radiographs (long-leg and standard short AP radiographs) were taken before and after the surgery to evaluate the degree of osteoarthritis based on the Kellgren-Lawrence classification [24]. Additionally, the axial alignment of the knee and components was assessed using TraumaCAD software [25] (Table 1).

The possible response options for the Satisfaction PROM were as follows: 0 = very satisfied, 1 = satisfied, 2 = neutral, 3 = dissatisfied, 4 = very dissatisfied. The focus of this study was on satisfied patients, defined as those who responded with 0 or 1, and dissatisfied patients, defined as those who responded with 3 or 4. Patients who selected neutral satisfaction were included in the sample description but were not considered for satisfaction prediction. This was done to ensure a clearer separation between the two classes of interest and to reduce the uncertainty associated with subjective evaluations in PROMs.

2.3. Data analysis

For sample characterization using classical statistical methods, both univariate and multivariate approaches were employed. Hypothesis testing was conducted to determine if each dependent variable differed based on the three levels of satisfaction (the independent variable). A statistical significance level of 0.05 was set. Discrete variables were tested using Fisher tests, while continuous variables were tested using Kruskal-Wallis or one-way ANOVA tests after confirming data normality using the Lilliefors test. Bonferroni-corrected post hoc tests were performed if significant differences were found. In the multivariate approach, a classifier based on Logistic regression (Log) was utilized.

To address the first research question (Q1), the performance of the Logistic model was compared to two machine learning (ML) models: Random Forest (RF) and Support Vector Machines (SVM) with a radial kernel. The procedure is exemplified in Fig. 2. The results obtained were compared to the baseline prediction, which involved assigning all observations to the Satisfied class.

To evaluate the potential benefits of collecting follow-up PROMs (Q2), the process outlined in Fig. 2 was repeated using two different approaches: (1) utilizing only pre- and peri-operative features ("Day-zero" model), and (2) incorporating PROMs up to a 12-month follow-up ("Year-after" model).

In both cases, the selected features were analyzed to gain insights into the factors influencing the predictions.

Data analysis was performed in R 4.0.1.

3. Results

A total of 147 subjects met the inclusion criteria for this study, comprising 110 females and 37 males, with a mean age of 72.3 ± 7.5 years. The average length of follow-up was 5.6 ± 0.9 years.

The distribution of the five-year satisfaction levels was as follows: 55 (37.4%) very satisfied, 41 (27.9%) satisfied, 34 (23.1%) neutral, 11 (7.5%) dissatisfied, and 6 (4.1%) very dissatisfied. The distribution of variables, stratified by satisfaction, can be found in Table 1, along with the results of the statistical testing. Fig. 3 provides a summary of the statistically significant findings.

To address the question of whether ML models outperform statistics in predicting mid-term satisfaction (Q1), the results of the predictions are presented in Fig. 4A. The percentage improvement from the baseline clearly illustrates the superiority of ML models, while statistics show minimal improvement over random guessing.

Regarding the potential benefits of collecting PROMs to enhance the prediction (Q2), Fig. 4A compares the satisfaction prediction at "Day-zero" with the prediction using data from the "Year-after" follow-ups. The inclusion of follow-up data leads to an improvement in performance, although the improvement is not statistically significant (Wilcoxon test for paired samples: $p = 0.098$). The importance of follow-up assessments is further emphasized by comparing the selected important features from the "Day-zero" (B) and "Year-after" (C) models. In both cases, the degree of deformity emerges as a crucial factor in the prediction. The importance of BMI and age diminishes when postoperative PROMs are included. Other

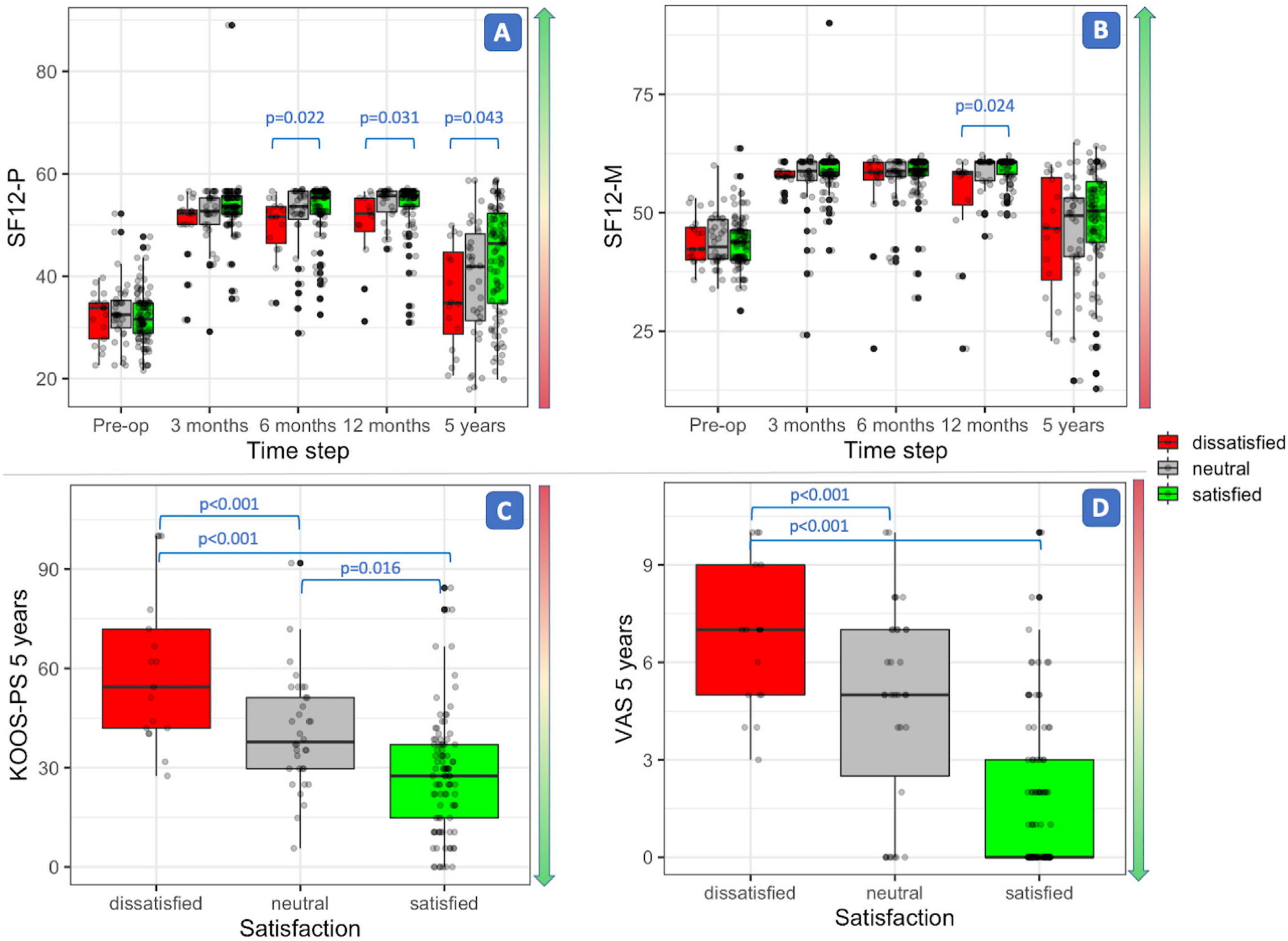

Fig. 3. Panels A and B: SF12 (y axis) sampled at different time steps (x axis); panels C and D: KOOS-PS and VAS at five year. Horizontal lines: medians; boxes: inter quartile ranges; whiskers: data range, excluding outliers. P-values are reported whenever significant. Colors group data to keep the dissatisfied-neutral-satisfied semantics. Arrows indicate the better score for the PROMs.

significant factors such as varus/valgus condition, femur angle, tibia angle, and preoperative SF12-M consistently demonstrate their importance in both models. However, with the inclusion of postoperative questionnaires, preoperative KSS and SF12-P are excluded in favor of SF12 assessments at 3, 6, and 12 months.

4. Discussion

The primary objective of this study was to investigate whether machine learning (ML) models could surpass conventional statistical methods in predicting patient satisfaction in the medium term (5 years) following total knee arthroplasty. Through the use of conventional statistical tests, it was observed that differences in satisfaction levels only became apparent six months after the surgery. Dissatisfaction was predominantly associated with physical dysfunctions (SF12-P, KOOS-PS, and VAS), rather than mental issues (SF12-M). While partially aligned with existing literature [26], particularly regarding pain levels, there was a weaker correlation with mental well-being (SF12-M) [8]. This discrepancy may be attributed to the relatively advanced age of the sample at the time of the intervention (mean age of 72 years), as the impact of age-related physical problems could have become more pronounced 5 to 7 years later.

When ML techniques were applied to uncover complex patterns (Q1), a notable improvement in dissatisfaction prediction of up to 72% over random guessing was observed, even on an imbalanced dataset with a low incidence of dissatisfaction (15%). This outcome is particularly impressive considering the limited number of examples available for the model to learn from. Such predictions can facilitate early targeted interventions to enhance the likelihood of positive outcomes, such as personalized rehabilitation programs. These findings confirm the potential of incorporating ML in satisfaction prediction, as previously demonstrated on short-term follow-ups [19], and extend its application to mid-term satisfaction, which can be influenced by random unrelated events over time, introducing more "noise" into the process. A comprehensive literature search revealed a scarcity of studies that successfully investigate this mid-term relationship, as addressed instead in this study.

While early detection of potential dissatisfaction holds value, it does not diminish the importance of continuous patient monitoring through a well-designed follow-up program (Q2). When PROMs collected up to one year after the surgery were included, substantial benefits in prediction performance were observed, with a median improvement of over 170% compared to the baseline. Existing literature suggests limiting PROMs collection to two time points: immediately before surgery and at 12 months postoperatively [14]. However, our findings suggest that assessments at 3 and 6 months using the SF12 questionnaire also serve as significant predictors of mid-term satisfaction. Further investigations are needed to determine the optimal timing for collecting PROMs. To strike a balance between usefulness and feasibility, PROMs collection could

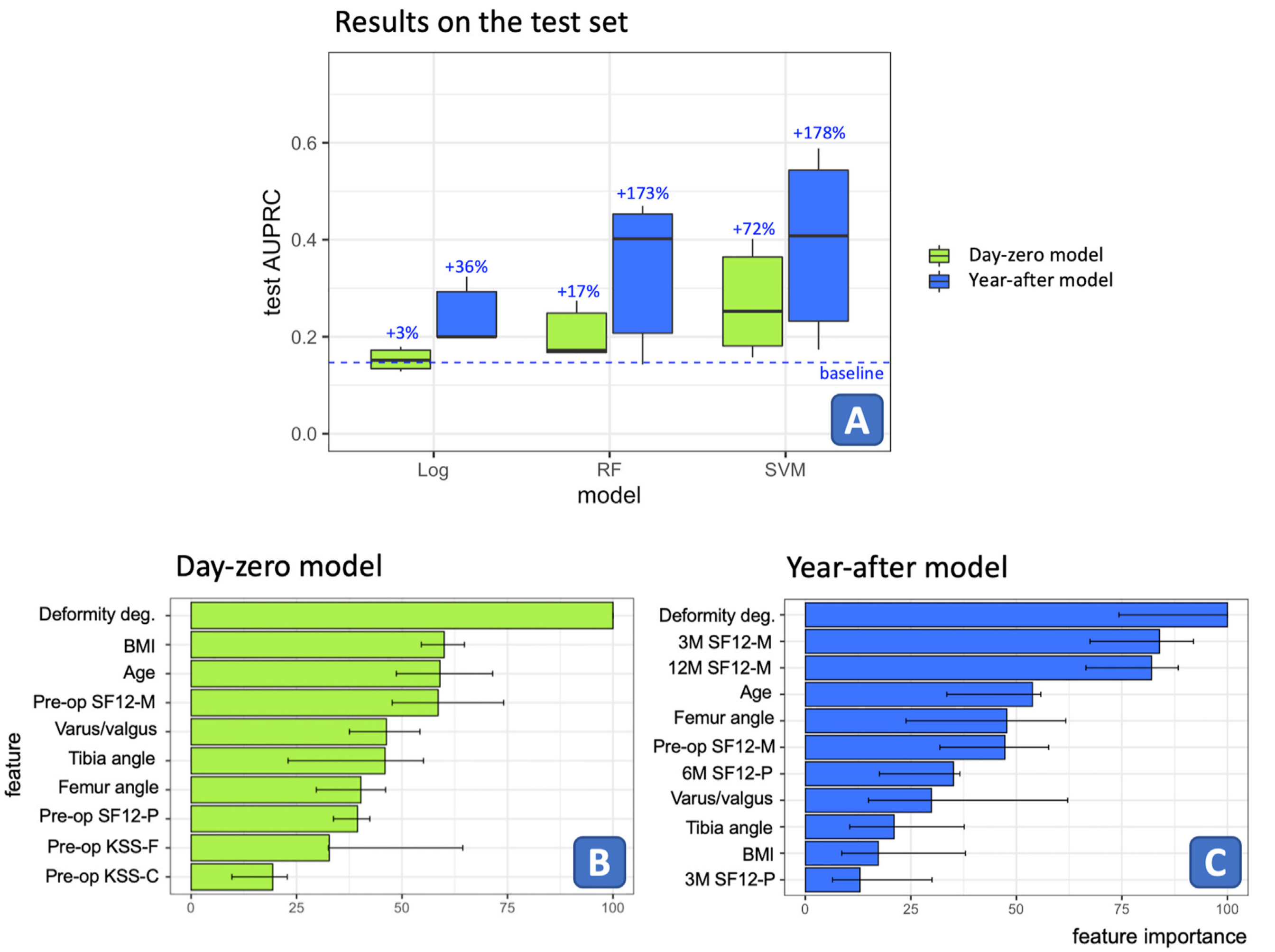

Fig. 4. Panel A: Results of satisfaction prediction for the "Day-zero" and "Year-after" models, computed thrice on different seeds. The percentages indicate the median improvement from the baseline (dashed line). Panels B and C: Important features for the prediction from the "Day-zero" (B) and from the "Year-after" model (C). Bars are medians, error bars are inter quartile ranges.

be focused on patients who are at a higher risk of dissatisfaction and possibly focus on the fulfillment of their expectation about the intervention [27].

The main limitation of our study is the relatively small sample size. Therefore, the results obtained from the models should not be considered as recommendations for guiding future clinical decisions. Instead, they highlight the necessity of a paradigm shift in evaluating patients' outcomes, fully utilizing the power of machine learning while providing explanations of the critical features used in the predictions. This approach can enhance awareness in the decision-making process within clinical settings.

5. Conclusions

The study results indicate that machine learning models exhibit higher sensitivity in identifying predictive parameters for patient satisfaction in the medium- to long-term (5 to 7 years) compared to traditional statistical analysis. Additionally, the findings support the promotion of PROMs collection as a valuable tool for satisfaction prediction. However, further investigation is necessary to determine the optimal administration approach for PROMs, considering both their usefulness and feasibility.

Trial registration number

NCT04960098 (clinicaltrials.gov).

Ethics approval and informed consent

All patients signed an informed consent before the surgery to allow the secondary use of their data to improve patient's care (IRB approval number: EC 82/INT/2015).

Data availability

data are available at https://osf.io/knr37/?view_only=e8ce444acbab49d8be7a353afdd842f9

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contributions

Conceptualization, M.U., L.O., L.G.D.; methodology, L.G.D, M.D., R.P; validation, M.D., R.P., L.G.D.; formal analysis, M.D., R.P. L.G.D.; investigation, M.U.; resources, S.F., M.U.; data curation, S.P., M.D.; writing–original draft preparation, M.U., L.O., L.G.D.; writing–review and editing, M.D., S.P., L.G.D., S.F.; visualization, L.G.D., S.P., R.P.; supervision, M.U., SF.; project administration, L.O., S.F.; funding acquisition, M.U.

Artificial Intelligence statement

No artificial intelligence was used for the writing of the submitted work.

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