Using the Empatica Sensor to Characterize Postoperative Pain and Opioid Response

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Introduction: Postoperative pain significantly impacts recovery and contributes to adverse long-term outcomes, including chronic opioid use, opioid misuse, and delayed healing.[1] Predicting, quantifying, and managing postoperative pain has long been a challenge, as existing methods of pain assessment rely on patient ratings which are often under-reported and vary by collection method and assessment tool. This study evaluates whether physiologic data from a wearable sensor (Empatica, USA) can be used to develop machine learning models to track patient's post-operative pain experiences. Ultimately, biometric monitoring can potentially provide more objective measures of postoperative pain and inform individualized pain management protocols.

Methods: Postoperative inpatients who underwent knee or hip arthroplasty were monitored using the Empatica EmbracePlus watch. Multimodal biometric data were collected and analyzed, including raw sensor data (blood volume pulse, electrodermal activity, temperature, and accelerometer and gyroscope) and derived "biomarker" data in one-minute aggregates (pulse rate, pulse rate variability, respiration rate, metabolic equivalent of task, etc.). Time-stamped opioid administration and doses, and visual analog scale (VAS) pain scores were collected from patient medical records. In addition, a specialized pain recording device was used to record patient-reported VAS scores more frequently. Using this data, machine learning models were developed to predict pain-related endpoints.

Features (minimum, maximum, mean, median, standard deviation, skewness, kurtosis, and IQR) of raw sensor and estimated biomarker data were assessed in 15-minute increments for 15-120-minute windows and fed into machine learning models to attempt binary prediction of several metrics associated with high pain. Up to 60 of the most important features were selected based on SHAP values. Five-fold cross-validation (CV) was used to assess AUROC of the models across the entire patient population.

Several machine learning models were evaluated, including logistic regression, random forests, XGBoost, LightGBM, and an ensemble "stacked" classifier consisting of XGBoost, LightGBM, and extra trees classifiers, followed by a final XGBoost classifier. Hyperparameters were tuned for each CV fold by further splitting the training dataset using smaller CV folds.

Results: Patients with sufficient data (N=42, Male = 27, Female = 14, Non-binary = 1) produced data for a median of 1.59 (interquartile rate [IQR]: 0.97-1.97) days. Ten thousand fifty-four machine learning modelling pipelines were evaluated. The best-performing pipeline had a 5-fold CV AUROC of 0.805, and used 13 features from the biomarker data, an ensemble classification model, and a high pain endpoint of poor pain alleviation (PPA, defined as VAS score ≥ 8 at least 3 times, separated by 4-12 hours) (Table 1). The most successful model for the raw data used a total of 17 features to predict pain scores with an AUROC of 0.616 (Figure 1).

Discussion: Wearable devices have previously been used to predict pain,[3] with sensor data recording signals reflecting physiological changes associated with pain. This exploratory analysis suggests that there are signals in the Empatica sensor data that are associated with post-orthopaedic surgery pain, with relatively effective prediction of some pain-related endpoints. With more complex models and sophisticated feature extraction techniques, better predictions of pain endpoints are expected, possibly enabling tailored opioid administration regimens for individual patients.

Significance/Clinical Relevance: Pain prediction model performance using continuous recordings of biometric data is expected to exceed the accuracy of prior models, which used demographics alone with limited focus specifically on patients undergoing orthopaedic surgery. In developing accurate and personalized methods to monitor postoperative pain, we can provide more specific and flexible pain management, reducing the risk of opioid misuse and improving recovery after orthopaedic surgery.

Keywords: Biomarkers, Computational Modeling, Statistical Methods, Sensors and Wearables, Pain

References:

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Figures and Tables:

Figure 1. 5-CV average AUROC analysis for the best pipeline.

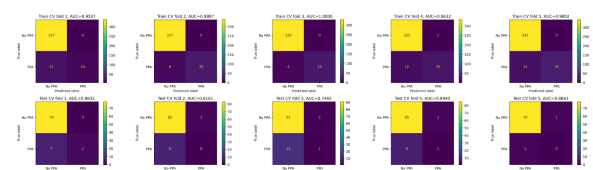

Table 1. Best model and best model features for each desired endpoint.

Endpoint	Data type	Model	Number of features	5-CV average AUROC
PPA	Empatica	Stacked	13	0.805
PPA day	Empatica	XGBoost	2	0.697
PPA during stay	Empatica	Stacked	3	0.624
Pain score ≥ 5	Raw	Stacked	53	0.658
Pain score ≥ 6	Empatica	XGBoost	19	0.682
Pain score ≥ 7	Empatica	XGBoost	27	0.746
Pain score ≥ 8	Empatica	Stacked	25	0.701