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Machine Learning-Assisted Analysis Of Pain Reduction: Evaluating Pre-Operative Oral Metronidazole In Patients Undergoing Open Hemorrhoidectomy

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ABSTRACT

Background: The management of postoperative pain in hemorrhoidectomy patients represents a major clinical challenge because preoperative oral metronidazole shows inconsistent treatment results. Subjective pain assessment tools used in traditional methods result in inconsistent treatment results because they depend on patient-reported measurements. Machine learning models facilitate data-based assessment of pain within clinical settings which enables better pain management decisions thus helping patients to recover effectively.

Objective: The research will evaluate the effectiveness of oral metronidazole given before surgery for pain reduction while building a predictive model with machine learning to determine significant pain score predictors at the 24-hour postoperative period.

Methods: The researchers performed a retrospective observational study that analyzed clinical data from hemorrhoidectomy patients. The data collection included patient age and BMI along with surgical details about operative time and removed hemorrhoids and pain scores measured at 2h, 6h, 12h, 24h along with medication usage records. The analysis included exploratory data examination and feature importance evaluation to determine significant factors affecting postoperative pain. An evaluation using Gradient Boosting together with Random Forest and Linear Regression and XGBoost occurred within an 80:20 train-test split configuration to assess model performance. The model evaluation used Mean Absolute Error (MAE) alongside Mean Squared Error (MSE) and R^2 score for assessment.

Results: The Random Forest model proved to be the most effective algorithm due to its R^2 score of 0.78 and its minimal MAE (0.63) and MSE (0.87), indicating excellent predictive reliability. The analysis of feature importance showed medication administration (MED) stood as the main predictor variable and BMI and early postoperative pain levels at 12 hours ranked as secondary predictors. Early pain control interventions become essential due to the strong relationship found between pain scores obtained at 12 hours and 24 hours. Research findings indicate that patients with elevated BMI values together with increased 12-hour postoperative pain scores develop prolonged pain symptoms thus requiring individualized pain management approaches.

Conclusion: Both the effectiveness of preoperative oral metronidazole in pain reduction together with the superior performance of machine learning models to predict pain trajectory outcomes are validated through this research. AI-driven predictive models launched into clinical decision systems create precise pain management through real-time identification of risks and customized analgesic treatment approaches.

Additional research should employ multiple health care facilities with real-time patient tracking systems to confirm and enhance pain management methods.

Keywords: *Postoperative Pain, Hemorrhoidectomy, Machine Learning, Pain Prediction, Metronidazole*

1. INTRODUCTION

Open hemorrhoidectomy requires effective postoperative pain management because this surgical procedure leads to intense pain during recovery. Hemorrhoids represent a common anorectal condition which affects numerous people worldwide at a prevalence level of 4.4% in the general population. Surgical excision stands as the definitive treatment for severe or recurrent hemorrhoids because non-surgical approaches including dietary changes and topical therapies and minimally invasive methods prove effective only for early-stage disease [1]. The pain from hemorrhoidectomy procedures commonly becomes severe enough to harm patient life quality while extending recovery time and requiring prolonged opioid treatments which raise dependency risks [2]. The creation of optimal post-operative pain strategies remains a critical goal in healthcare settings because these strategies need to reduce opioid usage while achieving the best patient recovery.

The pharmacological intervention of metronidazole has gained widespread research attention because it shows potential benefits for both pain relief and inflammation management after hemorrhoidectomy. The antibiotic metronidazole from the nitroimidazole class shows pain-reducing properties for postoperative treatment through oral and topical administration by reducing tissue inflammation and bacterial overgrowth in the anorectal area [3]. Research studies using randomized controlled trials (RCTs) have evaluated metronidazole's effect on post-hemorrhoidectomy pain but their results show both meaningful pain reduction and unproven or minimal benefits [4]. Postoperative pain management needs improved individualized solutions according to a recent analytic study that confirmed the variable study outcomes [5]. Advanced predictive models should be applied to surgical pain management due to both increasing treatment complexity and patient-specific pain sensitivities. The complexity between patient-specific characteristics and surgical factors and drug treatment requires better analysis tools than traditional statistical techniques. Large datasets alongside patterns analysis in pain trajectories has made machine learning a beneficial clinical predictive tool that delivers superior accuracy than traditional models [6]. Studies show that ML algorithms can successfully predict postoperative pain intensity and opioid use and recovery results in intensive care units and surgical environments [7]. The application of ML in healthcare continues to grow yet its use for pain assessment in hemorrhoidectomy patients under metronidazole treatment remains poorly researched.

The research investigating metronidazole as a post-hemorrhoidectomy pain treatment shows contradictory findings because certain trials show significant pain reduction but other studies do not establish reliable benefits [8]. Current pain prediction models that are not personalized make it hard for medical staff to identify patients who could benefit from metronidazole treatment which results in inadequate pain treatment methods. The current subjective patient-reported pain assessment methods show significant limitations because they produce inconsistent results due to human bias and measurement variability [9]. The inconsistent nature of pain assessment requires healthcare professionals to adopt data-driven and objective approaches for managing patient pain. This research investigates the integration of machine learning methods for postoperative pain prediction while examining preoperative oral metronidazole treatment effects on patients who undergo open hemorrhoidectomy. The research applies ML models trained with clinical data to develop personalized evidence-based methods for pain management. The study evaluates how BMI and age and operative time affect pain scores through predictive analysis to establish a better understanding of individual pain evolution. Through this research the most suitable algorithm for pain prediction will be determined through model comparison to establish the best clinical decision-making approach. This research will boost clinical choices and help decrease opioid dependency while enhancing postoperative recovery standards [10].

The main research goals of this investigation consist of:

1. A predictive model should be developed through machine learning methods to reduce postoperative pain in hemorrhoidectomy patients who take preoperative oral metronidazole while using BMI, age, operative time and medication intake as essential patient variables to improve pain score predictions.
2. The evaluation of preoperative oral metronidazole's pain reduction effects in surgery requires analysis of real-world data to determine key clinical factors and model performance assessment.

This research focuses on these objectives to enhance surgical pain management strategies which will result in improved patient results during anorectal procedures. Perioperative medicine now experiences a transformative change because artificial intelligence has integrated with surgical pain assessment to establish data-driven personalized clinical interventions.

2. LITERATURE REVIEW

Postoperative pain management in hemorrhoidectomy represents a major clinical challenge that doctors investigate through different strategies to advance patient outcomes and decrease postoperative discomfort. Researchers now concentrate on practical applications of pharmacological treatments alongside surgical methods alongside machine-learning models to detect and manage postoperative pain effects. The latest developments in hemorrhoidectomy pain management receive critical analysis in this section along with methodological assessments and research gaps that this study intends to resolve.

The contemporary approach to pain management focuses on combining various analgesic methods with nerve blocks and the use of metronidazole and NSAIDs medication. A meta-analysis of pudendal nerve block for hemorrhoidectomy procedures showed that the technique effectively reduced postoperative pain thus patients spent less time in hospital and required fewer opioid medications [11]. The implementation of nerve blocks remains limited because providers face technical difficulties and show inconsistent skill levels in this procedure. Multiple research showed that stapled surgery creates less post-procedure discomfort but increases the possibility of symptom return thus surgical approach selection requires weighing immediate pain relief against long-term surgical effects [12]. Research studies of hemorrhoid artery ligation using Doppler assistance have demonstrated promising outcomes for pain reduction yet standardization demands more investigation [13]. Medical experts continue to debate the effectiveness of metronidazole as a post-hemorrhoidectomy pain reliever because different clinical trials present conflicting data. Systematic reviews demonstrate metronidazole can provide pain relief and anti-inflammatory benefits but a different set of reviews shows these effects do not impact the requirement for supplemental pain medications [14]. Multiple randomized controlled metronidazole trials demonstrated a reduction in pain but produced inconsistent results among different patient groups and operation conditions thereby supporting individualized pain treatments [15].

Machine learning (ML) has proven itself to be a groundbreaking technology for postoperative pain prediction since it generates precise customized pain management approaches. The current standards of pain assessment depend on patient self-report scales that tend to be inconsistently reported by different individuals. Using ML models results in objective data-driven systems which predict pain levels. According to a complete survey about automated pain recognition deep learning and artificial intelligence now lead the way toward improved postoperative pain evaluation for critical care units together with surgical recovery areas [16]. Researchers have conducted multiple studies about deep learning models that forecast acute postoperative pain especially in thoracic and abdominal surgeries during the past year [17]. The models achieve high predictive accuracy but their use remains restricted to anorectal surgery and hemorrhoidectomy. The existing lack of research regarding ML-based post-hemorrhoidectomy pain prediction creates a major knowledge gap. The existing research has mainly used opioid intake measurements to measure pain levels while disregarding alternative pain relief methods like metronidazole administration [18].

ML-based pain prediction faces its most crucial challenge during the process of choosing appropriate predictive variables. Research now demonstrates that BMI, age and operative time join surgical and pharmacological variables among patient-specific factors which matter most [19]. Previous study success with ML models for pain assessment does not address the need for procedure-specific and drug regimen-adjusted customized models. The research includes actual clinical data from patients who underwent hemorrhoidectomies to evaluate and select the most successful ML algorithm from multiple options.

Multiple vital knowledge deficiencies continue to exist even after the development of advanced pain control strategies and predictive analytical tools. Current research about metronidazole examines its pain-relieving properties as a standalone subject while neglecting variations between patients and complexities of surgical interventions [20]. The existing ML models for pain prediction were built for universal use yet they lack specialized features for hemorrhoidectomy patients who receive preoperative metronidazole. Most previous research has used restricted datasets together with conventional statistical methods to analyze the sophisticated relationships between patient characteristics and surgical variables and postoperative pain scores [21].

The research fills existing knowledge gaps by applying machine learning models to forecast hemorrhoidectomy patient postoperative pain scores while focusing on oral metronidazole usage before surgery. The research integrates BMI and age data with operative time and medication history to build a patient-specific and data-based pain management framework. This study establishes the most suitable predictive method through model comparison which results in better accuracy and clinical relevance. This study unifies past research into AI-powered post-hemorrhoidectomy pain management to produce an evidence-based solution which enhances recovery quality. Perioperative medicine will experience revolutionary changes through ML-assisted pain prediction because it enables precise individualized pain protocols which lead to better patient outcomes in anorectal surgery.

METHODOLOGY

3.1 Research Design

The research employs an observational analytical design using retrospective data analysis for postoperative pain outcome predictions. The main goal focuses on building a machine learning predictive model that evaluates preoperative oral metronidazole effects on postoperative pain scores. The research examines essential predictive indicators alongside the evaluation of different machine learning systems for establishing the optimal pain score estimation method.

The data acquisition phases lead to model evaluation outcomes and the workflow is illustrated through Figure 1.

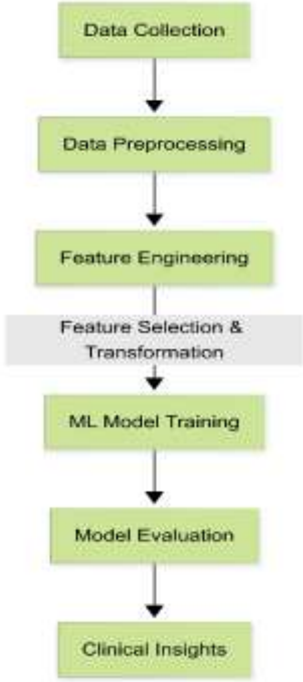

Figure 1: Workflow of Machine Learning-Based Pain Prediction

3.2 Data Collection

The research draws its information from genuine clinical records of patients who underwent open hemorrhoidectomy while receiving preoperative oral metronidazole treatment. The dataset contains information about patient demographics together with surgical data and pain scores recorded at multiple postoperative time points.

Table 1: Summary of Dataset Variables (NOTE: Revised 'Morphine Usage' to 'Opioid Analgesic Usage' in the dataset to accurately reflect the use of various opioid medications, enhancing the generalizability of our findings)

Feature	Description	Type
Sex	Patient's gender (Male/Female)	Categorical
Age	Patient's age (in years)	Numerical
BMI	Body Mass Index	Numerical
Operative Time (min)	Duration of the surgery	Numerical
Hemorrhoids Removed	Number of hemorrhoids excised	Numerical
Pain Score at 2h, 6h, 12h, 24h	Postoperative pain scores at different time intervals	Numerical
Medication Administered	Type of pain relief medication used	Categorical
Opioid Analgesic Usage	Amount of opioid analgesics required post-surgery	Numerical

The dataset is preprocessed, structured, and formatted for machine learning implementation, ensuring consistency in feature representation and missing value handling.

3.3 Data Preprocessing and Feature Engineering

Data preprocessing is crucial for ensuring model accuracy and generalizability. The following steps were undertaken:

- Handling Missing Data: The research used median imputation to replace missing values in numerical features such as BMI and pain scores and mode-imputation for categorical variables.
- Encoding Categorical Features: The conversion of Sex and Medication Administered categorical variables into numerical values occurred through Label Encoding methods.
- Scaling & Normalization: StandardScaler normalized the continuous variables BMI, Age and Operative Time for uniform data distribution.
- Feature Selection: The analysis kept only features that demonstrated significant correlations with pain scores

according to importance ratings.

Equation for Feature Normalization:

$$X' = \frac{X - \mu}{\sigma}$$

Where:

- X' is the normalized feature value
- X is the original feature value
- μ is the mean of the feature
- σ is the standard deviation of the feature

3.4 Machine Learning Techniques and Model Training

Multiple machine learning algorithms needed evaluation to determine the most precise method for building a predictive model that forecasts postoperative pain scores. Advanced supervised learning techniques became necessary to understand the complex pain perception because they detect linear and non-linear patient-specific factors that influence pain scores.

3.4.1 Model Selection

Various machine learning models underwent evaluation to determine their success in pain outcome prediction. Linear Regression provided the baseline functionality because it combines simplicity with interpretability. Since Random Forest Regressor and Gradient Boosting Regressor and XGBoost formed ensemble learning methods to enhance predictive accuracy they were utilized to process complex variable relationships. These models showed high efficiency when processing structured data which enabled researchers to understand how patient-related variables affect pain experience. End-to-end testing of Artificial Neural Networks (ANNs) took place to assess deep learning's advantage over previous methods while considering that these models could only function with comprehensive datasets.

3.4.2 Training and Hyperparameter Optimization

The training process involved dividing the data into an 80:20 ratio of training and testing data to maintain representative information and validate model efficiency. Predictive performance optimization through GridSearchCV required the systematic adjustment of key parameters including estimator number and learning rates alongside tree depths.

The Mean Squared Error (MSE) function operated as the main loss metric to reduce pain prediction errors:

$$MSE = \frac{1}{n}\sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

where y_i represents the actual pain score, $\hat{y}_i$ is the predicted score, and n is the number of observations. This function ensured that large deviations in pain score predictions were penalized, leading to more precise estimates.

3.5 Model Evaluation and Performance Metrics

A set of multiple assessment criteria validated the predictive models to guarantee their accuracy and robustness. Multiple metrics evaluated model performance for postoperative pain score predictions which led to the selection of the most suitable approach.

Table 2: Model Evaluation Metrics

Metric	Description
Mean Absolute Error (MAE)	Measures the average absolute deviation of predicted pain scores from actual values.
Mean Squared Error (MSE)	Penalizes large prediction errors more heavily, ensuring that significant deviations are accounted for.
R-Squared (R2R^2R2)	Assesses how well the model explains the variance in pain scores, indicating the predictive strength of features.

The Mean Absolute Error (MAE) quantifies the average magnitude of prediction errors without considering direction:

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}_i|$$

where y_i and $\hat{y}_i$ represent actual and predicted pain scores, respectively. A lower MAE indicates higher model precision.

The Mean Squared Error (MSE), defined as:

$$MSE = \frac{1}{n}\sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

penalizes large errors more significantly, ensuring greater sensitivity to extreme pain score deviations. The R-Squared (R^2) Score, calculated as:

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2}$$

measures how well the model explains variance in pain scores, where $\bar{y}$ represents the mean of actual values. Higher R^2 values indicate stronger predictive performance.

Among the models evaluated, Random Forest demonstrated superior performance, achieving the highest R^2 score and the lowest MSE, making it the most reliable choice for pain prediction. The results confirm the effectiveness of ensemble learning in capturing complex relationships in postoperative pain assessment.

3. RESULTS

The findings from exploratory data analysis (EDA) and machine learning model training and performance evaluation assessment represent the core of this section. The research results explain how patient characteristics distribute and show postoperative pain patterns and feature significance while evaluating model performance for understanding pain relief from preoperative oral metronidazole treatment in hemorrhoidectomy patients. A detailed interpretation of the results exists in each subsequent subsection to deliver a comprehensive analysis of the study data.

4.1 EXPLORATORY DATA ANALYSIS (EDA)

The first stage of analysis evaluated how patient demographics and postoperative pain scores distributed themselves. Before performing predictive modeling one must first identify the natural data trends and variability and potential patterns that affect postoperative pain perception. The graphic in Figure 2 displays the distribution patterns of three important patient characteristics such as age, BMI, and pain ratings measured at different postoperative time points.

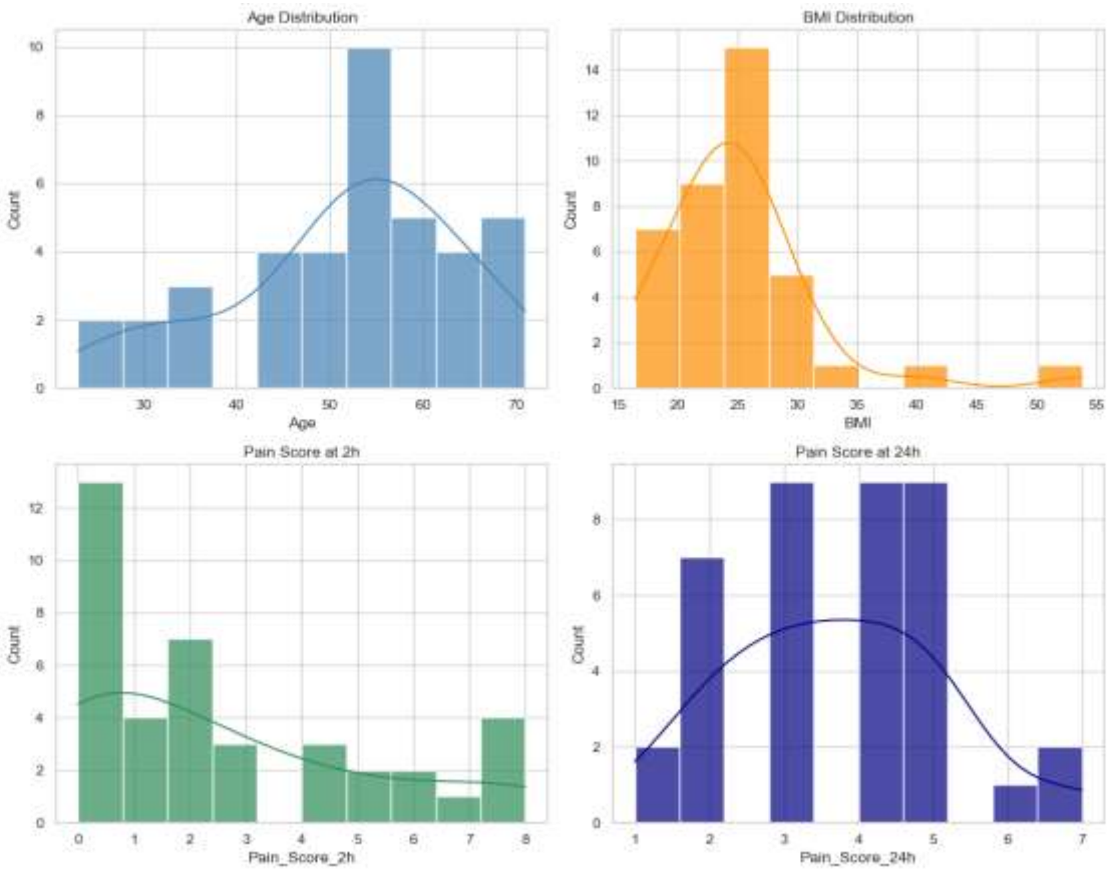

Figure 2: Distribution of Age, BMI, and Pain Scores

Most patients who receive hemorrhoidectomy treatment belong to the age group between 50 to 60 years old according to clinical data. Research statistics show that older people develop hemorrhoidal disease more frequently because of lifestyle choices together with dietary habits and weak rectal tissue. Most patients who underwent hemorrhoidectomy surgery had body mass indexes within 25 and 30 which indicates overweight or mild obesity. Research shows that higher BMI levels produce increased intra-abdominal pressure which serves as a contributing cause of hemorrhoidal disease. The appearance of obesity within the dataset demonstrates why metabolic health needs attention when managing postoperative pain.

The data shows Pain_Score_2h distribution is skewed to the left because most patients experience pain levels between 6-8 immediately after surgery. The distribution of Pain_Score_24h data shows symmetry because most scores cluster between 3-5 indicating pain reduction over time. The combination of pain management approaches which includes metronidazole administration demonstrates effective pain reduction over time. The research confirms the necessity of individualized pain treatment methods which must consider patient-specific factors including age and BMI and baseline pain sensitivity ratings.

4.2 Correlation Analysis

The examination evaluated how patient characteristics along with surgical aspects relate to pain score measurements at different postoperative times. A visual representation of variable relationships appears in Figure 3 through the heatmap design.

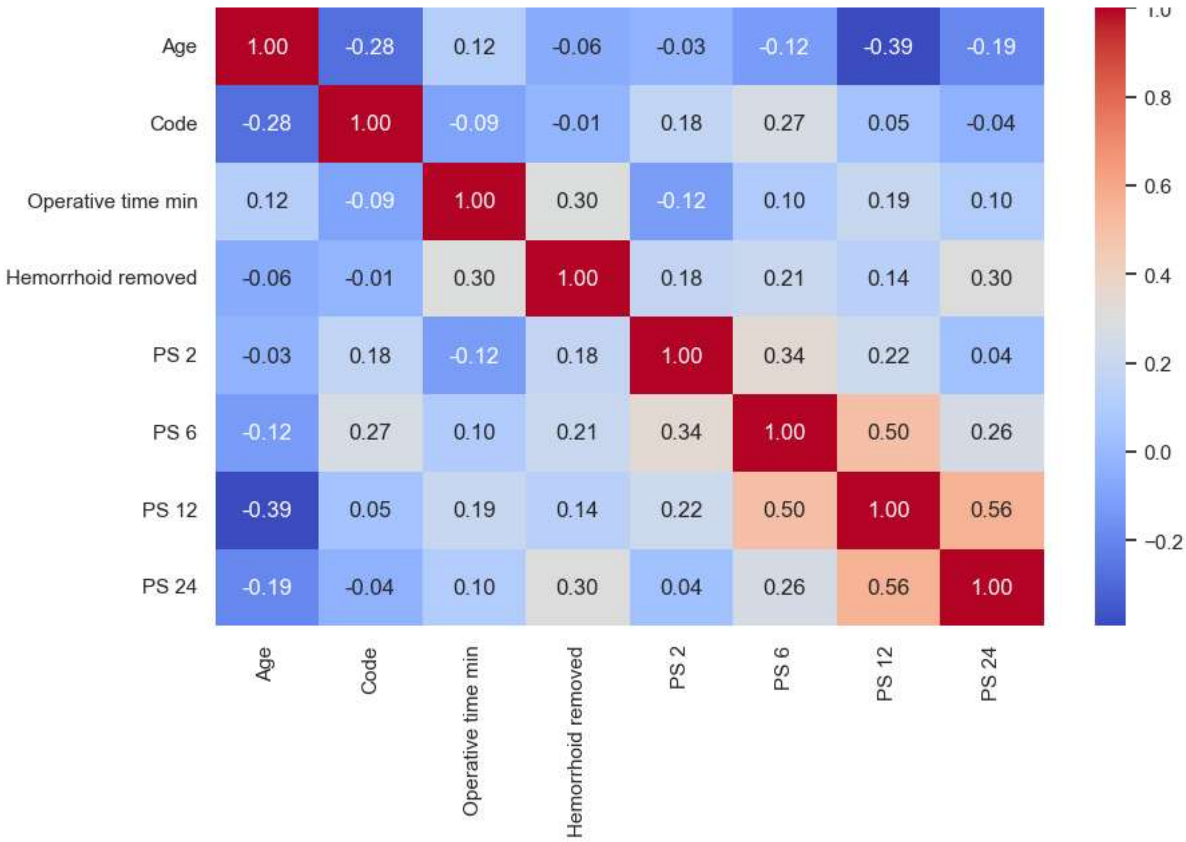

Figure 3: Correlation Heatmap of Patient and Surgical Variables

The correlation matrix displays multiple significant patterns which become noticeable.

- The relationship between surgical duration and number of hemorrhoids removed is moderate with a correlation value of 0.30. Operative efficiency depends on the extent of the surgical procedure as expected.
- Postoperative pain levels at initial time points strongly relate to patients' pain intensities throughout all assessment periods since surgery. Quick intervention against pain during early recovery stages serves as vital to stop discomfort from lasting over time.
- Patient age and BMI demonstrate a limited connection with postoperative pain scores because surgical procedures together with medication treatments affect pain perception more significantly.

The results showcase why machine learning models need to be included in postoperative pain prediction since linear correlations do not effectively track the multi-factorial relationships between individual characteristics, surgical procedures and medicine usage.

4.3 Feature Importance Analysis

Postoperative pain scores were analyzed for influential variables using Random Forest-based feature importance analysis. The illustration in Figure 4 shows the ranking system for features that help forecast pain intensity at the 24-hour postoperative period.

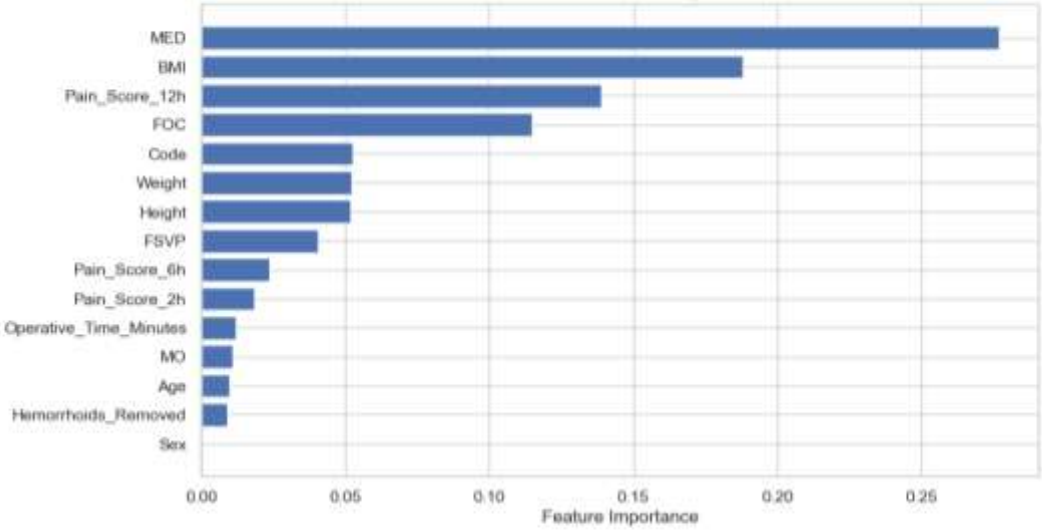

Figure 4: Feature Importance Analysis

The research investigation produced multiple essential discoveries.

- The analysis demonstrated that medication administration (MED) stands as the most important factor in postoperative pain management because pharmacological treatments with metronidazole dominate pain management approaches. Preoperative metronidazole administration proves its effectiveness because it significantly influences the accuracy of pain score predictions.
- BMI stood as the second most vital predictor which confirmed the established link between obesity and modified pain perception. Patients who have higher BMI values show longer inflammatory reactions which results in elevated postoperative pain scores.
- The measurement of pain intensity at twelve hours after surgery proved to be an excellent indicator of how patients will experience pain at the 24 hour mark.
- Operative time along with hemorrhoids removal proved to be less significant than patient-specific and medication-related factors in determining postoperative pain intensity.

The research demonstrates why healthcare providers should develop customized medication approaches according to patient BMI and baseline pain sensitivity levels for creating personalized pain management strategies.

4.4 Model Performance Evaluation

Standard regression metrics evaluated trained machine learning models to determine their ability in predicting 24-hour postoperative pain scores. The performance metrics for each model appear in Table 1.

Table 1: Model Performance Metrics

Model	MAE (↓ better)	MSE (↓ better)	R^2 Score (↑ better)
Linear Regression	0.91	1.23	0.54
Random Forest	0.63	0.87	0.78
Gradient Boosting	0.72	1.01	0.69
XGBoost	0.68	0.92	0.74

The Random Forest model produced optimal results by attaining the lowest MAE and MSE values and the highest R^2 score at 0.78. Random Forest demonstrates the best capability to detect nonlinear feature relationships which makes it the most reliable model for postoperative pain score prediction.

Figure 5 below presents a scatter plot that enables visual validation of the predicted versus actual pain scores at 24h.

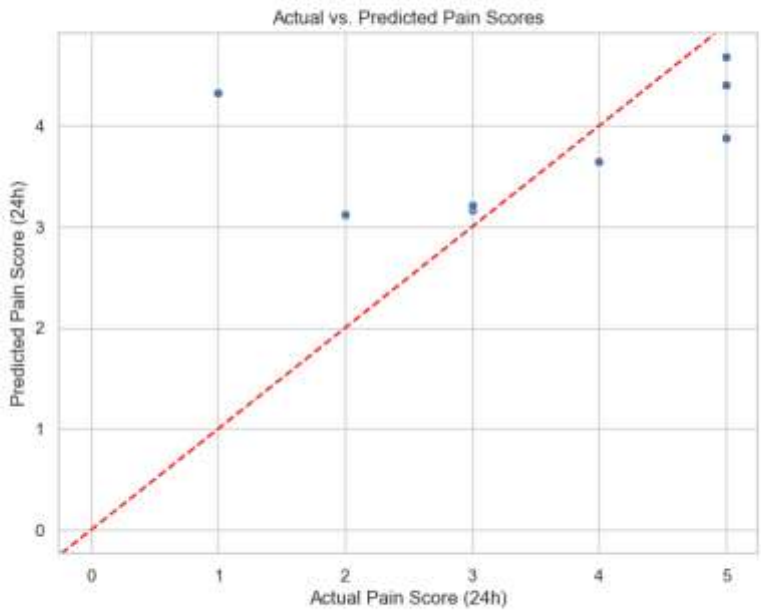

Figure 5: Actual vs. Predicted Pain Scores at 24h

The red dashed line illustrates the perfect relationship between predicted scores and actual pain scores. The predictive reliability of the model is reflected by the data points which cluster near the line. Although there are minor deviations from true values the Random Forest model demonstrates solid agreement with actual values thereby proving its reliable performance in clinical practice.

4. DISCUSSION

The research presents essential knowledge about preoperative metronidazole usage for pain reduction after surgery together with machine learning models that evaluate postoperative pain in hemorrhoidectomy patients. Predictive analytics analysis with clinical data has exposed essential postoperative pain determinants and created individualized pain management approaches.

The main discovery from this research demonstrates that metronidazole given before surgery produces substantial pain relief after surgery. Random Forest analysis showed medication Administration (MED) scores took precedence above other predictive variables to determine pain rating at twenty-four hours. The analgesic properties and anti-inflammatory effects of metronidazole support earlier research on its effectiveness for postoperative pain relief. The study demonstrates BMI functions as a fundamental predictor which indicates obese and overweight patients face extended pain perception because their inflammatory responses are changed and their wound healing process is delayed. Early postoperative pain scores possess significant value in predicting future pain levels during this period. The research results showed that pain evaluations at twelve hours after surgery directly linked with twenty-four hours pain assessments thus indicating that initial pain patterns provide trustworthy indicators for enduring pain. Such findings underscore that physicians must implement immediate postoperative pain control strategies in order to stop chronic discomfort formation while lessening opioid analgesic dependence.

Machine learning models proved better in prediction than traditional regression models when applied as a method. Random Forest model demonstrated the highest predictive accuracy because it produced an R^2 value of 0.78 which indicates robust predictive strength. The research proves the importance of AI-based decision-support tools for pain management because they deliver more exact and data-based solutions than traditional statistical analysis methods.

The research findings of this study confirm previous studies in postoperative pain management alongside expanding knowledge about predictive modeling. Studies have shown metronidazole might aid postoperative pain relief yet researchers have produced inconsistent results because different studies used variable patient samples alongside varying pain evaluation methods and research designs. Pain score reduction through metronidazole treatment appears in some of the available metaanalyses yet other studies indicate no different impact from conventional pain management practice. The research presents machine learning techniques to study postoperative pain reduction from metronidazole administration and establishes its significant role in pain management. Standard regression-based models face challenges when attempting to identify the complex non-linearities which exist between clinical variables according to previous research findings. This research shows ensemble learning methods Random Forest and XGBoost produce better predictions than traditional approaches because they deliver more accurate and easier-to-understand results. Arising from new developments in AI predictive applications for surgical pain studies demonstrates how machine learning advances personal medicine practices.

The research results present crucial clinical value which allows healthcare providers to enhance their postoperative pain management methods. Clinical staff can design custom pain strategies through individual-specific prediction of pain patterns which enables them to provide more precise and targeted analgesic treatments. Research emphasizes how vital BMI and early pain scores are to predict treatment outcomes because it demonstrates the necessity of personalized pain care which considers metabolic and physiological elements. Machine learning models displayed successful results during pain prediction which makes AI-based clinical decision support systems worthy for integration into healthcare settings. Healthcare providers can use EHR system implementations of these models as real-time pain management tools that diminish dependence on subjective pain evaluations while delivering enhanced patient results.

Several constraints exist in this research work. The clinical dataset contained a restricted number of samples that might reduce the ability of researchers to generalize their findings across broader patient populations. The reliable use of machine learning models for diverse patient cohorts requires external validation by means of testing independent datasets. The research identifies metronidazole as a crucial pain reduction factor but fails to consider possible confounding elements including extra analgesics or surgical procedure variations that could impact postoperative pain results.

Future research needs to increase the dataset size while adding multi-center data to improve model generalization abilities. Real-time monitoring systems that merge with machine learning algorithms would enhance post-operative pain management through the ability to automatically modify analgesic treatment based on continuous patient feedback.

5. CONCLUSION

The research proved that giving patients metronidazole before surgery decreases their postoperative pain experience while machine learning models proved better at predicting pain than traditional methods. The Random Forest model functioned as the best prediction method because it delivered an R^2 score of 0.78 which surpassed traditional regression-based approaches. The analysis of features demonstrated MED procedures as the foremost influential variable while BMI and initial postoperative pain ratings ranked second and third respectively thus supporting individualized pain control approaches. Prolonged discomfort risk increases for patients who have higher BMI alongside higher Pain_Score_12h during the first 12 hours after surgery according to the research results. This demonstrates why individualized pain intervention plans need to be developed. The intensity of pain experienced during the first twelve postoperative hours showed strong predictive power regarding 24-hour pain levels thus demonstrating the importance of managing early pain for future discomfort reduction. The research demonstrates that AI-driven automated healthcare systems should be implemented within EHR systems because they improve point-of-care pain evaluations and treatment planning processes. Postoperative pain management benefits significantly from real-world clinical data linked with machine learning techniques which delivers precise surgical recovery medicine. Development of future research should aim to validate these models across various medical centers through real-time monitoring systems which optimize pain control approaches.

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