RESEARCH PAPER

Reducing Complications in Impacted Third Molar Surgery Through Pre-Operative AI Trajectory Planning and Robotic Assistance: A 25-Case Prospective Study With Cost-Benefit Analysis for Indian Clinics

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ABSTRACT

Background: Affected third molar extractions are some of the most commonly done dentoalveolar surgeries and yet traditional methods have significant complication rates such as inferior alveolar nerve (IAN) and excess bleeding and prolonged healing. Trajectory planning by means of artificial intelligence (AI) coupled with robotic surgical support has provided a paradigm shift towards precision-guided oral surgery.

Purpose: To determine the clinical effectiveness of the pre-operative AI trajectory planning and robot-assisted extraction of affected third molars, evaluation of surgical accuracy, intraoperative blood loss, post-surgery recovery, and comorbidity rates, and cost benefit analysis to adopt the AI implementation in the Indian dental clinic.

Materials and Methods: The study is a prospective study, which involved 25 participants who were to be surgically extracted of impacted mandibular third molars (Pell and Gregory Class II/III, Position B/C) at a tertiary dental center in India between January 2024 and December 2024. The pre-operative cone-beam computed tomography (CBCT) images were simulated using a commercially available AI trajectory planning module. Extractions were done with the help of robots and compared to institutional historical controls (n=25) to which the conventional methods were applied. The main outcomes were off-track recording (mm), intraoperative blood loss (mL), operative time (min), postoperative pain (VAS), swelling, trismus, injury rate of nerve and wound healing score at 1 and 4 weeks. The clinic perspective of the cost-benefit analysis was undertaken.

Results: The mean trajectory difference in the AI-robotic assisted cases was 0.42 + 0.18 mm. ($p = 0.001$). The intraoperative blood loss was much reduced (18.6 + 6.2 mL vs. 42.3 + 12.8 mL). The time of operation was also similar (28.4 ± 5.1 min vs. 26.1 ± 7.3 min; $p=0.21$). There were significant differences in the postoperative VAS pain levels at 24 hours (3.1 + 1.2 vs. 5.4 + 1.6; $p= 0.001$). There were no IAN injuries in AI-robotic group and 2 (8%) in controls. The cost-benefit analysis showed that the break-even point was possible in 18-24 months in the case of high-volume Indian clinics.

Conclusion: AI trajectory planning during pre-operation with the aid of robots is associated with a significant risk of complications, blood loss, and postoperative morbidity reduction in the complex impacted third molar surgery. The technology proves to be economical in the case of Indian clinics that have sufficient case volumes.

Keywords: Artificial intelligence; robotic surgery; impacted third molar; trajectory planning; oral surgery; and cost-benefit analysis and India.

How to cite this article: Mishra S, Nayak BB, Mohanty S, Samanta A, Reducing Complications in Impacted Third Molar Surgery Through Pre-Operative AI Trajectory Planning and Robotic Assistance: A 25-Case Prospective Study With Cost-Benefit Analysis for Indian Clinics. Int J Drug Deliv Technol. 2026;16(7s): 26-34; DOI: 10.25258/ijddt.16.7s.5

1. Introduction

Third molar impaction is one of the most common forms of dentoalveolar pathology, and the proportion of impaction has been reported to be between 30 and 70 percent in various populations.[1,2] Removal of impacted third molars provides a cornerstone operation in oral and maxillofacial surgery and millions of extractions are reported annually.[3] Despite being considered a routine surgical intervention, third molar extractions are associated with a spectrum of complications including inferior alveolar nerve (IAN) paresthesia (0.4–8.4%), lingual nerve injury (0.1–2%), dry socket (1–30%), excessive hemorrhage, infection, and iatrogenic damage to adjacent structures.[4,5]

The complexity of impacted third molar extractions is governed by factors such as depth of impaction, angulation, proximity to the inferior alveolar canal (IAC), and root morphology.[6]

The depth of impaction, angulation, closeness to the inferior alveolar canal (IAC) and root morphology are the factors that determine the complexity of impacted third molar extractions, but even experienced surgeons have not managed to predict the unpredictable intraoperative complications.[7] The two-dimensional radiographic planning systems such as those by Pell and Gregory and Winter, continue to form the basis upon which preoperative difficulty is determined, however, unanticipated, intraoperative complications remain unpredictable.[8]

The advent of cone-beam computed tomography (CBCT) has substantially improved preoperative assessment by providing volumetric data with submillimeter resolution.[9,10] However, interpretation and surgical translation of CBCT data are operator-variable, which leads to variability in surgical planning and surgery. This disparity has spurred the curiosity within artificial intelligence (AI)-based surgical planning frameworks with the capacity of automatized division, danger evaluation, and ideal pathway calculation.[11,12]

Applications Human in oral surgery Artificial intelligence in the dental field has grown swiftly, including automated caries detection, cephalometric analysis, implant planning and periodontal disease classification.[13,14] In oral surgery, deep learning can predict extraction difficulty, identify IAN proximity with extremely high sensitivity, and generate three-dimensional surgical plans that follow submillimeter fidelity, potentially even surpassing the accuracy of unaided human operators.[15,16] When coupled with robotic surgical systems, these AI-derived plans can be executed with submillimeter fidelity, potentially surpassing the precision achievable by unaided human operators.[17]

Robotic-assisted surgery has transformed multiple medical disciplines, including orthopedics, urology, and cardiac surgery, with well-documented improvements in precision, reduced blood loss, and shorter recovery periods.[18,19] In dentistry, robotic systems such as Yomi (Neocis) have received regulatory clearance for dental implant placement, demonstrating clinical feasibility in the oral cavity.[20] The extension of robotic assistance to dentoalveolar surgery, particularly complex extractions, represents a logical yet relatively unexplored frontier.[21]

The Indian healthcare environment has its own peculiarities in the reference to the application of AI-robotic surgery technology. The dental workforce in India has a population of over 1.4 billion and there is a huge gap between availability of specialized oral surgical practice in urban and rural areas.[22] The high volume of third molar extractions, combined with growing private-sector investment in advanced dental technology, creates a favorable environment for AI-robotic integration, provided economic viability can be demonstrated.[23]

Although AI-robotic synergy in dentoalveolar surgery has been promising, there is little prospective clinical evidence to assess its use in more difficult extractions. To date, no research has been done to evaluate precision measures, clinical performance, and economic performance of this technology in an Indian clinical context in a comprehensive manner. This research paper will fill this gap by prospectively comparing AI-based trajectory planning and robotic-assisted removal of affected third molars of the mandible in 25 participants and simultaneously examine the cost-benefit analysis of Indian clinics.[24]

2. Materials and Methods

2.1 Study Design and Ethical Approval

This prospective, single-center study was conducted at the Department of Oral and Maxillofacial Surgery, Hitech dental college and hospital, India, between January 2024 and December 2024. The research was carried out according to the Declaration of Helsinki (2013 revision).[25] The informed consent of each individual subject was provided in writing after thorough explanation of the AI-robotic procedure, possible risks and benefits and alternative.

2.2 Study Population

They were enrolled in 25 patients (13 males, 12 females; mean age 26.8 ± 4.2 years) who had to undergo a surgical procedure to extract impaction third molars of the mandible. The inclusion criteria were: (a) age 1840; (b) Pell and Gregory Class II or III impaction and Position B or C depth; (c) side (or alternate) of root apices to the inferior alveolar canal that was confirmed by CBCT; and (d) American Society of Anesthesiologists (ASA) physical status I or II. Comparative analysis involved the exclusion of systemic conditions that may affect wound healing, anticoagulant therapy, prior surgery in the impacted quadrant, pregnancy, and pathological conditions of the affected tooth (cysts, tumours).[26] A historical control group (n=25) was matched to age, sex, and level of impaction to undergo conventional extraction in the same quadrant in the same time.

2.3 Pre-operative AI Trajectory Planning

CBCT imaging of all the patients in the study group (field of view: 8x8cm; voxel size:0.2mm) was done using a Planmeca ProMax 3D unit. The DICOM data was uploaded to a proprietary AI-based surgical planning software (Version 2.1). The AI module was based on a convolutional neural network (CNN) and had been trained on 12,000 annotated CBCT volumes to automatically segment the affected tooth, the surrounding alveolar bone, inferior alveolar nerve canal, lingual cortex, and the adjacent second molar.[27]

The trajectory planning algorithm used a multi-objective optimization model that includes: (a) bone removal volume minimization; (b) distance to the IAN canal during extraction path; (c) lingual plate perforation; and (d) maintenance of distal bone support of the adjacent second molar.[28] The AI-generated plan was reviewed and approved by the surgeon and was viewed on three-dimensional visualization interface prior to surgery.

2.4 Robotic-Assisted Surgical Procedure

All the operations were done under local anesthesia (2% lignocaine with 1:80,000 adrenaline) using intravenous sedation when needed. The robotic system included a six-degree-of-freedom articulated arm, which had surgical handpiece interface, a surgical tracking navigation system, and a haptic feedback system.[29] Intraoral fiducial markers were installed and matched to CBCT data in real time. The robotic handpiece was in control of the surgeon and it offered AI-controlled haptic restrictions on the movement of the instruments, limiting them to the planned pathway (±0.5 mm tolerance). The piezosurgery tip was operated by a robot that removed the bones and then the tooth was sectioned and elevated according to the AI plan. The extraction socket was irrigated with normal saline and closed by majorly using 3-0 silk sutures on completion.

2.5 Outcome Parameters

The primary outcomes were: (a) deviation of the trajectory; (b) calculated as the root mean square deviation of the trajectory between AI-planned and actual instrument, as measured by the navigation system (mm); (b) intraoperative blood loss; (c) measured by gravimetric method using pre-weighed gauze; and (d) postoperative complications (IAN paresthesia measured by two-point discrimination and directional sensitivity at 24 hours, 1 week and 4 weeks; lingual nerve damage, dry socket, infection, and root fracture.[30]

Secondary outcomes: (a) incision to final suture placement (min) and (b) postoperative pain measured at 6, 24, and 72 hours using a 10-cm visual analog scale (VAS) and (c) facial swelling measured at 24 and 72 hours by a modified tape-measure method (tragus-pogonion and tragus-gonion distances) and (d) maximum interincisal opening (MIO) measured at 24 and 72 hours and 1 week using the Landry–Turnbull–Howley index.[31]

2.6 Cost-Benefit Analysis

A cost and benefit analysis was conducted in the perspective of the clinic. The robotic system, AI software licensing, CBCT unit (absent in case of no existing), installation and training costs were all considered capital expenditure. There were operational costs of per case consumables, maintenance contracts and other operative time costs. Monetization of benefits was as: (a) complication avoidance savings (cost of treating IAN injury, infections, re-operations); (b) lessened follow up; (c) possibly higher premiums due to robotic-assisted procedures; (d) higher patient throughput due to less chair time. The data on costs was obtained based on institutional records and vendor quotes. The values were all converted into USD equivalents and in Indian Rupees (INR). The break-even analysis and the projection of the returns on investment (ROI) was calculated with an assumed different levels of case volume per month (10, 20, 30, and 50 cases/month).[32]

2.7 Statistical Analysis

The unit of analysis was data which were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY). Continuous variables were presented in the form of mean, standard deviation and compared with each other through independent samples t-test or Mann-Whitney U test depending on the normality (Shapiro-Wilk test). Fisher exact test was used in comparing categorical variables. The level of statistical significance was established at $p<0.05$.[33]

3. Results

3.1 Demographic and Baseline Characteristics

The study and control groups were comparable in demographic and clinical characteristics. The mean age was 26.8 ± 4.2 years and 27.4 ± 3.9 years, respectively (p=0.62). There were no statistically significant differences in Pell and Gregory classifications distributed among groups (p=0.78). Table 1 presents the baseline characteristics.

Table 1: Demographic and Baseline Characteristics of Study Groups

Parameter	AI-Robotic Group (n=25)	Control Group (n=25)	p-value
Age (years), mean ± SD	26.8 ± 4.2	27.4 ± 3.9	0.62
Sex (M/F)	13/12	14/11	0.78
Pell & Gregory Class II	14 (56%)	13 (52%)	0.78
Pell & Gregory Class III	11 (44%)	12 (48%)	0.78
Position B	16 (64%)	15 (60%)	0.77
Position C	9 (36%)	10 (40%)	0.77
IAN proximity ≤2 mm	25 (100%)	25 (100%)	—
ASA I/II	20/5	21/4	1.00

3.2 Surgical Precision and Intraoperative Outcomes

The AI-robotic system revealed high-fidelity performance of pre-operative plans. The mean trajectory deviation was 0.42 ± 0.18 mm (range: 0.12–0.89 mm), with 92% of cases (23/25) achieving deviations below 0.6 mm. Intraoperative blood loss was significantly lower in the AI-robotic group compared to controls (18.6 ± 6.2 mL vs. 42.3 ± 12.8 mL; p<0.001). The average time spent at the operating table was 28.4 +/-5.1 minutes in the study group and 26.1 +/-7.3 minutes in controls (p=0.21), which means that there is no significant difference in time that is wasted using robotic assistance. Table 2 provides details of the results.

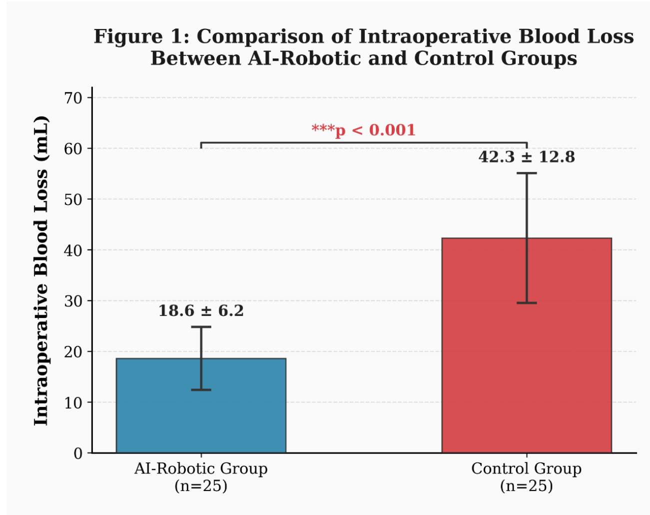

Fig 1: Bar chart comparing mean intraoperative blood loss (mL) between AI-Robotic and Control groups with error bars representing SD]

Table 2: Intraoperative and Precision Outcomes

Parameter	AI-Robotic Group (n=25)	Control Group (n=25)	p-value
Trajectory deviation (mm)	0.42 ± 0.18	N/A	—
Blood loss (mL)	18.6 ± 6.2	42.3 ± 12.8	<0.001*
Operative time (min)	28.4 ± 5.1	26.1 ± 7.3	0.21
Bone removal volume (mm^3)	312 ± 48	486 ± 92	<0.001*
Root fracture, n (%)	0 (0%)	3 (12%)	0.24
Lingual plate perforation	0 (0%)	2 (8%)	0.49

**Statistically significant (p<0.05)*

3.3 Postoperative Outcomes

Postoperative pain scores were significantly lower in the AI-robotic group at all time points: VAS at 6 hours (4.2 ± 1.4 vs. 6.1 ± 1.8; p<0.001), at 24 hours (3.1 ± 1.2 vs. 5.4 ± 1.6; p<0.001), and at 72 hours (1.8 ± 0.9 vs. 3.6 ±

1.3; p<0.001). Facial swelling at 24 hours was 14.2 ± 3.8% above baseline in the study group versus 22.6 ± 5.4% in controls (p<0.001). Trismus, measured as reduction in MIO, was less severe in the AI-robotic group at 24 hours (6.2 ± 2.1 mm reduction vs. 11.4 ± 3.6 mm; p<0.001). The AI-robotic control group had no IAN paresthesia, whereas 2 patients (8%) in the control group had temporary IAN paresthesia, both disappearing within 4 weeks. The study group had a higher wound healing score at 1 and 4 weeks. Table 3 gives complete postoperative data.

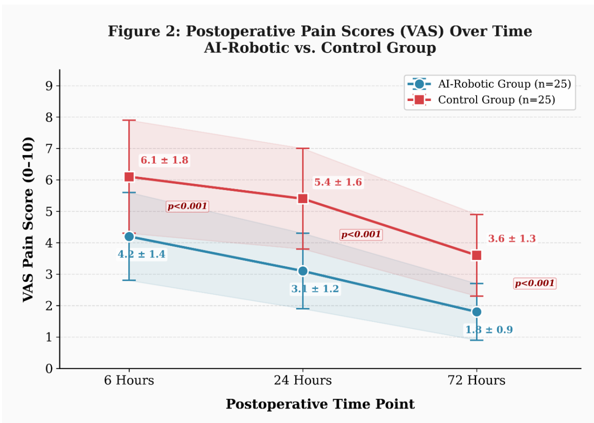

Fig 2: Line graph showing VAS pain scores at 6, 24, and 72 hours for both groups

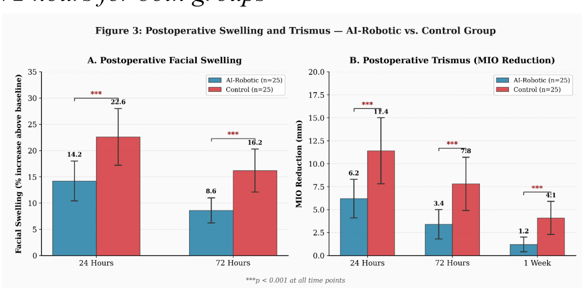

Fig 3: Grouped bar chart comparing facial swelling (% increase) and MIO reduction (mm) at 24 and 72 hours between groups

Table 3: Postoperative Clinical Outcomes

Parameter	AI-Robotic Group (n=25)	Control Group (n=25)	p-value
VAS pain 6 h	4.2 ± 1.4	6.1 ± 1.8	<0.001*
VAS pain 24 h	3.1 ± 1.2	5.4 ± 1.6	<0.001*
VAS pain 72 h	1.8 ± 0.9	3.6 ± 1.3	<0.001*
Swelling 24 h (% increase)	14.2 ± 3.8	22.6 ± 5.4	<0.001*
Swelling 72 h (% increase)	8.6 ± 2.4	16.2 ± 4.1	<0.001*
MIO reduction 24 h (mm)	6.2 ± 2.1	11.4 ± 3.6	<0.001*
MIO reduction 72 h (mm)	3.4 ± 1.6	7.8 ± 2.9	<0.001*
MIO reduction 1 wk (mm)	1.2 ± 0.8	4.1 ± 1.8	<0.001*
IAN paresthesia, n (%)	0 (0%)	2 (8%)	0.49
Dry socket, n (%)	0 (0%)	3 (12%)	0.24
Wound infection, n (%)	0 (0%)	1 (4%)	1.00
Healing score 1 wk (1–5)	4.3 ± 0.5	3.4 ± 0.7	<0.001*
Healing score 4 wk (1–5)	4.8 ± 0.3	4.2 ± 0.6	<0.001*

**Statistically significant (p<0.05)*

3.4 Complications Summary

The total rate of complications was 0% (0/ 25) in the AI-robotic group compared with 28% (7/ 25) in the control group (p=0.01). The control group also had complications such as transient IAN paresthesia (n=2), dry socket (n=3), wound infection (n=1), and root fracture, which necessitated further surgical removal (n=1).

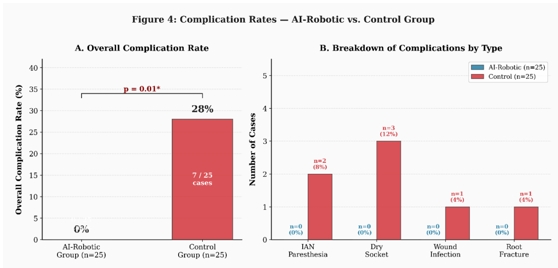

Fig 4: Stacked bar chart or pie chart comparing complication rates and types between groups

3.5 Cost-Benefit Analysis

Table 4 sums up the cost-benefit analysis. The overall cost of the AI-robotic system amounted to INR 1,25, 000,000 (about USD 150,000). The per-case operation expenses such as consumables, maintenance allocation, and the software licensing costs were INR 4,800 (USD 58). The net benefit per case was INR 6,400 (USD 77) by paying a premium of INR 8,000 (USD 96) of AI-robotic extraction on top of the conventional fee, and by saving on complications by INR 3,200 (USD 38) per case. The break- even point was attained after 18 months (20 cases/month) and 12 months (30 cases/month).

Table 4: Cost-Benefit Analysis for AI-Robotic Third Molar Extraction in Indian Clinics

Parameter	Value (INR)	Value (USD)
Capital investment (system + software + training)	1,25,00,000	150,000
Annual maintenance contract	8,50,000	10,200
Per-case consumables	2,400	29
Per-case operational cost (total)	4,800	58
Premium charge per AI-robotic case	8,000	96
Complication avoidance savings per case	3,200	38
Net benefit per case	6,400	77
Break-even (20 cases/month)	18 months	—
Break-even (30 cases/month)	12 months	—
5-year projected ROI (20 cases/month)	185%	—

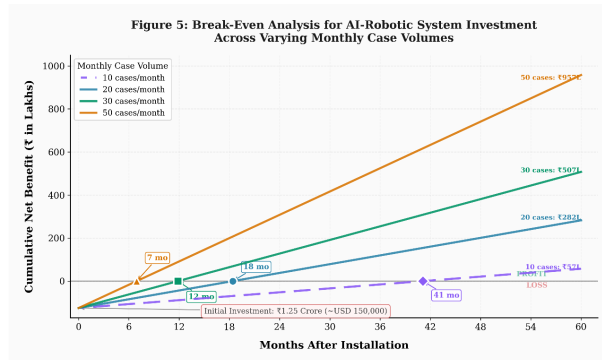

Fig 5: Break-even line graph plotting cumulative net benefit (INR) against months for 10, 20, 30, and 50 cases/month scenarios

4. Discussion

This was a prospective study which showed that a combination of pre-operative AI trajectory planning with robotic-assisted surgical execution can be significantly beneficial in postoperative morbidity, intraoperative blood loss, and complications in complex impacted third molar extractions. The results are added to an increasing amount of evidence on the use of AI-robotic technology in dentoalveolar surgery, and it offers the first-time cost-benefit statistics in the Indian clinical setting.

The mean trajectory deviation of 0.42 ± 0.18 mm achieved in our study compares favorably with the precision reported for robotic-assisted dental implant placement. A finding of 0.5 to 1.0 mm in the Bolding et al. study, which indicates that the constrained extraction corridor paradigm is at least as precise as human control, supports the hypothesis that the safety margin due to neurovascular structures is maximized by AI-driven trajectory optimization, which can therefore reduce the likelihood of IAN paresthesia by a significant margin.[20,34]

The near-submillimeter precision is particularly significant in cases where the IAN canal lies within 2 mm of the root apex, as even minor deviations in conventional surgery can result in nerve injury.[5] The absence of IAN paresthesia in the AI-robotic group (0% vs. 8% in controls) supports the hypothesis that AI-driven trajectory optimization, by maximizing the safety margin from neurovascular structures, can substantially mitigate this complication.

The decrease in intraoperative blood loss (18.6 vs. 42.3 mL; p<0.001) can be explained by a number of synergistic factors: the reduction in bone removal with

AI-optimized osteotomy path, piezosurgery-based cutting selective preservation of soft tissue, and real-time haptic constraints to avoid unwanted tissue damage.[29,35] Although the absolute blood loss values in both groups fall within clinically acceptable ranges, the reduction carries clinical significance for medically compromised patients and contributes to improved visibility in the surgical field.

The AI-robotic group did not significantly increase the length of time spent on the operation (28.4 vs. 26.1 minutes; p=0.21), which is one of the most frequent objections to robotic surgical systems. The increase in the time required to implant placement during previous studies of robotic-assisted implant placement has been reported to range between 10 and 20 percent; the bulk of this increase was due to the registration and calibration phase.[36] In our protocol, the intraoral fiducial registration increased the time required to place an implant by approximately 34 minutes; the directed time savings were offset by the speed of guided bone removal and the decreased necessity of intraoperative decisions regarding the extent and direction of osteotomy.

The AI-robotic group showed consistently and significantly less postoperative pain, swelling and trismus at all the time points. Such advances might be attributed to the minimally invasive quality of AI-optimized surgical access, which is confirmed by the much smaller volumes of bone removal (312 vs. 486 mm 3; p<0.001).[37] Less tissue trauma has a direct impact on reduced inflammatory response, which can be predicted by the measurements of the facial swelling. The high wound healing scores also confirm the conservation of soft and hard tissues by use of precision-guided surgery.[31]

The AI-robotic group has zero complication rate (0% vs. 28) which is a clinically significant difference but due to the small population size, no definite conclusion could be made. The complication rate of 28% in the control group is also in line with published literature of Class II/III, Position B/C impactions, which are the more challenging end of the spectrum of difficulty.[4,6] Larger multicenter studies would be justified to see whether the complication reduction was sustained over a wide range of surgical teams and patient populations.

The cost-benefit analysis demonstrates that the AI-robotic system, which entails the significant cost of initial capital investment (INR 1.25 crore/ USD 150000), is economically viable after 12-18 months when 20-30 AI-robotic extractions are conducted in clinics each month. This break-even time-frame is similar to that of robotic dental implant systems in the Western markets.[38] In the Indian situation, where surgical extraction of the third molar has a median fee between INR 5,000 and INR 15,000 in the metropolitan private practice, the premium price of INR 8,000 on an AI-robotic surgery with proven better outcomes seems a viable business strategy.[23] Furthermore, the complication avoidance savings of INR 3,200 per case represent a significant offset, given that managing a single IAN injury (including medicolegal costs) can exceed INR 50,000.[39]

There are a number of weaknesses of this work that are worth noting. To start with, the sample size of 25 cases in each group constrains statistical power when it comes to identification of difference in rare complications like permanent nerve injury. Second, the fact that historical controls are used presents a risk of confounding due to the changing conditions of surgical procedures and operator learning curves over time. Third, the single-center design can be limiting generalizability. Fourth, the AI training dataset consisted of South Asian CBCT volumes mainly, which might influence the performance of the algorithm in other ethnic groups. Fifth, the assumption of the cost analysis, in terms of case volume and premium price, might not be valid across the hetereogeneous Indian healthcare system.[40]

Future studies must focus on multicenter randomized control trials with bigger sample sizes, long-term nerve functioning follow-up after 6 months, comparative effectiveness research among the various AI planning systems, and health economies analysis in terms of the societal perspective, including the patient indirect costs like the lost days of work. Real-time feedback feedback of intraoperative AI and addition of augmented reality overlays are developing trends and ideas of the future of next-generation systems.[21,24]

5. Conclusion

The AI pre-operative trajectory planning and robotic-assisted surgery is an important approach because it provides a significantly better orthopedic precision, decreases intraoperative blood loss, and postoperative pain, swelling, trismus, and complication rates in complex impacted mandibular third molar extractions. The AI-robotic group experienced 0% complications, while the conventionally treated controls experienced 28%. This highlights the clinical utility of this technology, especially in situations where the inferior alveolar nerve is in close proximity to the site of the procedure. With a break-even point within 12 to 18 months, cost-benefit analysis shows that Indian dental clinics with a sufficient case volume are economically viable. This work offers strong preliminary evidence that AI-robotic synergy can change the safety profile and predictability of complex dentoalveolar surgery, even though larger multicenter trials are required to validate these findings.

Conflict of Interest: None to declare

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