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# Robot-assisted extraction of impacted mandibular tooth: a clinical report

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## Abstract

**Background** This clinical report presents the use of a minimally invasive, robot-assisted windowing surgery for the extraction of a median impacted mandibular tooth. The report highlights the precision and safety afforded by robotic assistance in performing complex dental procedures. However, this case report also critically examines the challenges associated with robotic systems, including high costs, prolonged setup times, and the need for specialized training. The financial burden and learning curve associated with robotic-assisted surgery are discussed in the context of their implications for widespread clinical adoption.

**Case presentation** A 24-year-old male patient, in good general health, was diagnosed with a median impacted mandibular tooth, as confirmed by cone-beam computed tomography (CBCT) scans. Preoperative in vitro simulations utilizing a robotic system were conducted to establish optimal surgical parameters and to validate the surgical approach. The robot-assisted windowing surgery was then performed under local anesthesia. The total operative time was approximately 90 min, with no major complications reported. Postoperative imaging at six months confirmed successful healing, and the patient expressed high satisfaction with the outcome. The case underscores the potential of robotic-assisted surgery to achieve precise outcomes while minimizing surgical trauma.

**Conclusions** Robot-assisted dental surgery has been demonstrated to be a feasible and precise technique for managing complex cases, such as impacted mandibular teeth. This approach enhances visualization, ensures safety, and improves accuracy, supporting its potential as a minimally invasive alternative in both dental and maxillofacial surgeries. However, this case report also highlights the need for further research to address the financial burden, learning curve, and long-term outcomes associated with robotic-assisted procedures. Future studies should focus on cost-effectiveness, comparative efficacy, and the development of more accessible robotic systems to ensure broader clinical adoption.

**Keywords** Robot-assisted surgery, Tooth extraction, Impacted teeth

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## Introduction

Impacted teeth represent a common clinical challenge in oral and maxillofacial surgery, typically arising from obstructions caused by adjacent teeth or surrounding bone structures. This obstruction inhibits normal eruption, resulting in the tooth being partially or fully embedded within the jawbone. While impactions most frequently occur in the third molars (wisdom teeth) and canines, impactions within the mandibular midline are notably rare [1]. Due to their unique anatomical location, mandibular midline impactions are associated with significant risks, including localized pain, infection, gingival inflammation, cyst formation, and potential damage to adjacent teeth [2].

Traditional surgical management of these impactions often involves invasive procedures, such as gingival incisions and extensive bone removal. These interventions increase patient trauma and are associated with complications, including nerve damage, postoperative infection, and prolonged recovery periods [3, 4]. Consequently, the management of mandibular midline impactions presents a distinct set of challenges, highlighting the need for safer and less invasive treatment options.

Recent advancements in medical technology have facilitated the integration of robotic-assisted surgery into oral and maxillofacial procedures, particularly in the treatment of complex dental and jawbone conditions. Robotic systems offer an innovative approach to improving surgical precision and minimizing invasiveness, particularly in cases characterized by challenging anatomical considerations and restricted surgical access [5, 6]. By utilizing preoperative imaging modalities, such as cone-beam computed tomography (CBCT), robotic systems can generate detailed three-dimensional models that support precise pre-surgical planning. During the surgical procedure, robotic systems enable accurate movements, facilitating precise tooth removal while minimizing damage to surrounding tissues, thereby enhancing both patient safety and comfort [7, 8].

However, the adoption of robotic systems in clinical practice is not without challenges. The high costs of robotic equipment, the need for specialized training, and the prolonged setup times are significant barriers to widespread adoption, particularly in resource-limited settings. Furthermore, the lack of tactile feedback and the potential for system malfunctions or calibration errors remain critical concerns that must be addressed to ensure patient safety and procedural efficacy. Additionally, the learning curve for surgeons transitioning to robotic-assisted procedures can impact early outcomes, as operators must become proficient in both the technical aspects of the robotic system and the nuances of robotic-assisted surgical techniques.

## Clinical report

A 24-year-old healthy male patient presented with localized swelling and discomfort in the midline of the mandible. The patient reported no history of systemic diseases. Cone-beam computed tomography (CBCT) confirmed the presence of a median impacted mandibular tooth (Fig. 1). Following informed consent, the patient opted to undergo robotic-assisted windowing surgery utilizing an autonomous dental robotic system (Beijing Ruiyibo Technology Co., Ltd.). CBCT data were imported in DICOM format into the robotic system, and segmentation tools were employed to precisely delineate the patient's mandible and teeth (Fig. 2A-B). The drilling angle was set perpendicular to the bony surface of the chin (Fig. 2C).

A 3D-printed resin model (Fig. 3A) of the mandible was created based on the CBCT data, and a marker was affixed to the right-side teeth of the model using autopolymerizing acrylic resin (Protemp; 3 M ESPE). The resin model, with the attached marker (Fig. 3B), was subsequently rescanned using CBCT, and the resulting data were reintegrated into the robotic system. The CBCT scans of the resin model were aligned with the patient's preoperative scans by referencing several prominent anatomical landmarks, and the surgical pathway was mapped onto the resin model for evaluation and validation. Successful registration, calibration, and osteotomy procedures were performed by the robotic system on the resin model (Fig. 3C). Osteotomy parameters, including depth, speed, and rotation count, were optimized and finalized as follows: crown depth of 1 mm, root depth of 2 mm, nine rotations, and a cutting speed of 0.5 mm/s. These parameters were optimized to ensure the best trajectory, resistance control, and operative time.

The patient's preoperative setup and surgical design mirrored those tested on the resin model (Fig. 3B-C). Local infiltration anesthesia was administered using Primacaine® (4% articaine with epinephrine, 4 ml, 1:100,000; ACTEON, France). A gingival sulcus incision was made from the right mandibular lateral incisor to the left lateral incisor, followed by full-thickness flap reflection to expose the alveolar bone (Fig. 4A). The robotic arm was positioned near the patient's oral cavity and automatically calibrated (Fig. 2D). In accordance with the preoperative surgical plan, the robotic arm autonomously performed the osteotomy and windowing, assisted by an angled handpiece (WS-91LG; WH Dental-Wark International) and guided by the pre-planned trajectory (Fig. 2E). A 1 mm diameter fissure bur (HX S5, Seawolf Medical) was used for the mandibular osteotomy (Fig. 4B), while the surgeon monitored real-time displays of the drilling position, depth, direction, and applied force on the robotic system's screen (Fig. 4C).

The robotic system's camera, with a refresh rate of 16 frames per second, allowed for real-time tracking

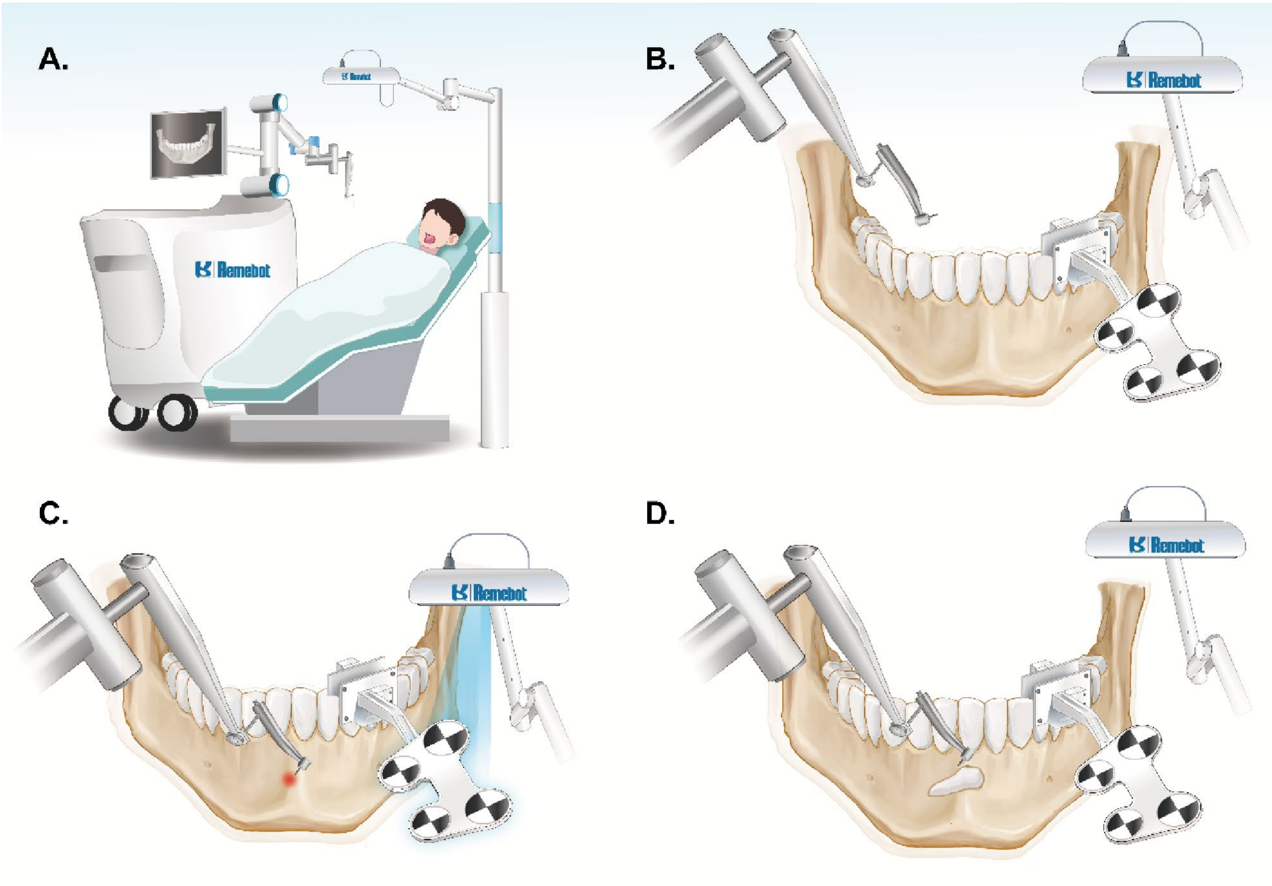


**Fig. 1** Overview of the robotic-assisted surgical system setup, showing the patient positioned on the surgical chair and the autonomous robotic arm calibrated for the procedure

of minute movements, achieving an accuracy of $<1°$ and 0.1 mm. The autonomous robotic arm effectively compensated for patient micro-movements, maintaining surgical precision throughout the procedure. Upon completion of the osteotomy, the bone fragment was carefully elevated and preserved, revealing the impacted tooth with an intact medial periosteum (Fig. 4D). After the impacted tooth was extracted, Bio-Oss bone graft material was placed into the extraction socket, (Fig. 4E) followed by coverage with the osteotomized bone fragment and a Bio-Guide collagen regenerative membrane (Fig. 4F). The surgical site was meticulously sutured, and compression dressing was applied to ensure hemostasis.

Postoperative follow-up at six months demonstrated excellent clinical outcomes, as evidenced by the CBCT reconstruction of the mandible, which revealed complete bone healing and successful integration of the bone graft material (Fig. 5A). The sagittal and axial CBCT images further confirmed the absence of any residual pathology and the optimal restoration of the mandibular architecture (Fig. 5B and C). Additionally, the intraoral examination showed complete soft tissue healing, with no evidence of inflammation or scarring (Fig. 5D). These findings collectively underscore the efficacy of the robotic-assisted extraction technique, highlighting its precision and minimally invasive nature. The positive postoperative results not only validate the effectiveness of robotic-assisted surgery in complex dental procedures but also suggest its broader applicability in oral and maxillofacial surgery, particularly for cases requiring high precision and minimal tissue disruption.

## Discussion

Historically, the extraction of impacted teeth has been considered a technically demanding procedure, largely reliant on preoperative radiographic imaging for localization and the surgeon's clinical judgment during surgery. While this approach has proven effective in many instances, it is heavily dependent on the operator's experience and skill, resulting in variability in outcomes and potential risks such as excessive bone removal, soft tissue damage, and prolonged operative times [9, 10]. The advent of robotic-assisted surgery has revolutionized this paradigm. By incorporating advanced imaging technologies such as cone-beam computed tomography (CBCT) and integrating them with autonomous robotic systems,

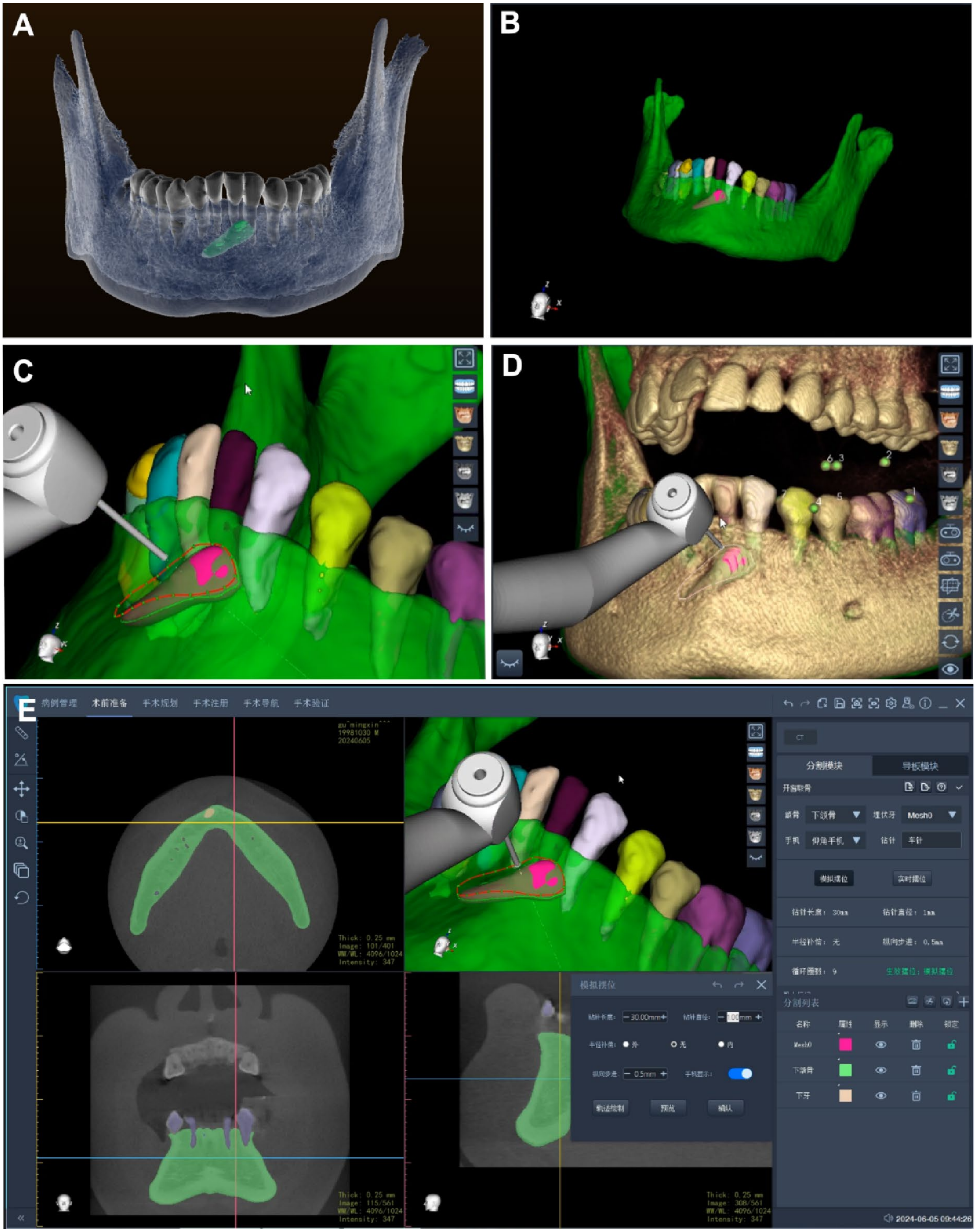


**Fig. 2** **A.** Three-dimensional reconstruction of the patient's mandible, highlighting the location of the median impacted tooth (green marker). **B.** Segmented model of the mandible and teeth, based on CBCT data, clearly identifying the anatomical structures and the impacted tooth (pink region). **C.** Visualization of the surgical pathway, showing the planned robotic drilling trajectory (red dashed line) to avoid critical anatomical structures and ensure precision. **D.** Fusion of the simulated surgical pathway with the virtual mandibular anatomy, displaying the robotic tool position and the drilling site on the system interface. **E.** Preoperative multi-plane CBCT images and parameter settings interface, illustrating the surgical trajectory with optimized parameters: crown depth (1 mm), root depth (2 mm), rotation count (9), and cutting speed (0.5 mm/s)


**Fig. 3** (**A**) Preoperative setup of the 3D-printed resin model with a fiducial marker attached to the right-side teeth, used for CBCT rescanning and alignment. (**B**) Robotic arm performing the simulated osteotomy on the resin model, demonstrating the accuracy of the surgical trajectory. (**C**) Completion of the osteotomy on the resin model, showing the precise removal of the bone segment as planned in the preoperative simulation

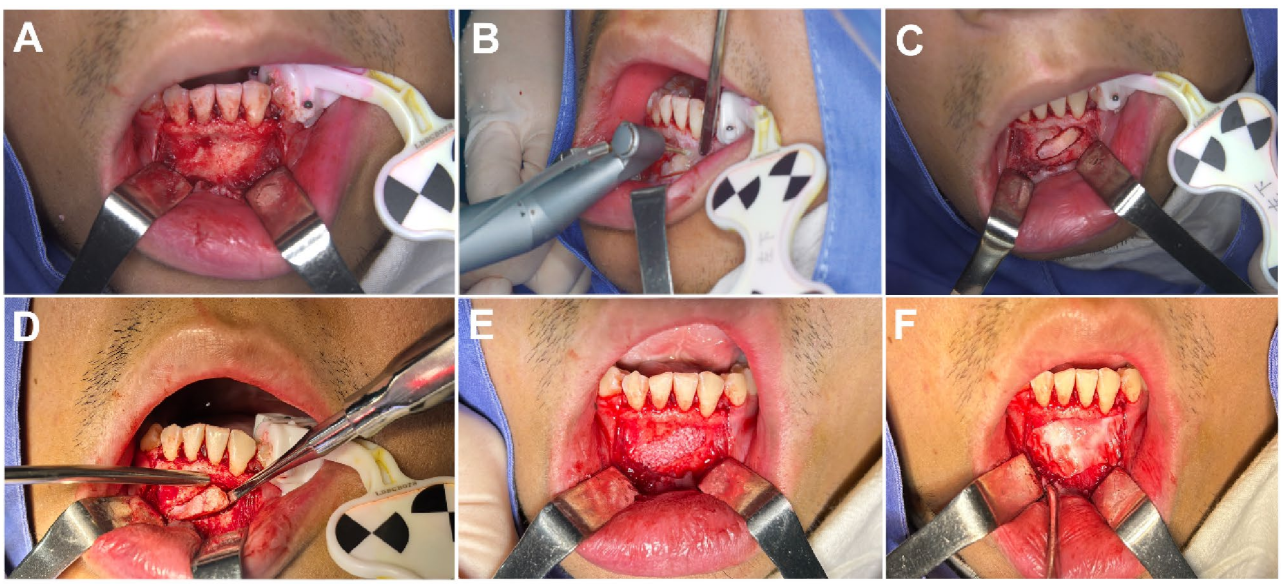


**Fig. 4** **A**. Full-thickness flap reflected to expose the mandible. **B**. Robotic arm performing osteotomy along the planned trajectory. **C**. Completion of osteotomy, exposing the impacted tooth area. **D**. Bone fragment elevated, and impacted tooth extracted. **E**. Bio-Oss bone graft material placed and bone fragment repositioned. **F**. Bio-Guide collagen membrane applied and site sutured

unprecedented precision can be achieved in navigating complex anatomical regions [11, 12]. These systems facilitate preoperative planning, allowing for the precise localization and definition of the trajectory for bone removal, thus significantly reducing intraoperative risks and enhancing surgical efficiency [13].

In the case presented, the robotic-assisted approach demonstrated exceptional precision in bone windowing and tooth extraction, preserving the integrity of surrounding structures while minimizing surgical trauma. Since the 2010s, robotic-assisted surgical systems have been progressively introduced into the field of oral and maxillofacial surgery, encompassing areas such as dental implantology and the management of impacted teeth [14]. Over time, substantial advancements in both hardware and software capabilities of these systems have been realized. However, several limitations persist that hinder their widespread adoption [15].

The first major challenge lies in registration accuracy, which directly impacts the precision of the surgical pathway. Misregistration can lead to deviations that may compromise surgical outcomes [16, 17]. The second challenge is the extended duration of surgery, often resulting from the need for meticulous calibration, real-time adjustments, and continuous surgeon oversight. These factors limit the practicality of robotic systems in busy clinical environments [18, 19].

To address these limitations, our team has conducted a series of investigations into the application of robotic-assisted techniques across various oral surgical procedures, with a particular focus on dental implant placement in different regions of the oral cavity. These studies have provided valuable insights into workflow

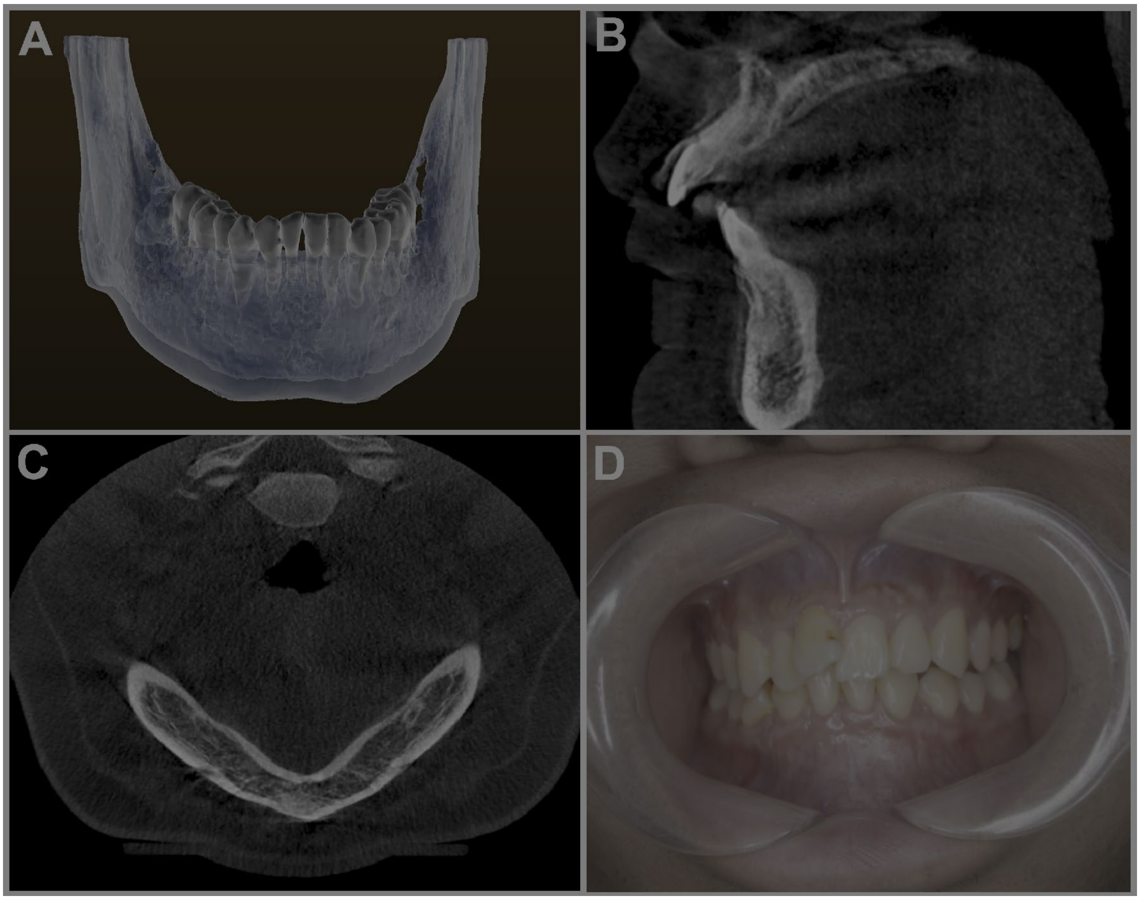


**Fig. 5** Postoperative follow-up six months

optimization, revealing that improvements in robotic calibration and registration processes can significantly enhance precision and reduce operative times [8]. Additionally, these findings underscore the importance of tailoring robotic systems to meet specific procedural needs, thereby paving the way for more efficient and targeted applications [20].

Despite these advancements, the financial burden associated with robotic systems remains a significant barrier to their widespread adoption. The initial investment in robotic equipment, coupled with the costs of specialized training and maintenance, poses a challenge for many institutions, particularly in resource-limited settings. Furthermore, the learning curve for surgeons transitioning to robotic-assisted procedures can impact early outcomes, as operators must become proficient in both the technical aspects of the robotic system and the nuances of robotic-assisted surgical techniques. Moreover, the lack of tactile feedback in robotic systems remains a critical limitation. While robotic systems offer unparalleled precision, the absence of haptic feedback can make it difficult for surgeons to gauge the force being applied during delicate procedures, such as bone cutting or tooth extraction. This limitation underscores the need for further technological advancements, such as the integration of haptic sensors or force feedback mechanisms, to enhance the surgeon's control and confidence during robotic-assisted procedures.

Additionally, the supplementary video provided in this case report offers a detailed visualization of the robotic system in action, demonstrating the precise execution of the osteotomy and tooth extraction. This video serves as a valuable resource for understanding the technical aspects of the procedure and highlights the potential of robotic-assisted surgery in complex dental cases. The video can be accessed in the supplementary materials section.

Robotic-assisted surgery represents a transformative innovation in oral surgery, with potential applications that extend well beyond current use cases. With ongoing advancements in artificial intelligence, machine learning, and sensor technologies, future robotic systems are expected to become increasingly autonomous, adaptive, and user-friendly. For instance, the integration of real-time feedback mechanisms, such as haptic sensors and advanced imaging overlays, could further enhance the surgeon's control and confidence during complex procedures [13, 21]. As the precision and efficiency of robotic systems continue to improve, it is anticipated that their application will expand to more intricate maxillofacial surgeries, including orthognathic procedures, tumor resections, and reconstructive surgeries [22]. The integration of robotic systems into oral surgery not only standardizes procedures but also offers a minimally invasive approach, thereby reducing patient recovery times and improving overall surgical outcomes [23].

## Conclusions

The application of robotic-assisted surgery in the management of a median impacted mandibular tooth underscores the transformative potential of advanced dental technologies. This case demonstrates the precision, efficiency, and safety that can be achieved through the integration of autonomous robotic systems with preoperative imaging and surgical planning. By utilizing CBCT data for precise surgical mapping and employing a robotic arm to perform the procedure, surgical trauma was minimized, vital structures were preserved, and optimal outcomes were ensured.

However, this case report also highlights the need for further research to address the financial burden, learning curve, and long-term outcomes associated with robotic-assisted procedures. Future studies should focus on cost-effectiveness, comparative efficacy, and the development of more accessible robotic systems to ensure broader clinical adoption.

## Supplementary Information

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Supplementary Material 1

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### Author contributions

M. M & W. Z: Writing - Original Draft, Visualization, Methodology, Y. Z & Y. G: Conceptualization, Writing - Review & Editing, H.M: Resources, Methodology, X.L & J. Z: Writing - Review & Editing, Supervision. M.M & W. Z are joint first authors and contributed equally to this work.

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### Data availability

The datasets generated or analyzed during this study are available from the corresponding author on reasonable request. Data is provided within the manuscript or supplementary information files.

## Declarations

### Ethics approval and consent to participate

This study did not involve human or animal subjects' experiment, and thus no ethical approval was required. The case report adhered to the guidelines established by the journal.

### Consent for publication

The informed written consent was obtained from the patient for publication.

### Competing interests

The authors declare no competing interests.

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