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Case report

Digital robot-assisted minimally invasive impacted tooth extraction: A case report

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ABSTRACT

Objective: This study investigated the clinical effects and applicability of minimally invasive impacted teeth extraction using digital robots.
Methods: A marker was bonded to the non-surgical area before surgery. A Cone-Beam Computed Tomography (CBCT) scan was obtained and uploaded to the robot software to determine the drilling position of the ring drill. During the surgery, the robot arm automatically navigated to a predetermined position, and the ring drill removed part of the bone tissue and exposed and extracted the impacted teeth. Finally, the surgeon tightly sutured the wounds to the surgical area.
Results: Three minimally invasive extractions of impacted teeth with robotic assistance were performed without complications. The surgical area showed good healing during the one-month follow-up examination.
Conclusions: Digital robot-assisted minimally invasive extraction of impacted teeth is a highly feasible clinical procedure as it minimises trauma to the surgical area and protects the surrounding blood vessels and nerve bundles, making it a safe and valuable technique with significant potential for clinical application.

Impacted teeth are a common occurrence in alveolar surgery and can lead to various complications, including displacement of adjacent teeth, compression of adjacent tooth roots, formation of odontogenic cysts, and obstruction of the normal eruption of permanent teeth [1,2]. The extraction of impacted teeth can be challenging owing to limited space, restricted field of view, and the presence of critical anatomical structures, such as blood vessels and nerves. Risks of complications include blood vessel and nerve damage, as well as mandibular fracture [3]. While a treatment plan is usually developed prior to surgery to mitigate such situations, it can still be difficult for dentists to accurately determine the position of the impacted tooth and proceed with the surgery as planned because of limited visibility.

Digital robots have been utilised in various fields, such as in oral surgery and head and neck tumours, oral implants, and endodontic treatment. These robots offer numerous advantages, including high accuracy, safety, independence from field-of-view limitations, and flexibility [4]. Autonomous robots are particularly well suited for tasks requiring precise alignment and stable work, which help surgeons reduce manual errors and minimise the risk of complications [5,6]. Robot-assisted surgery combines the benefits of real-time feedback and tactile constraints, making it a promising alternative to guided alveolar surgery.

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This article presents three clinical reports describing minimally invasive extraction of impacted teeth using digital robots. These autonomous robots can independently perform surgeries under the guidance and supervision of surgeons. This study aims to explore the clinical application value of autonomous robots in treating impacted teeth, providing reliable data and experience in clinical practice.

1. Material and methods

1.1. Clinical report

Three patients were admitted to the Department of Oral and Maxillofacial Surgery at the Qingdao Stomatological Hospital with the chief complaint of impacted supernumerary teeth, necessitating their removal. The patients underwent general condition and oral examinations conducted by the doctors Y.Z.W. and Y.H.Y. The patients were in good general condition with no systemic disease or family history of genetic diseases. The patients' clinical data are presented in Table 1.

Ethical statement

This study was approved by the Institutional Review Board of the Qingdao Stomatological Hospital in accordance with the Declaration of Helsinki (No. 2023KQYX029). Before surgery, all patients and their families signed informed consent forms, agreeing to undergo robot-assisted extraction of the impacted teeth under general anaesthesia.

1.2. Preoperative preparation and surgical planning

Prior to surgery, a flowable restorative material (3M, Z350XT) was used to fix the marker to the teeth in the non-surgical area of the maxilla (Fig. 1A-1F, Fig. 3A).

Cone-Beam Computed Tomography (CBCT, Planmeca) was performed to obtain Digital Imaging and Communications in Medicine (DICOM) format data, which were then imported into robot software (RemebotDent, v1.0.0.2, Beijing) for three-dimensional reconstruction and surgical planning of the impacted teeth (Fig. 1A–F and Fig. 2A-2C).

On the computer, a cylindrical simulated object was designed and drilled with dimensions slightly larger than the distance between the surface of the jaw and the impacted tooth, as well as a diameter larger than the maximum circumference of the dental crown. The doctor confirmed the final position of the drill (Fig. 1D–F).

The marker fixed on the teeth contained seven magnetic beads that could be visualised in the CBCT image data. The main function of the marker is to perform registration and calibration in surgical preparation and to facilitate robot positioning and tracking during surgical operations.

1.3. Registration and calibration

The patient was administered general anaesthesia on the day of surgery, and the maxillofacial and oral cavities were disinfected.

The navigation software was opened using a visible light optical locator (Remebot, Beijing, China), and the marker and calibration plate were registered and calibrated sequentially. According to the robot's product specification, the calibration plate was positioned 'the frontal part (Approximate 4 fingers above the tip of the nose)', 'the left cheek (Approximate left molar position)', and 'the right cheek (Approximate right molar position)', ensuring a match with the marker (Fig. 3B).

1.4. Surgical procedure

According to the established surgical plan, the palatal gingiva were incised with a steel knife and a palatal flap was reflected to expose the maxillary surgical area.

A ball drill was placed on the robot manipulator, and the manipulator automatically navigated to the surgical position to determine its location (Fig. 3C-D).

The ball drill was removed and replaced with a ring drill. The robot automatically navigated to a fixed position, and using ring drilling, the bone from the surface of the jaw to the impacted teeth was resected (Fig. 3E-F). The doctor monitored the screen and surgical area simultaneously throughout the robot-assisted surgery to ensure safety.

Bone removal exposed the impacted teeth. The surgeon inserts an extraction handpiece into the neck of the tooth to separate the

Table 1
Clinical data of patients.

Number	Gender	Age	General Condition	Impacted Tooth Position	Disease discovery time	Clinical diagnosis
1	Male	8	good shape	21-22 palatal side of teeth	1 month	impacted tooth
2	Female	26	good shape	21-22 tooth root square	1 month	impacted tooth
3	Male	40	good shape	Located in the maxillary bone and maxillary sinus	2 weeks	1. impacted tooth; 2. mandibular cyst

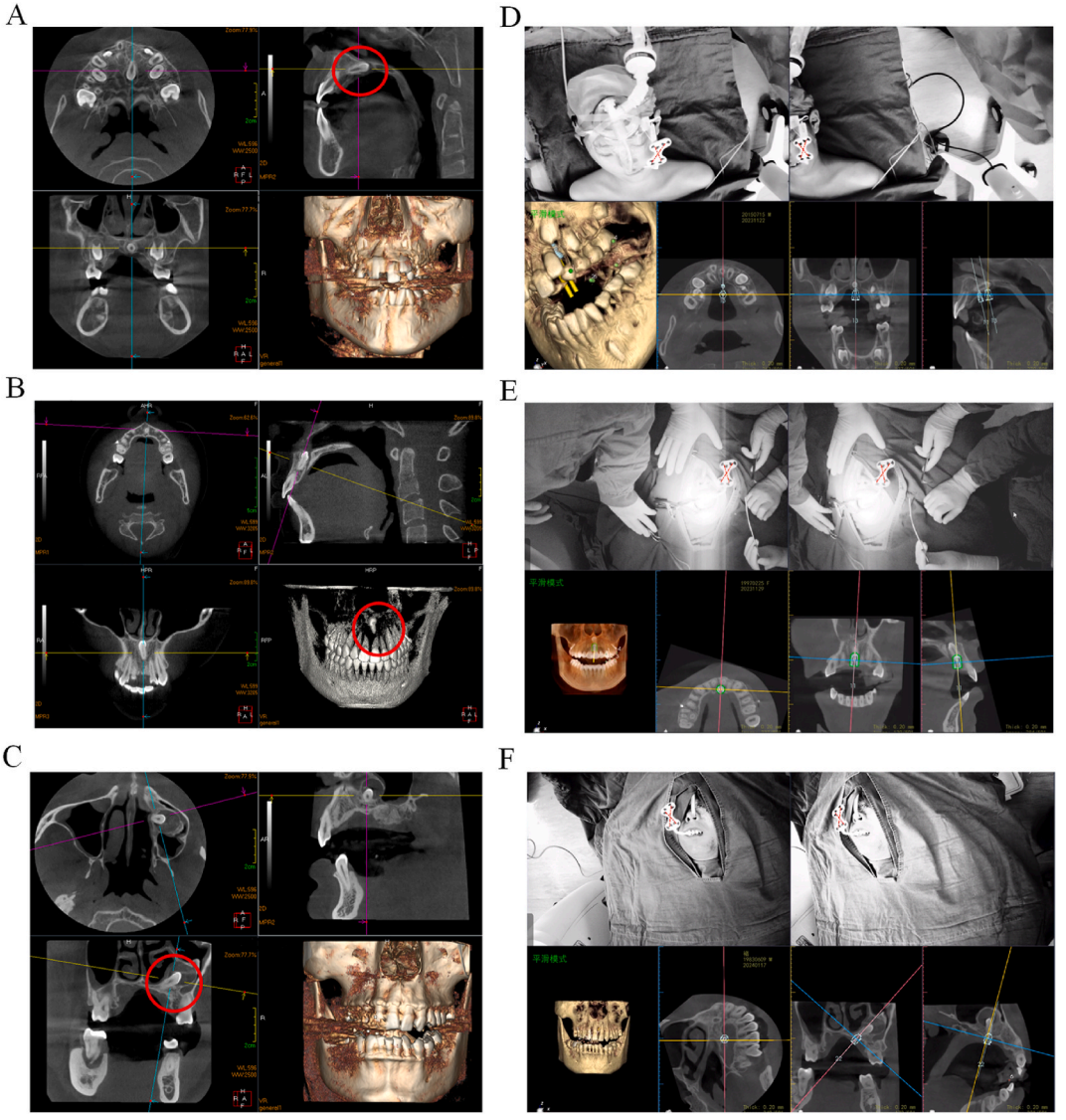

Fig. 1. The position of impacted teeth in CBCT and preoperative plans in the robot operating system. A. Impacted tooth position: The impacted tooth was located in the 21–22 palatal side of teeth. B. Impacted tooth position: The impacted tooth was located in the 21–22 tooth root square. C. Impacted tooth position: The impacted tooth was located in the maxillary bone and maxillary sinus. D-F. Preoperative planning pictures in the robot software.

dental crown and root, or the dental elevator was used to extract the tooth. Vascular forceps were used to facilitate the removal of the loose teeth (Fig. 3G-H). Finally, the removed bone was returned to the surgical area and the wound was tightly sutured.

1.5. Postoperative care

Prophylactic antibiotics were administered to prevent postoperative infections in the surgical area. Simultaneously, the patient rinsed his mouth with a povidone-iodine gargle and mouthwash.

2. Results

Three cases of minimally invasive extraction of impacted teeth using robotic assistance were successfully treated. The mean operative time was 20 min ± 5 min. One day after the surgery, there was no bleeding or swelling in the surgical area, and no complications such as maxillary sinus fistula, oral-nasal communication, or nerve damage. During the follow-up visits one month and three months after the surgery, the patient's wound healed well, and the patient was extremely satisfied with the application of this technology.

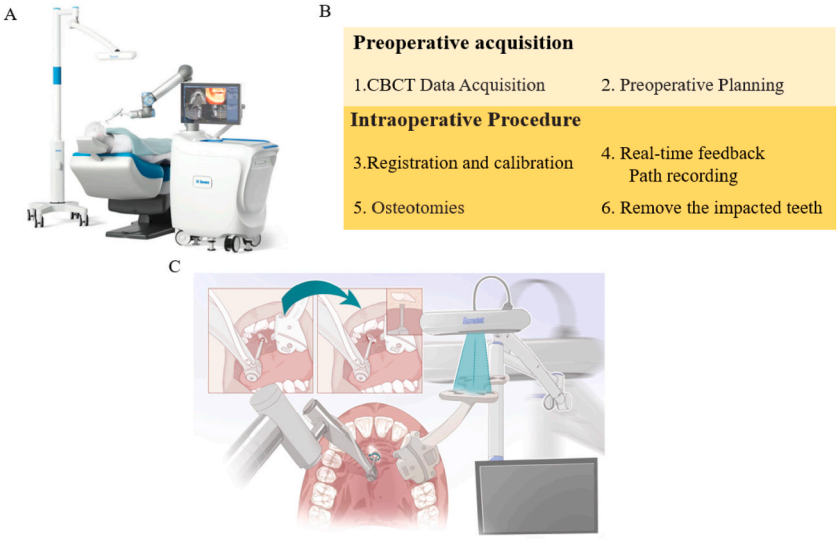

Fig. 2. Clinical workflow. A. Main components of the robotic system. B. Clinical experimental procedure. C. Surgical model diagram.

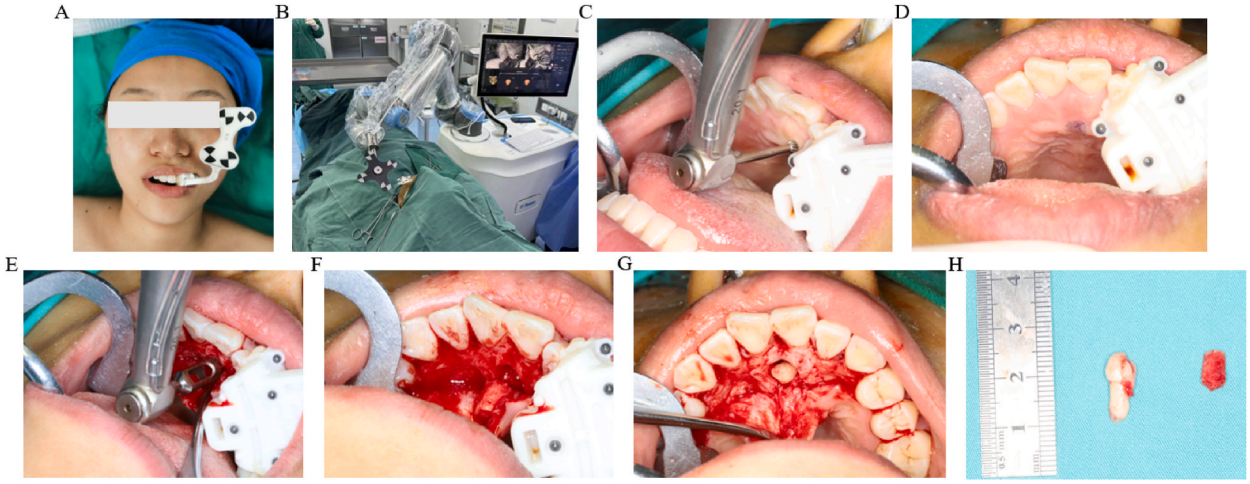

Fig. 3. Surgical procedure. A. A marker is stabilized on the contralateral teeth. B. Robotic arm registration and calibration: The calibration plate was placed on the left cheek (Approximate left molar position) to match the marker. C-D. A ball drill positioning and locating point. E. Partially removed bone using ring drill. F. Surgical area after bone removal. G. Impacted tooth extracted by surgeon. H. Removal of impacted tooth and part of bone.

3. Discussions

Impacted teeth are those that remain fully embedded in the jaw for an extended period and are unable to erupt normally [2,7]. Owing to their position within the jaw, they can be obstructed by the surrounding teeth, soft tissue, and bone tissue. This often leads to lesions or displacement of neighbouring teeth, hindering normal tooth eruption, and causing absorption of the alveolar bone. Additionally, impacted teeth can contribute to the development of odontogenic diseases, increasing the risk of cysts and oral infections, and significantly affecting the patient's quality of life [8–10]. Therefore, it is crucial to extract the impacted teeth accompanied by relevant clinical symptoms that promptly affect the adjacent teeth to improve the patient's clinical symptoms.

Because of the resistance of soft tissue, bone tissue, adjacent teeth, inferior alveolar nerve canal, and maxillary sinus cavity, as well as the particularity of the anatomical position of the oral cavity, it is necessary to expose impacted teeth as much as possible during the extraction process to prevent damage to the surrounding soft and hard tissues, as well as important blood vessels and nerves [11]. However, this process may lead to complications, such as severe trauma, postoperative swelling, and wound infection [12]. In the cases reported in this article, the impacted teeth were located near the palatal protuberance and apical area of the maxillary anterior teeth, which are close to critical anatomical parts, including the nasal floor, tooth apex, and nasopalatine nerve canal. Therefore, it is important to expose the impacted teeth as much as possible during the routine extraction process to ensure accurate and safe extraction. However, this approach may result in significant bone removal and trauma to the surgical site.

The increasing popularity of minimally invasive tooth extraction has raised the question of improving accuracy, reducing surgical difficulty, minimising trauma to the surgical area, while decreasing surgery-related complications. Oral alveolar surgeons have been actively addressed this critical clinical issue. Utilising new technologies and methods such as high-speed turbine handpieces, piezosurgery, and digital guides has significantly enhanced the precision, safety, and size of the trauma associated with these procedures. The introduction of high-speed turbine handpieces has eliminated the need for traditional invasive bone removal methods, which carry high risks and often lead to numerous severe postoperative complications. Piezosurgery offers the advantage of selective cutting, thereby reducing bone damage caused by high-speed friction and minimising nerve damage as well as postoperative swelling and pain [13]. Digital guides utilising CBCT data and 3D printing enable the production of fixed guides that accurately and swiftly locate impacted teeth. This technology shortens the operative time, reduces surgical trauma, and minimises damage to adjacent teeth and vital nerves [4,14].

To determine new, minimally invasive, safe, and convenient methods for extracting impacted teeth, it is important to explore robot-assisted surgery. Robot-assisted surgeries have gained popularity and are being researched worldwide [15]. Surgical robotic systems compensate for the limitations of human motor skills and offer precise motion control, high operating precision, good repeatability, and stability [16]. Currently, robot-assisted surgery is being gradually implemented in various fields such as oral implantology [17], urology [18], and oncology [19,20]. The high-precision positioning of the implant robot ensures accurate angle and depth of implantation and long-term stability [21]. Additionally, computer-assisted implant surgery provide higher accuracy and surgical success rates and shorter operative times than traditional methods [4]. Furthermore, expanding robotic manipulators to other surgical and nonsurgical procedures may increase the range of applications and benefits of these systems based on the specific needs of different diseases. With advancements in machine learning and artificial intelligence, there is potential for new opportunities and autonomous robotic surgical applications [22].

There are no clinical application reports on robot-assisted extraction of impacted teeth. This article presents three cases that represent the earliest instances of robot-assisted extraction of impacted teeth in China. A comprehensive approach was adopted in these cases, involving preoperative case discussions and the use of CBCT and other imaging data to design an optimal surgical plan. During the surgery, the robot-assisted procedure resulted in minimal trauma to the surrounding bone and facilitated safe removal of the impacted teeth (the robot drilled from the bone surface of the jaw to the surface of the impacted teeth using a ring drill according to the set path). Simultaneously, smaller incisions in the surgical area were made during the surgery to keep the procedure as minimally invasive as possible. The other two cases were conducted following the operating methods detailed in this article, and the procedures yielded favorable outcomes. In the first patient, the design of the optimal bone removal pathway successfully avoided damage to adjacent teeth, nerve injury, and excessive bone resection. The third patient presented with a mandibular cyst resulting from an impacted tooth. During the robotic-assisted extraction of the impacted tooth, the surgeon was able to concurrently excise the maxillary cyst. This approach not only minimized trauma in the surgical area but also facilitated the simultaneous treatment of the maxillary cyst and other lesions.

However, the robotic arm used in these cases had limited mobility, could only move up and down or forwards and backwards, and could not swing or move laterally. Future research will focus on upgrading the system to incorporate additional functionalities and developing a fully automated and freely moving robot, thereby enhancing its application in alveolar surgery. The overall surgical efficiency is affected by the variable positions of the impacted teeth and the need for operators to design personalised surgical plans and prepare surgical accessories before surgery.

The advantages of surgical robots include high precision, flexibility, stability, and absence of visual fatigue. These features reduce the surgical time to a certain extent. However, it should be noted that comparing the operative time between robot-assisted liver resection and laparoscopic liver resection shows that robot-assisted liver resection takes longer [23]. Nineteen comparisons between robot-assisted surgery and laparoscopic surgery in the treatment of rectal cancer demonstrated that robot-assisted surgery took a relatively longer time. However, we cannot deny that robot-assisted surgery is effective because it has fewer postoperative complications and lowers the risk of tissue and blood vessel damage [24]. Although the surgery performed on the three patients was completed in 20 ± 5 minutes, which was longer than that for conventional tooth extraction with a high-speed turbine handpiece, improvements in proficiency, and cooperation among the robot, surgeon, and patient, and changes in anaesthesia methods are expected to enhance the overall operative times significantly.

This study was conducted under general anaesthesia to ensure the safety of robotic surgery, while considering the patient's actual mouth opening, comfort, and nervousness. Experienced doctors must consider the surgical area and movement of the robot to ensure surgical accuracy. The surgeon supervised the entire surgery; the robot was equipped with pedals to stop all robotic activities quickly. Performing surgeries using intelligent robotic assistance is a future trend [5] and is likely to become the preferred choice for oral and maxillofacial surgery in the near future.

4. Conclusions

All impacted teeth were successfully extracted and recovered postoperatively. With limited data, this case demonstrates that robot-assisted extraction of impacted teeth yields more satisfactory results than traditional surgeries in terms of precision, safety, and chances of trauma. Additionally, this study confirmed the feasibility, safety, and accuracy of robot-assisted impacted tooth extraction. The successful execution of this procedure expands the potential applications of intelligent robots and offers valuable data and experience for future clinical practice.

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Ethical declaration and informed consent

This study was approved by the Institutional Review Board of the Qingdao Stomatological Hospital Affiliated to Qingdao University (No. 2023KQYX029). The patient gave written informed consent to publish all of the images, clinical data, and other data.

Data availability statement

All dates are included in the article. Videos of robot-assisted extraction of minimally invasive tooth are available upon reasonable request by contacting the first or corresponding author.

CRediT authorship contribution statement

Lin-zi Han: Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Investigation, Formal analysis, Data curation. **Hang Wang:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Data curation, Conceptualization. **Qun-li Guan:** Software, Resources, Project administration, Methodology, Investigation, Formal analy. **Yin-hui Yang:** Supervision, Project administration, Methodology, Investigation, Formal analysis. **Xiao-ni Li:** Software, Resources, Project administration, Methodology. **Yang Yu:** Software, Resources, Project administration, Methodology. **Yao-zhong Wang:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Yao-zhong Wang reports financial support was provided by Qingdao Stomatological Hospital Affiliated to Qingdao University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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