Somatosensory changes in Chinese patients after coronectomy vs. total extraction of mandibular third molar: a prospective study

Zi-Yu Yan 1 · Xiao-Yan Yan 2 · Chuan-Bin Guo 1 · Qiu-Fei Xie 3 · Guang-Ju Yang 3 · Nian-Hui Cui 4

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Abstract
Objectives This study aimed to quantitatively compare the somatosensory function changes of inferior alveolar nerve (IAN) after mandibular third molar extraction with a surgery protocol of coronectomy, as opposed to the conventional method.

Materials and methods Patients with a lower third molar directly contacting IAN were recruited and assigned either to a test group (coronectomy group) or a control group (conventional extraction). A standardized quantitative sensory testing (QST) battery was performed for four times: one week before surgery and the second, seventh, and 28th days after surgery. Z-scores and the loss/gain coding system were applied for each participant.

Results A total of 140 molars (test group: n = 91, control group: n = 49) were enrolled. The sensitivity of the mechanical detection threshold (MDT) and pressure pain threshold (PPT) significantly increased after surgery more than before surgery in both groups (P ≤ 0.001). After the surgery, the sensitivities of the cold detection threshold (CDT), cold pain threshold (CPT), and heat pain threshold (HPT) were significantly higher in the test group than in the control group (P ≤ 0.027). The risk of IANI was significantly larger (P = 0.041) in the test group than in the control group.

Conclusions QST was a sensitive way to detect somatosensory abnormalities even with no subjective complaint caused by surgery. Coronectomy had less influence on IAN function than conventional total extraction.

Clinical relevance The somatosensory function changes after mandibular third molar extraction were quantitatively studied, and coronectomy was proved a reliable alternation to reduce IAN injury rate.

Keywords Coronectomy · Inferior alveolar nerve injury · Quantitative sensory testing · Somatosensory function

Abbreviations
CBCT cone-beam computed tomography
CDT cold detection threshold
CNTs clinical neurosensory tests
CPT cold pain threshold
DFNS the German Research Network on Neuropathic Pain
DMA dynamic mechanical allodynia
HPT heat pain threshold
IAN inferior alveolar nerve
IANI inferior alveolar nerve injury
MDT mechanical detection threshold
MPS mechanical pain sensitivity
MPT mechanical pain threshold
NS no significant difference
PHSs paradoxical heat sensations
PPT pressure pain threshold
QST quantitative sensory testing
RCTs randomized controlled trials
SD standard deviation
Introduction

The prevalence of mandibular third molar impaction is increasing, and inferior alveolar nerve injury (IANI) after tooth extraction, one of the most serious complications [1], is attracting more attention. The incidence of IANI in normal cases, using conventional surgery, is reported to be 0.35%–8.1% for temporary complications and 0.0145%–3.6% for permanent ones [1–4]. In high-risk cases, the rate is up to 35.64% [1, 5, 6].

Coronectomy is an alternative to conventional extraction surgery; it removes the crown only and intentionally leaves the root to reduce the compression or direct contact injury to the inferior alveolar nerve (IAN), which is regarded as the origin of inferior alveolar nerve injury (IANI) [7–9]. This technique was first described in 1984 by Ecuyer and Debien [10] and suggested as a way to prevent IANI in 1989 [7]. In 2004, Pogrel detailed the method and presented basic rules [9]. Many studies claimed that coronectomy was significantly safer than conventional extraction. However, only two studies were randomized controlled trials (RCTs) [11, 12] with high-quality evidence [13, 14]. Most of these studies used clinical neurosensory tests (CNTs), that is, light touch sensation or two-point discrimination, to recognize IANI [2, 8, 11, 12]. The sensitivity and specificity of these methods proved unsatisfactory and did not permit standard comparison among studies [15].

In 2006, the German Research Network on Neuropathic Pain (DFNS) established a standardized quantitative sensory testing (QST) protocol for examination and data analysis, which systematically evaluates thermal and mechanical somatosensory functions [16–18]. Compared with CNTs, QST has better reproducibility and sensitivity in diagnosing and grading nerve injuries [15]. It has been widely applied in the orofacial region [19–23], and somatosensory sensitivity changes related to IANI can also be quantitatively measured.

The aim of this study was to use a standardized QST protocol to assess somatosensory function changes and recovery duration after mandibular third molar extraction by coronectomy or conventional surgery.

Materials and methods

This is a prospective study of postoperative IAN function and other complications from two surgical procedures, coronectomy and conventional tooth extraction. The biomedical ethics committee of Peking University Hospital of Stomatology (PKUSSIRB-201736080) granted ethical approval, and the research approach was pre-registered in the China Clinical Trial Center (ChiCTR1800014862). The study design was non-randomized controlled trials with an open-label and endpoint blinded. The hypothesis of this study was that conventional extraction surgery impairs IAN somatosensory function more than coronectomy does.

Participants

From 2018 to 2019, Chinese individuals with an impacted lower third molar to be extracted were recruited from the Department of Oral and Maxillofacial Surgery of Peking University School and Hospital of Stomatology, China. A flow diagram appears in Fig. 1. Inclusion criteria comprised healthy males and females ranging from 18 to 40 years old; at least one root of the lower third molar directly contacted the IAN, proven by preoperative cone-beam computed tomography (CBCT); and the patients’ physical condition was tolerant of surgery. Exclusion criteria were the following: presence of preexisting neurosensory disorders affecting IAN function; local susceptible factors, such as caries or periodontitis of the third molar, cystic or neoplastic conditions around the third molar; general systemic disease contributing to infection (e.g., diabetes, immunodeficiency); or history of radiotherapy or chemotherapy.

All participants signed informed consent. Group selection was based on individual preference under the principle of ethics. Those preferring coronectomy were included in the test group, whereas those choosing conventional extraction were gathered in the control group.

Experiment protocols

1. CBCT examination was applied three times. Preoperatively, CBCT was used to determine the relationship between the lower third molar and the IAN and measure the size of perforation in the inferior alveolar canal (IAC). The other two CBCT scans were taken on the day after surgery and six months postoperatively.

2. QST was applied on the skin overlying the mental foramina of the affected side four times: one week before surgery and on the second, seventh, and 28th days after surgery [24, 25].

3. A visual analogue scale (VAS) of 10 cm was applied to record postoperative pain. Pain scores ranged from 0 (no pain) to 10 (most severe pain).

Surgical technique

All operations were performed under local anesthesia, by one experienced oral surgeon. During coronectomy, we applied a partial crown section (more than three quarters in depth) 1–2 mm below the cementoenamel junction and then separated them with an elevator [4]. The surface of the root was trimmed.
Unsuccessful coronectomy was defined as any evidence of root looseness [9, 12, 26]. After routine debridement and irrigation, the wound was primarily sutured. Conventional extraction was applied in the control group. Neither antibiotics nor analgesic was taken by either group.

**Quantitative sensory testing**

The standardized QST battery developed by DFNS [27–29] and modified for the trigeminal region [29–32] was used in this study. All QST measures were performed in a quiet room with approximate temperature between 21 and 23 °C. The QST consisted of seven tests, measuring a total of 13 thermal and mechanical parameters. (A) Thermal testing comprised detection and pain thresholds for cold, warm, and hot stimuli (C- and A-delta fiber mediated): cold detection threshold (CDT); warm detection threshold (WDT); number of paradoxical heat sensations (PHSs) during the thermal sensory limen (TSL) procedure for alternating warm and cold stimuli; cold pain threshold (CPT); and heat pain threshold (HPT). (B) Mechanical detection threshold (MDT) was used as a test for A-beta fiber function, using von Frey filaments. (C) The mechanical pain threshold (MPT) was used as a test for A-delta fiber-mediated hyperalgesia to pinprick stimuli. (D) Stimulus–response functions were tested with mechanical pain sensitivity (MPS) for pinprick stimuli, and dynamic mechanical allodynia (DMA) assessed A-delta-mediated sensitivity to sharp stimuli (pinprick) and A-beta fiber-mediated pain sensitivity to stroking light touch (CW, cotton wisp; QT, cotton wool tip; BR, brush). (E) Wind-up ratio (WUR) compared the numerical ratings within three trains of a single pinprick stimulus (a) with a series (b) of 10 repetitive pinprick stimuli to calculate WUR as the ratio: b/a. (F) Vibration detection threshold (VDT) tested for A-beta fiber function, using a Rydel–Seiffer 64 Hz tuning fork. (G) Pressure pain threshold (PPT) was the only test for deep pain sensitivity, most probably mediated by muscle C- and A-delta fibers [16, 29, 31]. The investigator in this study was carefully instructed and trained under supervision, according to the latest guidelines [29, 32]. A standard set of instructions, lasting ~1 min, was read to the participants for each modality just before the beginning of each test; that is, there were one-minute intervals between tests [16, 29, 33, 34].

**Thermal thresholds and thermal sensory limen**

Thermal testing was performed using Medoc Pathway (Medoc Ltd., Israel) with an advanced thermal stimulator (30 mm × 30 mm) [16, 29, 33, 34]. CDT, WDT, CPT, and HPT were measured in triplicate [16, 29, 33, 34]. For the TSL, the temperature first went up, and the participants pressed a button when they perceived a change [16, 29, 33, 34].
The number of PHSs during this procedure was recorded [16, 29, 33, 34]. Baseline temperature was set at 32 °C for all thermal testing, ramped stimuli of 1 °C/s was used, and cutoff temperatures were set at 0 and 50 °C [16, 29, 33, 34].

**Mechanical detection threshold**

The MDT was measured with a standard set of Semmes-Weinstein monofilaments (Touch Test™ Sensory Evaluator, North Coast Medical, Inc., Morgan Hill, CA) with 20 diameters [29, 33–35]. Five repeated threshold measurements were made, each by applying a series of ascending and descending stimulus intensities; the final threshold was the geometric mean of the five series [16, 29, 33, 34].

**Mechanical pain threshold, mechanical pain sensitivity to pinprick stimuli, dynamic mechanical alldynia, and wind-up ratio for repetitive pinprick stimuli**

Weighted pinprick stimuli were delivered with seven custom-made punctate mechanical stimulators with fixed stimulus intensities (flat contact area 0.2 mm in diameter) that exerted forces of 8–512 mN to determine the MPT [16, 29, 33, 34]. The method of limits, which was used to determine the MDT, was also used to determine the MPT [16, 29, 33, 34]. MPS and DMA were evaluated using two sets of instruments in a stimulus–response assessment [16, 29, 36]. To determine MPS, seven weighted pinprick stimulators were used (as for MPT). Three tactile stimulators were used to determine DMA: a cotton wisp (~3 mN), a cotton wool tip (Q-tip, ~100 mN) attached to a flexible handle, and a disposable toothbrush (Top Dent®, Meda AB, Solna, Sweden, ~200–400 mN). A series of 10 measurements was made three times, each with 10 stimulators (seven pinpricks and three tactile stimulators) applied in a different order, as specified in the DFNS protocol [16, 29, 33, 34]. For each of the resulting 30 stimuli, the participant chose a pain rating on a 0 to 100 scale with the endpoints 0 indicating “no pain” and 100 indicating “most intense pain imaginable.”

To measure the WUR for repetitive pinprick stimuli, the perceived magnitude of a train of 10 pinprick stimuli repeated at 1 Hz was divided by that of a single pinprick stimulus with the same force [16, 29, 33]. The WUR test was repeated three times [16, 29, 33, 34].

**Vibration detection threshold**

The vibration detection threshold (VDT) was measured with a tuning fork (64 Hz, 8/8 scale) [16, 29, 36]. VDT was performed on bony prominences bilaterally for each participant: the zygomatic process, the lower edge of the mandible, and the ulnar styloid process. The participant indicated when the vibration could no longer be sensed on a nine-point (0–8) scale [16, 29, 33–35]. The test was repeated three times.

**Pressure pain threshold**

The pressure pain threshold (PPT) was measured using a computerized pressure algometer (Medoc AlgoMed, Israel) [16, 29, 33, 34]. PPT was measured on the painful site, the corresponding contralateral site, and the right thenar muscle of patients; and on the temporalis, masseter, and thenar muscles bilaterally of healthy participants, both with a constant application rate of 30 kPa/s [16, 29, 33, 34]. The test was repeated three times.

**Data analysis and statistics**

**Z-transformation of QST data**

For all 13 parameters, the recently published reference data for Chinese of both genders and three body regions (two facial sites and hands) were available as reference values for two age groups [28, 29]. Data of cold and heat pain thresholds and vibration detection thresholds were normally distributed. Other parameters were log-transformed before analysis [27–29]. Each variable of individual QST data was Z-transformed based on reference data:

\[ Z = \frac{X_{\text{single patient}} - \mu_{\text{reference}}}{\sigma_{\text{reference}}} \]

Where \( Z \) is the Z-score and adjusted in such a way that \( Z \)-scores > 1.96 indicate abnormally large preoperative and postoperative WDT, TSL, MDT, or VDT) were abnormal on the affected side in comparison with the reference data (absolute abnormality), or if abnormally large preoperative and postoperative differences were detected (relative abnormality), they were recorded as one of the following: L1, isolated loss of small fiber function (if abnormal thermal detection thresholds [CDT,
TSL, or WDT] alone); L2, isolated loss of large fiber function (if abnormal mechanical detection thresholds [MDT or VDT] alone); or L3, mixed loss of function (if loss of both small and large fiber function) [23, 29, 36]. Likewise, for somatosensory gain, thermal hyperalgesia (G1) was recorded if gain of function in cold or heat pain thresholds (CPT or HPT) were found (absolute or relative abnormality). Mechanical hyperalgesia (G2) was recorded if gain of function (absolute or relative abnormality) was detected for MPT, MPS, or PPT, or if the DMA score exceeded zero. Mixed gain (G3) was recorded in individuals with gain of both thermal and mechanical somatosensory function. L0 was scored if no loss of somatosensory function was presented, and G0 if no gain of somatosensory function was detected.

**Statistical analysis**

All statistical analyses were performed using SPSS 21.0 software. Age and size of perforation in IAC differences between groups were compared using an unpaired t test. Operation time and postoperative pain differences between groups were analyzed using a Mann–Whitney U test. The distribution of gender and frequencies of loss and gain function according to the loss/gain coding system differences between groups were evaluated with Chi-square and Fisher’s exact tests.

The effects of four primary factors (gender, group, what time, and size of perforation in the IAC) on QST results were calculated using a four-way repeated-measure ANOVA [16, 28, 29]. If significant influence were found between size of perforation in the IAC and QST results, a linear regression model was applied to estimate further. The effect of other secondary factors (postoperative pain, infection rate) on QST values were analyzed with multiple factors ANOVA analysis. Multiple comparisons were calculated using a Bonferroni post hoc test. In addition, for each surgical method, the variation of QST data and pain scores were analyzed with the Friedman test. Statistically significant difference was estimated with a value of $P < 0.05$.

**Results**

A total of 140 impacted lower third molars of 121 patients were assigned to two groups. A total of 91 teeth were allocated the test group, and the other 49 teeth were included in the control group (Table 1). No significant age or gender differences were detected in the two groups.

**Clinical assessments**

The size of perforation in the inferior alveolar canal (IAC) in the test group ($5.87 \pm 2.82$ mm, mean $\pm$ SD), which was measured on CBCT, was higher than that of the control group ($4.86 \pm 2.63$ mm) ($P = 0.041$).

Length of operation for coronectomy ($13.89 \pm 5.17$ min) was significantly greater than for traditional extraction ($12.65 \pm 4.68$ min) ($P = 0.015$).

Two patients (2.20%) in the test group complained of lower-lip numbness; only one patient in the control group complained of tongue numbness (2.04%) (control vs. test group, $P = 0.951$).

There was no significant difference in postoperative pain rating or infection rate between the two groups ($P \geq 0.196$). No suspicious pulpitis or root-related infection was found. The occurring of infection or dry socket, following treatment and recovery, was basically similar in two groups. No significant difference between infection and QST parameters changes was found because the sample of infection was too small.

**QST results**

No PHS or DMA was found in this study. The effect of factors (gender, group, test time, and size of perforation in the IAC) on QST results was assessed by four-way repeated-measure ANOVA (Table 2).

Significant gender differences were detected for most QST parameters except for WUR, with females more sensitive than males ($P \leq 0.046$, Table 2), with an exception for VDT (males were more sensitive than females, $P = 0.003$).

There were no group differences in any QST parameters before surgery ($P \geq 0.128$). Postoperatively, however, in thermal parameters for the test group, CDT ($-0.48 \pm 0.20$ °C), CPT ($25.26 \pm 6.64$ °C), and HPT ($37.93 \pm 3.39$ °C) were significantly more sensitive than the CDT ($-0.53 \pm 0.30$ °C, $P = 0.005$), CPT ($23.25 \pm 7.48$ °C, $P = 0.027$), and HPT ($38.52 \pm 3.30$ °C, $P = 0.006$) in the control group. Furthermore, the mechanical parameter, PPT ($104.44 \pm 44.81$ kPa, $P = 0.004$), in the test group was significantly more sensitive (lower threshold) than that ($112.92 \pm 39.72$ kPa) in the control group.

There were significant time effects on the MDT and PPT ($P \leq 0.001$) (Table 2). The MDT before surgery ($0.14 \pm 0.09$ mN) was higher (less sensitive) than that of seven ($0.12 \pm 0.08$ mN) or 28 days ($0.11 \pm 0.07$ mN) after surgery. The PPT one day after surgery was lower (more sensitive) than that preoperatively ($114 \pm 34.15$ kPa) or seven ($112.22 \pm 40.94$ kPa) or 28 days ($111.71 \pm 40.44$ kPa) after surgery.

The effects of time on each QST parameter were also assessed in each group separately (Fig. 2). Significant time effects were detected for mechanical parameters (MDT, PPT) in both groups. The MDT seven days after surgery was lower (more sensitive) than that preoperatively or one day after surgery ($P \leq 0.016$). The PPT one day after surgery was lower (more sensitive) than that of seven days after surgery.
Significant time effects were detected for thermal parameters (CDT, HPT) only in the test group. Abnormalities based on Z-scores

The abnormality included a relative Z-score (compared with data before surgery) and an absolute Z-score (compared with established age and gender-stratified data) for each QST parameter (Fig. 3). There was no significant group difference for abnormal frequencies between the two groups (rate for control group ≤ 22.14%, rate for test group ≤ 37.14%, P ≥ 0.17), but mechanical parameters changed obviously. The abnormal frequency for MDT (preoperatively: 24.43%) almost tripled one day after surgery (59.29%) and then decreased apparently seven days after surgery (7.14%), and the abnormal frequency for PPT varied in a similar way, with the result (4.29%) greatly increasing one day after surgery (22.14%) and then decreasing sharply seven days after surgery (5.71%). Finally, 28 days after surgery, the abnormal frequency for PPT reverted to preoperative level (5.71%) but the level for MDT did not completely recover (test 7.14%). However, thermal parameters just showed a little variation during those periods.

Regarding the loss/gain coding system, all data was calculated without group separation (Table 3). Compared with other testing points (62.20% preoperatively, 68.75% seven days postoperatively 72.26%, 28 days postoperatively), the absence of somatosensory abnormalities (L0G0) significantly decreased one day after surgery (34.88%, P < 0.001). Change of mechanical sensory data was greater than thermal sensory data change. The cumulative proportion of those manifesting mechanical somatosensory loss (L2G0, L2G1, L2G2, L2G3) was significantly higher one day after surgery.

### Table 2 Four-way repeated-measure ANOVA analysis

|          | CDT | WDT | TSL | PHS | CPT | HPT | MDT | MPT | MPS | DMA | WUR | VDT | PPT |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Gender   | <0.001 | <0.001 | <0.001 | NO | <0.05 | <0.001 | <0.001 | <0.001 | NO | NS | <0.01 | <0.001 | NO |
| Group    | <0.01 | NS | NS | NO | <0.05 | <0.01 | NS | NS | NO | NS | NS | <0.01 | NS |
| Time     | NS | NS | NS | NO | NS | NS | <0.001 | NS | NO | NS | NS | NS | <0.001 |
| Size of perforation in IAC | NS | NS | NS | NO | NS | NS | <0.05 | <0.001 | NO | <0.001 | NS | <0.001 | NS |
| 1 × 2    | <0.05 | NS | NS | NO | <0.01 | <0.05 | NS | NS | NO | NS | NS | NS | NS |
| 1 × 3    | NS | NS | NS | NO | NS | NS | NS | NS | NO | NS | NS | NS | NS |
| 2 × 3    | NS | NS | NS | NO | NS | NS | NS | NS | NO | NS | NS | NS | NS |
| 1 × 2 × 3 | NS | NS | NS | NO | NS | NS | NS | NS | NO | NS | NS | NS | NS |

Effective size of

Gender difference 0.084 0.034 0.039 NO 0.008 0.041 0.398 0.035 0.038 NO 0.003 0.016 0.123
Coronectomy vs. extraction 0.015 0.005 0.002 NO 0.009 0.015 0.002 0.003 0.000 NO 0.001 0.001 0.017
Testing point of QST 0.006 0.004 0.007 NO 0.001 0.007 0.032 0.001 0.020 NO 0.009 0.005 0.049
Risk of IANI 0.002 0.007 0.001 NO 0.000 0.000 0.005 0.007 0.011 NO 0.006 0.031 0.002

Four-way repeated-measure ANOVA and effect size of gender, group, time, and size of perforation in inferior alveolar canal (IAC) on quantitative sensory testing (QST) parameters in 140 participants. P values were filled in blanks. “NS” means “no significant difference”, which means P > 0.05 NO, no occurrence; CDT, cold detection threshold; WDT, warmth detection threshold; TSL, thermal sensory limen; PHS, paradoxical heat sensation; CPT, cold pain threshold; HPT, heat pain threshold; MDT, mechanical detection threshold; MPT, mechanical pain threshold; MPS, mechanical pain sensitivity; DMA, dynamic mechanical allodynia; WUR, wind-up ratio; VDT, vibration detection threshold; PPT, pressure pain threshold
than that of seven days (16.41%) and 28 days (14.60%) \((P<0.001)\). Similarly, the cumulative proportion of those manifesting mechanical somatosensory gain (L0G2, L1G2, L2G2, L3G2) was significantly higher one day after surgery (17.83%) than it was preoperatively (0.00%), seven days (1.56%), or 28 days (2.92%) \((P<0.001)\) after surgery (Table 3, light-gray shading). However, thermal somatosensory data exhibited little variation; no significant differences were found in the cumulative proportion of those exhibiting thermal somatosensory loss (L1G0, L1G1, L1G2, L1G3) or gain (L0G1, L1G1, L2G1, L3G1) among different testing time points \((P>0.05)\).

Discussion

This prospective study systematically compared the somatosensory profiles of two groups of patients with an impacted lower third molar extracted by one of two surgical methods, by using a comprehensive QST protocol for the first time [13, 14]. According to the previous studies, the Ethics Committee suggested that random grouping was not suitable for this study. In addition, participants with higher risk of IANI were more willing to join coronectomy group. It could account for the unbalanced sample size between two groups and the result that the size of perforation in IAC in the test group was significant higher than that of the control group \((P=0.041)\). However, this made it more conductive to demonstrate the superiority of coronectomy. The main finding of this study was that QST was a sensitive way to detect somatosensory abnormalities even with no subjective complaint caused by surgery. Coronectomy, which had less influence on the IAN somatosensory function in situations when the third molar contacted the IAN on CBCT, was a good alternative to conventional total extraction.

QST is a sensitive way to detect somatosensory abnormalities

The advantage of QST protocol was that it could be applied to identify many kinds of somatosensory abnormalities and help elucidate various mechanisms of nerve injury [16]. This protocol had already been widely used in the oral facial region [19–23]. In this study, most participants did not complain of subjective paresthesia of the lower lip, but significant variations were detected on QST values; for example, according to the loss/gain coding system, the absence of somatosensory abnormalities (L0G0) decreased significantly after surgery \((P<0.001)\), which was consistent with previous studies of implant surgery and third molar extraction [21, 22, 24, 25]. In addition, patients underwent minor orofacial surgery with no subjective somatosensory changes, which could present both central and peripheral sensitizations [25] identified by a similar QST protocol.

In this study, the sensitivity of mechanical parameters exhibited a significant increase after surgery (MDT and PPT, \(P \leq 0.001\)), whereas the sensitivity of thermal parameters showed little variation \((P>0.05)\). The same results were also determined in the loss/gain coding system, in which only the frequency of mechanical somatosensory abnormalities varied significantly \((P<0.001)\). A previous study reported that mechanical tests yielded more abnormalities than thermal tests in patients with sensory abnormalities [36]. Hyperalgesia to pressure stimulus, evaluated by PPT, was probably caused...
The sensitivity of MDT would decrease after surgery compared with the preoperative baseline. This was contrary to many studies, which reported that the sensitivity of MDT after surgery also confirmed that the influence on the IAN was not enough to decrease the sensitivity of the MDT. The greater variation of the MDT before and after surgery, compared with thermal parameters, indicated that it was more sensitive to surgical injury than thermal thresholds were, as well as a more sensitive indicator of recovery [20, 45].

Coronectomy is a better choice than conventional extraction when the root is close to the nerve.

IANI often resulted from direct compression, such as pressure from the tooth’s root and surgical instruments [8]. The nerve injury rate would increase 20% if exposure of the IAN was larger than 3 mm [46], which meant the size of perforation in the IAC could indicate the risk of IANI. In this study, the size of perforation in the IAC was significantly larger (P = 0.041) in the test group (5.87 ± 2.82 mm) than in the control group (4.86 ± 2.63 mm), but no significant difference (P > 0.05) in abnormal frequencies of QST values was found between the two groups after surgery. Thus, coronectomy had less influence on IAN function than conventional extraction when tooth roots contacted the IAN directly. This was consistent with previous studies. Long H’s systematic review indicated that the risk of incurring IANI during conventional extraction would be nearly 10 times higher than during coronectomy [13], and the safety of coronectomy had also been reported in many qualitative studies [1, 12, 47].

Different injury led to different manifestation [39]; this study provided more detail about the difference. CDT, HPT only exhibited the time effect in the test group (P ≤ 0.036) and, after surgery, CDT, CPT, and HPT in the coronectomy group were significantly more sensitive than those in the extraction group (P ≤ 0.027). Thermal parameters seemed to be more
effective in reflecting postoperative IAN function in coronectomy. Retained dental pulp was probably an important factor contributing to this phenomenon. It was reported that dental pulp would retain vitality after coronectomy [48, 49]. Neurogenic inflammation after pulpectomy might lead to higher sensitivity to thermal stimulus [50]. The hypoalgesia to thermal stimuli, HPT and CPT, caused by surgery may recover slower than the MDT [40]. The current study obtained a contrary result regarding different thermal parameters, indicating that the variation of thermal parameters might be motivated by pulpectomy, leading to peripheral sensitization of cold fibers (CPT) and heat hyperalgesia [42, 51].

There was no difference between the two groups in the incidence of postoperative complications (pain, dry sockets, and infection) ($P \geq 0.196$), which was consistent with previous studies [13, 26]. Dry socket is microscopically characterized as osteomyelitis and macroscopically has many similarities to infection [52]. Dry socket and infection may impair IAN function similarly through inflammation, so we counted the two complications together during analysis. There was no significant correlation between infection and QST results. The operation time for coronectomy (13.89 ± 5.17 min) was about 1 min longer than conventional extraction (12.65 ± 4.68 min) and was within acceptable time; it could hardly lead to significant nerve damage.

The failure rate of coronectomy was 2.1% (2/94), which was lower than previous reports, 2.3%–38% [12, 26, 49]. Among the infected cases, all participants recovered through conservative treatment, which indicated that the retained fragment of roots were not involved and did not require further operation [26]. Unfortunately, the follow-up time in our study was too short to propose a conclusion on root prognosis. The migration of retained root rates is reported to be from 14% to 81% [26, 53, 54]. We just presented a case with a follow-up time of more than six months to draw a general impression of later prognosis that is safe and good. Subsequent results will be presented in our further report.

**Conclusion**

This prospective study on postoperative IAN function demonstrated that coronectomy had less influence on IAN function and was a good alternative to conventional total extraction when the third molar contacted the IAN directly. QST was a...
sensitive way to detect somatosensory abnormalities even with no subjective complaint caused by surgery. Mechanical parameters, especially MDT, were a sensitive indicator of both injury and recovery. Thermal parameters, CDT, CPT, and HPT, were probably more suitable to reflect IAN condition after coronectomy.

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**Compliance with ethical standards**

**Conflict of interest** Zi-Yu Yan declares that he has no conflict of interest. Xiao-Yan Yan declares that she has no conflict of interest. Chuan-Bin Guo declares that he has no conflict of interest. Qiu-Fei Xie declares that she has no conflict of interest. Guo declares that he has no conflict of interest. Nian-Hui Cui declares that he has no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

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