INTRODUCTION
Apical surgery is a well-established treatment option to retain teeth with persisting or recurrent periradicular infection. Apical surgery, also known as endodontic microsurgery, is considered a safe intervention with good long-term prognosis (1-3). However, as surgery requires flap elevation, osteotomy, and curettage, a risk to adjacent structures is present. Such structures include neighbouring roots, blood vessels, nerves, the nasal floor, and the maxillary sinus. In addition, in the mandible, apical surgery of premolars or molars may cause damage to the neurovascular content of the mental foramen (MF) or mandibular canal (MC). Consequently, the patient may have temporary or permanent altered sensation in the lower lip and/
or chin region. The altered sensation could include dysesthesia, paresthesia, hypesthesia or hyperesthesia. Such sensitivity changes may result in irritation of the lip or drooling, eating disorders, speech problems, depression, and eventually may have medicolegal consequences (4, 5).

The assessment of healing in apical surgery has traditionally been on the radiographic assessment of new bone formation within the former bone defect and around the cut root end. Other studies have addressed soft tissue healing or postsurgical quality of life in conjunction with apical surgery (6). In contrast, data about neurosensory changes following apical surgery have only been reported occasionally. A study limited to apical surgery of molars reported an incidence of lower lip sensory deficit in 20-21% of 738 treated mandibular molars (7). Another study including 143 periapical surgeries in the posterior mandible described an incidence of 10.4% of altered sensation (8). In a recent retrospective analysis of 13 mandibular premolars and 50 mandibular molars treated with apical surgery, altered lip/chin sensation was observed in 14.3% of cases (5).

The primary objective of this retrospective analysis was to determine the rate of neurosensory disturbances after apical surgery of mandibular premolars and molars. The secondary objective was to evaluate a possible correlation between the occurrence of altered sensation and the distances from the apex or periradicular lesion to the relevant anatomical structures.

**MATERIALS AND METHODS**

Cases were retrospectively selected from a pool of patients who were treated with apical surgery by a single surgeon from September 1999 to December 2015. The study was approved by the institutional review board (Ethics Commission of Canton Bern, Switzerland, KEK approval number 2016-01711). Cases had been evaluated and treated according to the declaration of Helsinki (www.wma.net) with written consent of all patients.

Cases were included when patients were ≥18 years of age, the apical surgery involved a mandibular premolar or molar, and a 1-year follow-up was documented in the patient chart. Exclusion criteria were patients who have had trauma or other surgical interventions in the same hemimandible, or presented preoperative signs of sensitivity changes in the lower lip/chin regions.

**TABLE 1. Study population undergoing apical surgery**

| Number of patients | Scenario                                         | Number of teeth | Inclusion/exclusion | Number of teeth analysed |
|--------------------|--------------------------------------------------|-----------------|---------------------|-------------------------|
| 223                | One single tooth operated                        | 223             | All teeth included  | 223                     |
| 6                  | One single tooth operated and later re-operated  |                 | Both interventions included | 6                       |
| 13                 | Two teeth operated at the same time in the same hemimandible | 26             | Only one tooth included (at random) | 13                      |
| 3                  | Three teeth operated at the same time in the same hemimandible | 3              | Only one tooth included (at random) | 1                       |
| 6                  | One single tooth treated in each hemimandible at two different timepoints | 6              | All teeth included  | 6                       |
| 243                |                                                  | 264             |                     | 249                     |
Radiographic evaluation
For the evaluation of a possible correlation between the occurrence of neurosensory disturbances and the proximity of relevant anatomical structures – i.e. MF or MC – cases of the test group were identified that had adequate preoperative radiographic depiction of the MF or MC, either by two-dimensional radiography (2D panoramic view) or three-dimensional imaging (cone-beam computed tomography, CBCT). Cases with inadequate radiography, i.e. distorted pictures, images with artefacts, and unclear or incomplete depiction of the MF or MC, were excluded from the radiographic analysis.

Case-control selection
From the pool of treated cases without postoperative altered sensation, cases matching those with postoperative neurosensory disturbances were selected. The selection was based on the following criteria (order of priority): same type of imaging technique (2D panoramic views or CBCT), same root, same sex, and similar age.

Technical details with regard to radiographic imaging
Panoramic images were taken with a Cranex D machine (Soredex, Tuusula, Finland). CBCT images were available from 2004, using a 3D-Accuitomo device (Morita, Kyoto, Japan). Field of views ranged from 4x4 to 8x8 cm. Operating parameters were set at 5 mA and 80 kV, and exposure time was 17.5 seconds. The data were reconstructed with slices at an interval of 0.5 mm.

Radiographic measurements
Roots of test and control teeth were evaluated with the shortest distances measured from the apex and from the lower margin of the periapical lesion, respectively, to the superior border of the MF/MC, whichever was closer (Fig. 1). In cases where the apex or the lesion projected onto the anatomical structure, the distance received a negative value. In CBCT images, these distances were measured in the sagittal as well as in the coronal plane. On coronal CBCT scans, also the distances from the buccal cortex to the apex and to the lingual margin of the lesion were measured (Fig. 2) (11).

2D panoramic views were printed out and measurements were done by hand using a ruler. The measured distances were divided by the magnification factor 1.3 of panoramic tomography as indicated by the manufacturer. CBCT images were analysed by using the program i-Dixel (Version 2.5.7, Morita, Kyoto, Japan) with a Dell Precision Tower 5810 workstation (Dell Technologies Inc., Round Rock, TX) and a 27-inch Philips 273E LCD monitor with a resolution of 1920×1080 pixels (Philips Electronics N.V, Amsterdam, Netherlands). All measurements were taken twice by a single observer (S.B.) at a minimum interval of 4 weeks. The calculated mean values were utilised for the final analysis.

Statistical analysis
Mean comparisons were performed by independent t-tests separately. For the associations between two continuous variables, Pearson's correlations were estimated separately. To investigate the association between the location of the long-axis of the root in relation to the mandibular canal, Fisher's exact test was performed. For comparing the rates of neurosensory disturbances and the proportion of altered sensitivity among different groups, Fisher's exact test or Fisher-Freeman-Halton exact test was utilised.

All of the tests performed were two-tailed tests with α=0.05 significance level. The analyses were done using IBM SPSS Statistics for Windows Version 26 (IBM Corp. Armonk, NY, USA).

RESULTS
The study population (n=243) included 109 males (44.9%) and 134 females (55.1%). The mean age was 49.9 years.

Figure 1. 2D panoramic view (cropped image) of the lower right first molar in a 27-year-old female showing the shortest distances from the mesial root apex (white line) as well as from the inferior margin of the lesion to the roof of the mandibular canal (red line).

Figure 2. CBCT scans of the lower left first molar in a 34-year-old female. (a) Sagittal cut showing the shortest distances from the distal root apex (white line) as well as from the inferior margin of the lesion to the roof of the mandibular canal (red line). (b) Coronal cut exhibiting the same distances, but also the shortest distances from the buccal bone surface to the apex (yellow line) as well as to the lingual margin of the lesion (blue line).

CBCT: Cone-beam computed tomography
Neurosensory disturbances were categorized as hypoaesthesia (n=23), paresthesia (n=7), or a combination of the two (n=2). Complete anaesthesia, dysesthesia or hyperaesthesia was not recorded. The rate of altered sensation did not differ significantly between males (12.8%) and females (13.4%). In the majority of the affected cases (56.3%), the neurosensory disturbances occurred more frequently on the right (16.5%) compared to left sides (8.2%) (p=0.058). Moreover, altered sensation was observed more frequently on the right (16.5%) compared to left sides (8.2%) (p=0.058). The difference was not statistically significant (p=0.310). Further, either factor could contribute to altered sensation within this study's weaknesses are the retrospective nature of the analysis. The data was collected from the charts, and the records could not be verified clinically. For example, if there was no mention of sensitivity change in the patient record, it was assumed that the patient had no altered sensation. Furthermore, sensitivity changes were only determined with the “two-point discrimination” and “sharp vs blunt discrimination” tests without further quantitative, neurological and/or imaging assessments (12). Another shortcoming of this retrospective study was that histology of the removed lesions was not performed routinely. Therefore, a possible correlation of the type of periapical pathology and the occurrence of neurosensory disturbances could not be determined.

The frequency of neurosensory disturbances (12.9%) was similar to previously reported rates of 10.4% (8) and 14.3% (5). In contrast, a marked higher rate (20 to 21%) was described in a large study including only molars (7). Although molars are not necessarily located closer to MF or MC than premolars, the surgical access to molar root apices is more complex. This might result in a larger flap and a longer duration of the surgery. Therefore, either factor could contribute to altered sensation within the supply area of the mental nerve of the lower lip, corner of the mouth and chin (Table 2).

The distribution of treated teeth, of teeth with subsequent altered sensation, and the calculated percentage rates are summarized in Table 3. In second premolar cases, neurosensory disturbances were noted more often (22.6% out of all second premolars operated) than in the other tooth groups (11.2 to 13.0%). However, this difference was not statistically significant (p=0.310). Furthermore, altered sensation was observed more frequently on the right (16.5%) compared to left sides (8.2%) (p=0.058).

**TABLE 2.** Area(s) of neurosensory disturbances

| Area(s)                      | n  | %   |
|------------------------------|----|-----|
| Lower lip, corner of mouth, chin | 18 | 56.3|
| Lower lip, corner of mouth    | 1  | 3.1 |
| Lower lip, chin              | 6  | 18.8|
| Lower lip                    | 5  | 15.6|
| Chin                         | 2  | 6.3 |
| Total                        | 32 | 100.0|

**TABLE 3.** Distribution of treated teeth and rates of neurosensory disturbances per tooth group

| Tooth                  | Right side | Left side | Total |
|------------------------|------------|-----------|-------|
| Distribution of treated teeth (n) |            |           |       |
| First premolar         | 10         | 13        | 23    |
| Second premolar        | 18         | 13        | 31    |
| First molar            | 108        | 79        | 187   |
| Second molar           | 3          | 5         | 8     |
| Total                  | 139        | 110       | 249   |

| Distribution of teeth with neurosensory disturbances (n) |            |           |       |
|---------------------------------------------------------|------------|-----------|-------|
| First premolar                                          | 1          | 2         | 3     |
| Second premolar                                         | 3          | 4         | 7     |
| First molar                                             | 18         | 3         | 21    |
| Second molar                                            | 1          | 0         | 1     |
| Total                                                   | 23         | 9         | 32    |

| Rate of neurosensory disturbances per tooth group (%) |            |           |       |
|------------------------------------------------------|------------|-----------|-------|
| First premolar                                       | 10.0       | 15.4      | 13.0  |
| Second premolar                                      | 16.7       | 30.8      | 22.6  |
| First molar                                          | 16.7       | 3.8       | 11.2  |
| Second molar                                         | 33.3       | 0         | 12.5  |
| Total                                                | 16.5       | 8.2       | 12.9  |

With regard to the measured distances (Tables 5, 6), none reached a statistically significant difference when comparing values of the test and control groups. The only statistically significant difference (p=0.005) was noted in the test group for the distance “apex to MF/MC” in 2D panoramic views comparing females (5.1 mm) and males (8.5 mm). A borderline significance (p=0.097) was observed, also in 2D panoramic views of the test group, for the same distance comparing premolars (4.1 mm) and molars (6.8 mm).

**DISCUSSION**

This study assessed the incidence of altered sensation after apical surgery of mandibular premolars and molars. The strengths of the study include the high number of analysed cases, a single surgeon performed all surgeries, and all interventions were carried out in the same institution. However, the study's weaknesses are the retrospective nature of the analysis. The data was collected from the charts, and the records could not be verified clinically. For example, if there was no mention of sensitivity change in the patient record, it was assumed that the patient had no altered sensation. Furthermore, sensitivity changes were only determined with the “two-point discrimination” and “sharp vs blunt discrimination” tests without further quantitative, neurological and/or imaging assessments (12). Another shortcoming of this retrospective study was that histology of the removed lesions was not performed routinely. Therefore, a possible correlation of the type of periapical pathology and the occurrence of neurosensory disturbances could not be determined.

The frequency of neurosensory disturbances (12.9%) was similar to previously reported rates of 10.4% (8) and 14.3% (5). In contrast, a marked higher rate (20 to 21%) was described in a large study including only molars (7). Although molars are not necessarily located closer to MF or MC than premolars, the surgical access to molar root apices is more complex. This might result in a larger flap and a longer duration of the surgery. Therefore, either factor could contribute to altered sensation within the supply area of the mental nerve of the lower lip, corner of the mouth, and chin region. In the present sample of patients, special attention was paid to spare the mental nerve with regard to the mesial release incision for apical surgery of molars. Specifically, the initial part of the release incision was placed at the mesial line-angle of the second premolar, then slightly angulated inferiorly but immediately below the mucogingival line. The incision was then directed anteriorly to circumvent the mental foramen with its neurovascular bundle (Fig. 3).

Two vital structures are at risk when performing interventions in the posterior mandible, the MC and the MF. The MC originates from the mandibular foramen at the medial aspect of the ramus. The MC then traverses the body of the mandible. Four typical courses of the MC have linear curve (approximate to a straight line);
lated with the occurrence of altered sensation (Pearson correlation coefficient: 0.564 in test group and 0.527 in control group).

In the axial plane, the MC may also have different configurations, i.e. running along the lingual plate with an anterior sharp turn towards the MF, a stretched S-shaped curve or a linear course through the body of the mandible (20-22). The latter two may pose a higher risk than a lingual position of the MC with regard to the buccal access in apical surgery. However, a separate analysis of the MC position relative to the root apex in the buccolingual plane (coronal CBCT cuts) in the present study did not find any correlation with the occurrence of altered sensation following apical surgery. Therefore, the MC positions in the test and the control groups did not differ significantly.

**TABLE 4.** Frequency of neurosensory disturbances per gender, age group, and type of root-end filling

| Gender | Number treated | % Treated | Number with altered sensitivity | % Altered sensitivity | P-value |
|--------|----------------|-----------|---------------------------------|-----------------------|---------|
| Male   | 112            | 45        | 14                              | 12.5                  | >0.999  |
| Female | 137            | 55        | 18                              | 13.1                  |         |
| Age group* |  |  |  |  |  |  |
| <45 years | 81           | 32.5      | 14                              | 17.3                  | 0.160   |
| ≥45 years | 168          | 67.5      | 18                              | 10.7                  |         |
| Root-end filling material |  |  |  |  |  |  |
| SuperEBA | 20          | 8         | 2                               | 10                    | 0.074   |
| MTA     | 161           | 64.7      | 15                              | 9.3                   |         |
| Retroplast | 63         | 25.3      | 14                              | 22.2                  |         |
| BCRRM   | 4             | 1.6       | 1                               | 25                    |         |
| None (resection only) | 1         | 0.4       | 0                               | 0                     |         |
| All     | 249           | 100       | 32                              | 12.9                  |         |

*Cut-off age according to von Arx et al. (26), EBA: Ethoxy benzoic acid, MTA: Mineral trioxide aggregate, BCRRM: Bioceramic root repair material

**TABLE 5.** Distances measured in 2D panoramic views

| Study parameter | Subcategory | Test group mean distance±SD (mm) | Control group mean distance±SD (mm) | P-value |
|-----------------|-------------|---------------------------------|-------------------------------------|---------|
| Apex to MF/MC   | All         | 6.2±2.49a                       | 7.1±2.56a                           | 0.348a  |
|                 | Males (n=5) | 8.5±1.80a                      | 7.2±3.31a                           | 0.003b  |
|                 | Females (n=10) | 5.1±1.88a                      | 7.1±2.31a                           | 0.925c  |
|                 | Premolars (n=3) | 4.1±1.53a                      | 5.5±1.46a                           | 0.097d  |
|                 | Molars (n=12) | 6.8±2.39a                      | 7.5±2.65a                           | 0.228e  |
|                 | All (n=15) | 4.8±2.11b                       | 5.0±2.87b                           | 0.846f  |
| Lesion to MF/MC | All (n=15) | 4.8±2.11b                       | 5.0±2.87b                           | 0.846f  |

Same superscripts denote statistical comparison. Bold P-value denotes a statistically significant difference, MF/MC: Mental foramen/mandibular canal, SD: Standard deviation

**TABLE 6.** Distances measured in CBCT

| Study parameter | Subcategory | Test group mean distance±SD (mm) | Control group mean distance±SD (mm) | P-value |
|-----------------|-------------|---------------------------------|-------------------------------------|---------|
| Apex to MF/MC   | All         | 6.6±2.64a                       | 6.8±3.07a                           | 0.881a  |
|                 | Males (n=7) | 8.2±4.01b                      | 7.7±2.40b                           | 0.074b  |
|                 | Females (n=11) | 5.6±1.40b                      | 5.9±2.65b                           | 0.159c  |
|                 | Premolars (n=3) | 7.1±4.05a                      | 7.7±3.42a                           | 0.831d  |
|                 | Molars (n=15) | 6.7±3.01a                      | 6.3±2.44a                           | 0.362e  |
|                 | All (n=18) | 4.5±3.19f                       | 4.5±2.80f                           | 0.974f  |
| Lesion to MF/MC | All (n=18) | 4.6±1.14a                       | 5.1±1.55g                           | 0.253g  |
| Cortex to apex  | All (n=18) | 6.8±1.28a                       | 7.6±1.73h                           | 0.119h  |
| Cortex to lesion| All (n=18) | 6.8±1.28a                       | 7.6±1.73h                           | 0.119h  |

Same superscripts denote statistical comparison. CBCT: Cone-beam computed tomography, MF/MC: Mental foramen/mandibular canal, SD: Standard deviation

- Linear curve (approximate to a straight line);
- Spoon-shape curve (similar to an asymmetric elliptic arc);
- Elliptic arc curve (approximate symmetry);
- Turning curve (unsMOOTH curve with turning point) (13).

These different MC configurations and varying lengths of roots of the posterior teeth explain that the distances from root apices to MC may show great variability (14). In general, females have shorter distances than males from the relevant root apices to the MC (15-18). With regard to age, root apices of younger individuals tend to be closer to the MC compared to older individuals (16, 19). However, in the present study, age was not found be corre-
In the region of the premolars, the MC separates into two structures, i.e. the mental canal leading to the MF, and the mandibular incisive canal, extending anteriorly eventually reaching the symphysis. The mental canal is only a short structure, but often shows a “so-called” loop to the MF that is usually directed superoposteriorly. Therefore, the neurovascular bundle of the MF may be closely positioned to the access window of the mandibular premolars (Fig. 4). Minimum distances from the MF to the closest root apex were reported in the literature to range from 0.0 to 2.1 mm (22-24).

Since the MC is located more lingually in the molar region, but then approaches the buccal cortex and ascends to the mental foramen in the second premolar region, apical surgery of second premolars may have an increased risk of postoperative altered sensation. In the present study, second premolars had the highest rate of neurosensory disturbances. Also, Mainkar et al. (5) reported a statistically significant higher rate in premolars (38%) versus molars (8%) (odds ratio 7.19, p=0.014).

In the present study, altered sensation on the right side (16.5%) was twice as high as on the left side (8.2%). However, no apparent reasons were found to explain this borderline significant difference. However, an operator effect cannot be ruled out as the surgeon was right-handed.

Altered sensation in apical surgery may be caused intraoperatively by direct damage of neural structures with instruments, rotary burs, excessive tension or compression on the flap. While particular caution was exercised to avoid contact of the applied hemostatic agents with the mandibular canal/mental foramen, possible neurotoxic effects could not be ruled out completely. Postoperative haematoma or oedema may also result in altered sensation when they occur in the proximity of the inferior alveolar nerve or mental nerve, respectively. The clinician is therefore advised to exert caution when performing apical surgery in the vicinity of these anatomical structures. In order to avoid compression of the mucoperiosteum by wound retractors, retracting sutures attached to a haemostat are an option. Others have advocated to drill a longitudinal groove into the buccal cortex with the wound retractor engaging this furrow, so the retractor is firmly anchored and does not slip or squeeze the mucoperiosteal flap (25). Location and visualisation of the neurovascular bundle arising from the MF during surgery helps in avoiding inadvertent damage to these vital structures. When root apices or associated periapical lesions project onto the MF or the MC, a CBCT is recommended to assess the three-dimensional relationship and to plan the access window.

CONCLUSION
In the present study, 12.9% of apical surgeries of mandibular premolars or molars resulted in postoperative altered sensation. In addition, the frequency of neurosensory disturbances was notably higher in second premolars (22.6%) compared to the other tooth groups (11.2 to 13.0%). It is further noteworthy that skin sensitivity returned to normal in all cases with altered sensation. However, due to the retrospective nature of this analysis, the results must be interpreted with caution.

Disclosures
Conflict of interest: The authors deny any conflict of interest.
Ethics Committee Approval: The study was approved by the institutional review board (Ethics Commission of Canton Bern, Switzerland, KEK approval number 2016-01711). Cases had been evaluated and treated according to the declaration of Helsinki (www.wma.net) with written consent of all patients.
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