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The surgical anatomy of the inferior alveolar nerve: a meta-analysis with clinical implications

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Background: *The main goal of the present meta-analysis was to provide physicians, especially surgeons, with crucial data on the complete anatomy of the inferior alveolar nerve (IAN). It is hoped that our results will help reduce the complication rates in procedures associated with this anatomical entity.*

Materials and methods: *Major online medical databases such as PubMed, Embase, Scopus, Web of Science, Google Scholar, and Cochrane Library were searched to gather all studies on IAN anatomy, including topography, morphology, and variations.*

Results: *The mean thickness of the IAN in the mandibular angle area was found to be 2.32 mm (LL: 1.82 ; HL: 2.78). The mean thickness of the IAN in the mandibular body region was found to be 2.49 mm (LL: 2.02 ; HL: 2.98). The mean thickness of the IAN in the mental region was established at 1.70 mm (LL: 1.54; HL: 1.86). The mean distance from the IAN to the external (buccal) surface of the first molar was found to be 4.99 mm (LL: 3.84; HL: 6.13).*

Conclusions: *In conclusion, this is currently the most up-to-date and thorough analysis of the complete anatomy of the IAN. We have provided morphometric data that present the spatial relationship of the IAN with numerous anatomical landmarks in the mandibular region. These include the ramus of the mandible, the first, second, and third molars, and the body of the mandible, among others. It is hoped that the results of the present meta-analysis will be a helpful tool for physicians, especially surgeons, performing various oral and maxillofacial procedures, such as third molar removal or IAN block anaesthesia.* (Folia Morphol 2024; 83, 3: 509–516)

Keywords: anatomy, alveolar nerve, inferior, mandible, mandibular nerve, surgery, oral

INTRODUCTION

The inferior alveolar nerve (IAN) is a branch of the mandibular division of the trigeminal nerve and enters the mandibular foramen, subsequently passing through the mandibular canal. Before entering the said foramen, it gives off a motor branch to the mylohyoid muscle. Along its course, it forms the inferior dental plexus, which sends branches to all mandibular teeth on its side. Another branch of the dental plexus, the mental nerve, passes through the mental foramen and supplies the skin and mucous membrane of the lower lip, the skin of the chin, and

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the vestibular gingiva of the mandibular incisor teeth. Furthermore, the section of the nerve in front of the mental foramen and just before its ramification to the incisive nerve has been defined as the anterior loop of the IAN. The IAN transmits pain signals from mandibular teeth, gingiva of the mandible, and the lower lip [43].

The "norm" in anatomy is not as precise a concept as one would wish, and can be considered an approximation [39, 44]. Anatomical variations are frequently observed by medical professionals of many distinct specialties worldwide and oftentimes influence the daily clinical practice in the form of treatment options [22, 29–31, 33, 34, 39]. The anatomy of the IAN is highly variable, and numerous studies have analysed this anatomical entity. As mentioned above, the IAN runs through the mandibular canal [35]. However, studies in the past have shown that the said nerve may run in accessory mandibular canals [17], which can increase the risk of damaging this anatomical entity. The relationship of the IAN to other anatomical landmarks has also been thoroughly discussed in the past. These include the body and ramus of the mandible, and the molars, among others [26]. Knowledge about the location and morphology of the anterior loop of the IAN is of utmost importance due to its significance in implant installation procedures. Surgeries involving the anterior mandible, such as implant placement or bone graft fixing, may violate the anterior loop of the IAN, resulting in neurosensory disturbances in the area of the lower lip and chin. Although the only named branch of the IAN before it enters the mandibular foramen is the mylohyoid nerve, some studies have reported the occurrence of a variable recurrent branch of the IAN. Buch et al. reported an occurrence rate of 44.4%, making it a relatively frequent variation [8]. This variant branch may also be the cause of failure of conventional IAN block anaesthesia and peripheral neurectomy used for the treatment of trigeminal neuralgia.

Having adequate knowledge about the anatomy of the IAN is undoubtedly of great importance when performing surgical procedures involving the mandible. Variations in the course and morphology of the said nerve could increase the risk of possible complications that may occur during these surgeries. Therefore, the main objective of the present meta-analysis was to provide physicians, especially surgeons, with crucial data concerning the complete anatomy of the IAN. It is hoped that our results may help reduce the rates of complications in procedures associated with this anatomical entity.

MATERIALS AND METHODS

Search strategy

Major online medical databases such as PubMed, Embase, Scopus, Web of Science, Google Scholar, and Cochrane Library were searched to gather all studies on IAN anatomy, including topography, morphology, and variations. The following search terms were used: (alveolar nerve) AND (anatomy). Subsequently, another search was performed with the following search terms: (1) {[alveolar nerve (Title/Abstract)] AND [morphometry (Title/Abstract)]}; (2) {[alveolar nerve (Title/Abstract)] AND [morphology (Title/Abstract)]}; (3) {[alveolar nerve (Title/ /Abstract)] AND [topography (Title/Abstract)]}; (4) {[alveolar nerve (Title/Abstract)] AND [variation (Title/Abstract)]}. The search terms for each database were adjusted to maximise the number of studies found. No date, language, article type, and/or text availability conditions were applied. An additional search was conducted through the references of the identified studies at the end of the search stage to ensure the precision of the process. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed during the study. The Critical Appraisal Tool for Anatomical Meta-Analysis (CATAM) was also used to provide the highest-quality findings [11].

Eligibility assessment

After the search of the databases and an additional manual search through the references, a total of 6377 studies were identified and reviewed by 2 independent reviewers. After removing duplicates and irrelevant records, a total of 128 articles were qualified for full-text evaluation. Papers such as case reports, case series, conference reports, reviews, letters to editors, and studies that provided incomplete or irrelevant data were excluded to minimise potential bias and maintain an accurate statistical methodology. The inclusion criteria involved original studies, both cadaveric and based on radiological imaging, with extractable numerical data on the general anatomy of the IAN. The results obtained on the cadavers did not differ statistically significantly from those obtained by magnetic resonance imaging ($p > 0.05$); therefore, an overall analysis could have been performed. A total of 107 articles were excluded from the study because they were case reports or case series (n = = 14) or because they did not have relevant and/or sufficient data regarding the anatomical parameters of the IAN (n = 93). Finally, a total of 21 studies were included in this meta-analysis [1, 2, 4–6, 8, 9, 13, 17–21, 23–27, 36, 41, 42]. The AQUA tool, which was specifically designed for anatomical meta-analyses, was used to minimise the potential bias of included studies [14]. The data collection process is shown in Figure 1. The characteristics of the submitted studies can be found in Table 1.

Data extraction

Two independent reviewers performed the extraction. Qualitative data, such as year of publication, country, and continent, were gathered. Quantitative data, such as sample size, and numerical data regarding the anatomical aspects of the IAN in specific groups were gathered. Any discrepancies between the studies identified by the 2 reviewers were resolved by contacting the authors of the original studies whenever possible or by consensus with a third reviewer.

Statistical analysis

To perform this meta-analysis, STATISTICA version 13.1 software (StatSoft Inc., Tulsa, OK, USA), MetaXL version 5.3 software (EpiGear International Pty Ltd, Wilston, Queensland, Australia), and Comprehensive Meta-analysis version 4.0 software (Biostat Inc., Englewood, NJ, USA) were applied. A random effects model was used. The chi-square test and the I-squared statistic were chosen to assess the heterogeneity among the studies [7, 15, 16]. A p-value and confidence intervals were used to determine the statistical significance between studies. A p-value lower than 0.05 was considered statistically significant. In the event of overlaps of confidence intervals, differences were considered statistically insignificant. The I-square statistics were interpreted as follows: values of 0–40% were considered "may not be important", values of 30–60% were considered "may indicate moderate heterogeneity", values of 50–90% were considered "may indicate substantial heterogeneity", and values of 75–100% were considered "may indicate substantial heterogeneity". The results obtained on the cadavers did not differ statistically significantly from those obtained by magnetic resonance imaging ($p > 0.05$); therefore, an overall analysis could have been performed.

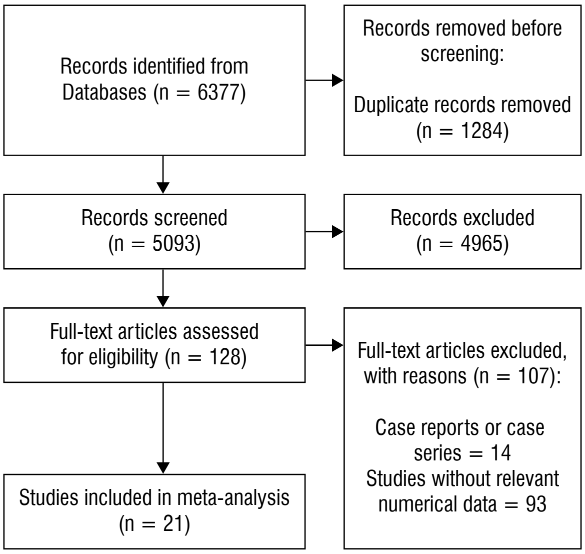

Figure 1. Flow diagram presenting the process of collecting data included in this meta-analysis.

Table 1. Characteristics of the studies included in this meta--analysis.

First Author	Year	Continent	Country	Number of studied nerves
Al-Haj Husain A.	2021	Europe	Switzerland	19
Burian E.	2020	Europe	Germany	8
Yeh A.	2018	Europe	France	230
Moghddam M.R.	2017	Asia	Iran	452
Agbaje J O.	2016	Europe	Belgium	6
Juan D.V.L.	2016	North America	Mexico	55
Lee J.H.	2016	Asia	South Korea	196
Li X.	2013	Asia	China	136
Buch H.A.	2012	Asia	India	12
Apostolakis D.	2011	Europe	Greece	93
Hur Mi-Sun	2011	Asia	South Korea	17
Yoshioka I.	2010	Asia	Japan	60
Liu. T.	2009	Asia	China	386
Levine M.H.	2007	North America	USA	100
Hwang K.	2005	Asia	South Korea	80
Bell G.W.	2004	Europe	United Kingdom	35
Kieser J.A.	2004	Oceania	New Zealand	39
Anil A.	2003	Europe	Turkey	20
Roy T.S.	2002	Asia	India	80
Kane A.A.	2000	Asia	Taiwan	20
Heasman P.A.	1988	Europe	United Kingdom	96

Table 2. Statistical results of this meta-analysis regarding the thickness and maximal diameter of the inferior alveolar nerve (IAN).

Category	Mean	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value
IAN thickness in the mandibular angle area [mm]	2.32	0.24	0.06	1.82	2.78	9.39	0.00
IAN thickness in the mandibular body region [mm]	2.49	0.24	0.06	2.02	2.98	10.21	0.00
IAN thickness in the mental region [mm]	1.70	0.08	0.01	1.54	1.86	20.82	0.00
Mean maximal diameter expansion of IAN in the axial plane at the level of the third molar tooth	4.07	0.23	0.05	3.61	4.52	17.61	0.00
Mean maximal diameter expansion of IAN in the sagittal plane at the level of the third molar tooth	3.34	0.27	0.07	2.82	3.87	12.54	0.00
Mean maximal diameter expansion of IAN in the coronary plane at the level of the third molar tooth	5.42	0.14	0.02	5.13	5.70	37.38	0.00

Table 3. Statistical results of this meta-analysis regarding the topographical location of the inferior alveolar nerve (IAN).

Category	Mean	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value
Distance from IAN to the external (buccal) surface of the forst molar [mm]	4.99	0.58	0.34	3.84	6.13	8.55	0.00
Distance from IAN to the external (buccal) surface of the second molar [mm]	6.23	0.73	0.53	4.81	7.65	8.59	0.00
Distance from IAN to the external (buccal) surface of the third molar [mm]	3.54	0.11	0.01	3.32	3.76	31.17	0.00
Distance from IAN to the internal lingual surface of the first molar [mm]	2.80	0.11	0.01	2.58	3.02	25.04	0.00
Distance from IAN to the internal lingual surface of the second molar [mm]	2.40	0.10	0.01	2.20	2.60	23.85	0.00
Distance from IAN to the superior alveolar border of the first molar [mm]	18.10	0.70	0.49	16.73	19.47	25.86	0.00
Distance from IAN to the superior alveolar border of the second molar [mm]	16.32	0.43	0.18	15.48	17.15	38.17	0.00
Distance from IAN to the superior alveolar border of the third molar [mm]	12.07	0.10	0.01	11.87	12.27	116.24	0.00
Distance from IAN to the inferior alveolar border of the forst molar [mm]	7.90	0.39	0.15	7.14	8.67	20.35	0.00
Distance from IAN to the inferior alveolar border of the second molar [mm]	8.25	0.85	0.71	6.60	9.91	9.76	0.00
Distance from IAN to the inferior alveolar border of the third molar [mm]	9.64	0.64	0.42	8.38	10.90	14.95	0.00
Distance from IAN to the anterior border of ramus [mm]	11.61	0.36	0.13	10.90	12.30	32.42	0.00
Distance from IAN to the posterior border of ramus [mm]	12.09	0.51	0.26	11.09	13.11	23.53	0.00
Distance from IAN to the medial surface of ramus [mm]	1.81	0.11	0.01	1.58	2.02	16.10	0.00
Distance from IAN to the lateral surface of ramus [mm]	4.71	0.22	0.05	4.26	5.14	21.02	0.00

RESULTS

The mean thickness of the IAN in the mandibular angle area was found to be 2.32 mm (LL: 1.82; HL: 2.78). The mean thickness of the IAN in the mandibular body region was found to be 2.49 mm (LL: 2.02; HL: 2.98). The mean thickness of the IAN in the mental region was established at 1.70 mm (LL: 1.54; HL: 1.86). The results mentioned above and more detailed results regarding the thickness and maximal diameter of the IAN can be found in Table 2. The mean distance from the IAN to the external (buccal) surface of the first molar was found to be 4.99 mm (LL: 3.84; HL: 6.13). Detailed results on the topography of the IAN can be found in Table 3. The IAN was found to run in the superior part of the mandible body in 32.27% [95% confidence interval (CI): 22.32–43.07%] of cases. Detailed results on the location of the IAN in the body of the mandible can be found in Table 4. The prevalence of the anterior loop of th eIAN was established at 77.45% (95% CI: 27.36–100.00%). Detailed results on the prevalence and length of the anterior loop of the inferior IAN can be found in Table 5.

DISCUSSION

The anatomy of the IAN is highly variable, and numerous studies have analysed this anatomical entity. Being aware of the spatial relations of the IAN with the surrounding anatomical landmarks may help physicians locate this vital nerve and therefore decrease the risk of injuring it [22, 32, 33] (Fig. 2). The IAN is said to run through the mandibular canal. However,

Table 4. Statistical results of this meta-analysis regarding the location of the inferior alveolar nerve (IAN) in the body of the mandible.

Category	Pooled prevalence	LCI	HCI	Q	I^2
IAN in the superior part of the body of the mandible	32.27%	22.32%	43.07%	0.06	0.00
IAN in the inferior part of the body of the mandible	67.73%	56.93%	77.68%	0.06	0.00

HCI — higher confidence interval; LCI — lower confidence interval; Q — Cochran's Q.

Table 5. Statistical results of this meta-analysis regarding the prevalence and length of the anterior loop of the inferior alveolar nerve (IAN) and the number of mandibular canals found near IAN.

Category			Pooled prevalence	LCI	HCI	Q	I^2
Prevalence of the anterior loop of IAN			77.45%	27.36%	100.00%	404.25	99.26
IAN runs in the only mandibular canal			69.52%	51.86%	84.77%	0.45	0.00
IAN runs in accessory mandibular canals			30.61%	15.33%	48.28%	0.01	0.00
Category	**Mean**	**Standard error**	**Variance**	**Lower limit**	**Upper limit**	**Z-value**	**P-value**
Mean length of the anterior loop of IAN [mm]	2.11	0.14	0.02	1.83	2.39	14.63	0.00
Mean angle of the anterior loop of IAN [deg]	16.66	3.73	13.94	9.34	23.97	4.46	0.00

HCI — higher confidence interval; LCI — lower confidence interval; Q — Cochran's Q.

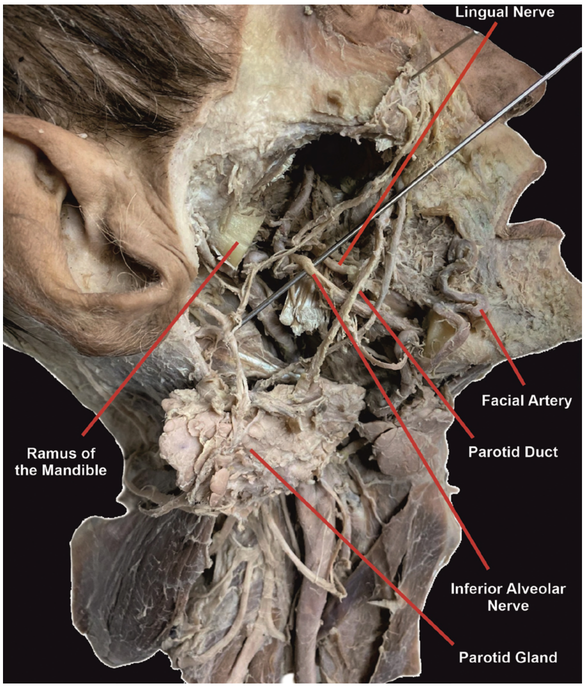

Figure 2. Photograph of a cadaver with an inferior alveolar nerve and its close anatomical area dissected. The parotid gland (preserved) was reflected, and part of the mandible was removed to expose the inferior alveolar nerve.

previous studies have reported instances where the said nerve passes through an accessory canal [17]. In the past, the prevalence of a bifid or accessory canal has been reported to be less than 1.00% [12, 40]. However, due to advancements in imaging modalities, it is now possible to analyse minute anatomical variations, which may have great clinical significance. In a more recent study by Hur et al. [17], the presence of accessory or bifid mandibular canals was found to be 30.00%, which is much higher than what was thought in the past. In a systematic review and meta-analysis of mandibular canal variations, Shan et al. found that the incidence of an accessory or bifid mandibular canal was 38.00% [37]. In the present study, we found that the IAN may give off branches that course through accessory or bifid mandibular canals in 30.61% of cases. This variation should be kept in mind when performing implant surgical procedures in the mandibular region.

The location of the IAN with respect to other anatomical landmarks has also been widely discussed, due to its importance in numerous maxillofacial procedures. The relationship of the IAN to the body and the ramus of the mandible is a topic that has been studied in the past. The results of the present meta-analysis show that the IAN is found more frequently in the inferior part of the mandible (67.72%) than in the superior part (32.27%). Furthermore, we calculated the distances from the IAN to the anterior and posterior border of the ramus of the mandible to be 11.61 mm and 12.09 mm, respectively. Furthermore, the distances from the IAN to the medial and lateral surfaces of the ramus of the mandible were found to be 1.81 mm and 4.71 mm, respectively. These data may be useful for physicians dealing with mandible ramus fractures or when performing split ramus osteotomy in cases of deeply impacted third molars of the mandible. Moreover, the complete anatomy of the anterior loop of the IAN was analysed. The present study demonstrates that the pooled prevalence of the anterior loop of the IAN was 77.45%, with a mean length of 2.11 mm.

Third molar surgery is the most frequently performed ambulatory procedure by oral and maxillofacial surgeons [38]. Possible postoperative complications associated with third molar surgeries include alveolitis, infection, and IAN injury, among others. Injury to the IAN is one of the most problematic consequences of dental surgeries. The most common cause of injury to the said nerve has been reported to be mandibular third molar surgery, followed by local anaesthetic block injection and, lastly, implant placement procedures [3, 10]. Therefore, numerous anatomical studies have attempted to provide data about the morphometric relationships of the IAN and the structures of the molar region. Yeh et al. [41] provided thoroughly gathered data on the course of IAN in the mandibular molar region. In the study, the distance from the IAN to the inferior alveolar border of the first and second molars was 7.30 and 7.00 mm, respectively. Other studies have reported similar results, ranging from 7.30 to 7.77 mm [23, 26]. The distance to the third molar region has been reported to range from 8.99 mm to 10.28 mm. In the present meta-analysis, the distances from the IAN to the inferior alveolar border of the first, second, and third molars were reported as 7.90 mm, 8.25 mm, and 9.64 mm, respectively. Subsequently, the distances from the IAN to the superior alveolar border of the first, second, and third molars were found to be 18.10 mm, 16.32 mm, and 12.07 mm, respectively. These data can undoubtedly be of great use for physicians performing third molar surgeries and other procedures in the mandibular molar region.

The only major branch of the IAN is said to be the mylohyoid nerve, which originates from the said nerve just before it enters the mandibular canal. However, the branching pattern of the IAN is more variable than one might think. This variability was presented in a cadaver study conducted by Buch et al. [8]. In the study, the recurrent variant branch of the IAN was analysed. The said branch was found in 8 out of 18 cadavers (44.40%). However, it may be premature to comment on the frequency of this variant due to the small sample size. This variable branch was also presented in a case reported by Muraleedharan et al. [28], in which numerous variations in the branching pattern of the posterior division of the mandibular nerve were presented. In the case report, the variant recurrent branch emerged from the left IAN and supplied the lateral pterygoid muscle. This variation may be a potential source of referred and neuropathic pain. Furthermore, the failure of conventional IAN block anaesthesia and the peripheral neurectomy used for the treatment of trigeminal neuralgia may be due to the presence of this variant recurrent branch [8]. Unfortunately, due to inconsistent data provided in the literature, we were unable to statistically analyse the occurrence of variable branches of the IAN and the anatomy of the mylohyoid nerve.

The present study is not without limitations. It may be burdened with potential bias, because the accuracy of the data taken from various publications limits the results of this meta-analysis. Additionally, most of the evaluated studies come from Asia. Therefore, the overall results of this study can be burdened because they can reflect the anatomical features of Asian people rather than the global population. Several articles were not included in this meta-analysis due to the potential risk of biased results. Although not without limitations, our meta-analysis attempts to estimate pituitary morphology based on data from the literature that meet the requirements of evidence-based anatomy.

CONCLUSIONS

In conclusion, this is currently the most up-to-date and thorough analysis of the complete anatomy of the IAN. The results of the present meta-analysis show that IAN is found more frequently in the inferior part of the mandible (67.72%) than in the superior part (32.27%). Furthermore, in has been established that the distances from the IAN to the anterior and posterior border of the ramus of the mandible are 11.61 mm and 12.09 mm, respectively. Subsequently, the distances from the IAN to the medial and lateral surfaces of the ramus of the mandible were found to be 1.81 mm and 4.71 mm, respectively. It is hoped that the results of the present meta-analysis may be a helpful tool for physicians, especially surgeons, performing various oral and maxillofacial procedures, such as third molar removal or IAN block anaesthesia.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

The data presented in this study are available on request from the corresponding author.

Author contributions

All authors contributed equally to the process of the overall study creation.

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Conflict of interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/ /or publication of this article.

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