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Variation in Anatomy of the Anterior Nerve Loop Using Cone Beam Computed Tomography

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ABSTRACT

Background: The anterior loop (AL) of the inferior alveolar nerve (IAN) plays a crucial role in mandibular implant planning, as its location and length directly influence surgical outcomes and patient safety. Accurate identification of AL is vital to minimize iatrogenic injuries, such as paresthesia, and to optimize implant placement.

Objective: This study aims to assess the variation in the anatomy of the AL in mandibular arches using Cone Beam Computed Tomography (CBCT), and to explore its correlation with anatomical types and clinical significance.

Methods: A retrospective analysis was conducted using CBCT images to identify and measure the AL's presence, length, and anatomical variation across a sample population. The relationship between AL presence and mandibular nerve morphology was examined.

Results: Approximately two-thirds of the subjects did not exhibit the AL, while one-third demonstrated its presence. The AL was associated with a greater mean length and was primarily linked to the Type-3 Y-shape. The absence of AL was predominantly observed in the Type-1 Y-shape, with a lesser occurrence in Type-2 T-shape. Variations in AL length were attributed to genetic, environmental, and anatomical factors, suggesting the need for population-specific surgical guidelines.

Conclusion: CBCT provides superior 3D visualization for accurate AL identification, essential for preventing complications in mandibular implant surgeries. The findings underscore the importance of precise AL assessment in reducing the risks of nerve-related injuries, improving patient safety, and optimizing surgical outcomes.

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Keywords: *Anterior loop, CBCT, Mandibular nerve, Nerve loop, Surgical planning*

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1. INTRODUCTION

The mandibular canal, which contains the inferior alveolar nerve (IAN), is an important neurological structure that must be considered when planning for implant placement in mandible [1]. This canal runs through the mandible and terminates in mental foramen (MF), where it may undergo a bend, which is known as anterior loop (AL). This research explores the anatomy of AL and its occurrence as well as how it may affect dental implant operations [2]. Different types of AL, such as type 1 (uncertain Y-shaped), type 2 (unseen T-shaped), and type 3 (distinctive Y-shaped) patterns have been identified and can be associated with the safety and pre- planning of implant placement [3]. The inter-foraminal area of the mandible is frequently-considered for implant insertion, as it provides a remedy for edentulous arch. The position of the MF is especially important in establishing the most distal implant site, posterior spread and extension over the cantilever and to achieve adequate biomechanics for an implant-supported prosthesis [4].

However, iatrogenic injuries have been described related to the surgical encounter of the AL including anesthesia, paresthesia and pain during drilling near the region of the AL. These sensory disturbances are related to implant proximity to the MF. AL is present in 5.2–7% of people according to previous researches [5]. With the potential hazards to consider, a discussion about the precise relationship between AL presence and postoperative sensory disturbances continues. The accurate identification of the AL still poses significant difficulties, primarily due to the use of standard radiography, which is unable to provide detailed images of the AL [6]. On the other hand, imaging modalities have been improving and advanced techniques, such as Cone Beam Computed Tomography (CBCT), allow a more detailed analysis of the AL and three-dimensional images which lead to less radiation exposure from conventional CT scans [7].

In the present study, a fundamental understanding of prevalence, patterns and variations involved in AL using CBCT has been sought to be established for continued deliberation on safe implant placement. The results emphasize the importance of accurate preoperative planning and sound familiarity with anatomy in limiting sensory deficits and implant success at the inter-foraminal mandible. Knowledge of its span and variations among the AL are important to reduce potential risks in implant treatments, and also for the functional rehabilitation of completely edentulous patients.

2. AIMS AND OBJECTIVES

The aim of this study is to determine the variation in the anatomy of the AL of the mandibular nerve in the mandibular arches using CBCT, with objectives including observing the position of the AL in relation to the MF and measuring the length of the AL.

3. METHODOLOGY

Study design: This was an observational cross-sectional study, done with CBCT of the patients. For this study 40 subjects were selected. CBCT was made for all the subjects to observe the position of AL with respect to MF and the length of AL. Ethical clearance was obtained prior to the start of the study from the Institutional Ethical Committee.

Study sample: Microsoft Excel 2007 was used to enter data for this investigation, and SPSS statistical software version 23.0 was used for analysis. The mean, standard deviation, frequency, and percentage were among the descriptive statistics. For the current investigation, the significance level was set at 5%. The projected sample size was 40 based on the answer distribution of 57 percent, the 95 percent confidence interval, and the 15 percent allowed error.

Software used

The program G Power Version 3.1.9.6 was created by Franz Faul University.

Formula used

Source of participants

$$\text{Sample size} = \frac{Z^2 \times (p) \times (1-p)}{c^2}$$

Patients from the Department of Prosthodontics, Crown & Bridge OPD at Teerthanker Mahaveer Dental College and Research Centre were chosen based on decided factors. Medical and dental histories were documented. Participants were selected according to their inclusion and exclusion criteria.

The inclusion criteria consisted of participants who were willing to take part in the study and had no existing pathology in the targeted mandibular premolar region. Additionally, participants were thoroughly informed about the procedure, including its purpose, risks, and benefits, ensuring transparency. Informed consent and ethical clearance were obtained using standardized forms for procedural details. The exclusion criteria for this study included patients less than 25 years of age, those with a history of mandibular trauma, bony pathology, cysts, tumors, or developmental anomalies.

CBCT Imaging

CBCT images of the mandible of chosen subjects were taken. The CBCT software employed in the current study was New Tom Neuro Technology (NNT), a state-of-the- art imaging system designed by New Tom for CBCT scan processing and analysis. It is specifically tailored for 3D reconstruction, diagnosis, and treatment planning purposes to ensure high quality imaging with low radiation exposure.

This was obtained by using Adaptive Exposure Control (AEC) and Pulsed Emission Technology (PET) to optimize the tradeoff between picture quality and patient safety. This system operates at a tube current range of 1-16 mA with a voltage of 60-110 kVp as function of the metric requirements for the images CBCT. Proper procedures performed during the scans to achieve high resolution and low distortion images. In order to improve image resolution with minimal radiation exposure, the patient's field of view (FOV) was limited to the mandibular region for safety and reliability.

Visualization and Evaluation: The AL of the mental nerve was identified and analyzed using CBCT scans. The assessment included determining its presence or absence and evaluating its position relative to the MF. To measure the length of the Anterior Nerve Loop (ANL), a series of sequential coronal reconstructions were performed, extending from the anterior border of the loop to the anterior boundary of the MF on both right and the left sides of the mandible (Figure 1, 2, 3). The measurement process involved counting the number of slices required to cover the loop, with each slice having a thickness of 1 mm. The final length was calculated using the formula:

Length of AL = Number of Slices ×1 mm

Additionally, the spatial relationship between the AL and the MF was carefully documented to understand its anatomical variations.

Observed ANL were categorized as follows: (as per Solar et al. (1994) Classification of the AL)

Type I: (Figure no.1)

AL is invisible.

The shape appears Y-shaped.

AL is absent.

Mental branch of IAN exits trunk of alveolar nerve posterior to the MF

Type II : (Figure no. 2)

AL is lacking.

The shape is T-shaped.

Incisive arm extends perpendicularly to the central nerve trunk.

The mental branch enters the MF at ninety degrees.

Type III : (Figure no. 3)

AL is clear.

Shape is Y-shaped.

A distinct AL is present.

Class 1 and 2 were considered as absent loop. Class 3 was considered as loop present.

Figure 1: ANL tracing in Type -1 Y shape

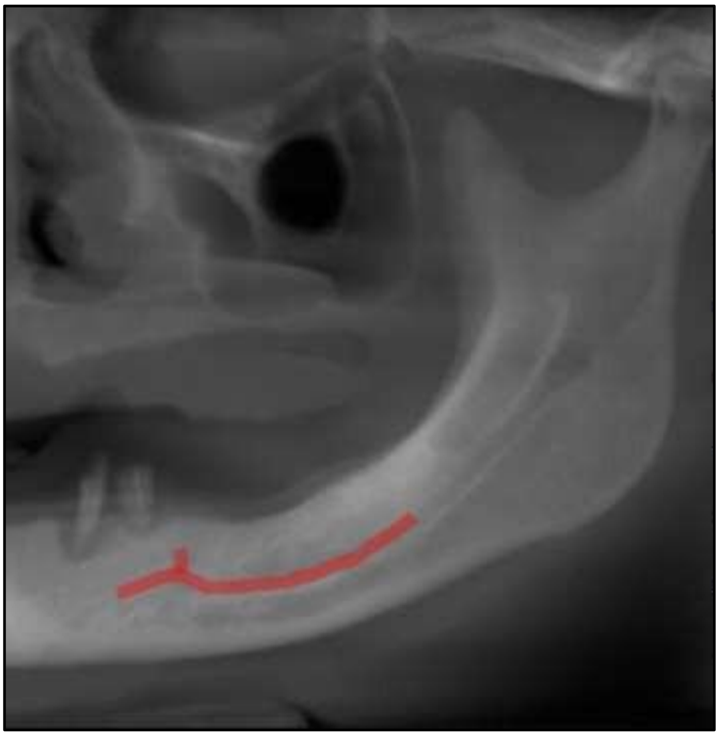


Figure 2: ANL tracing in Type -2 T shape

Figure 3: ANL tracing in Type -3 Y shape

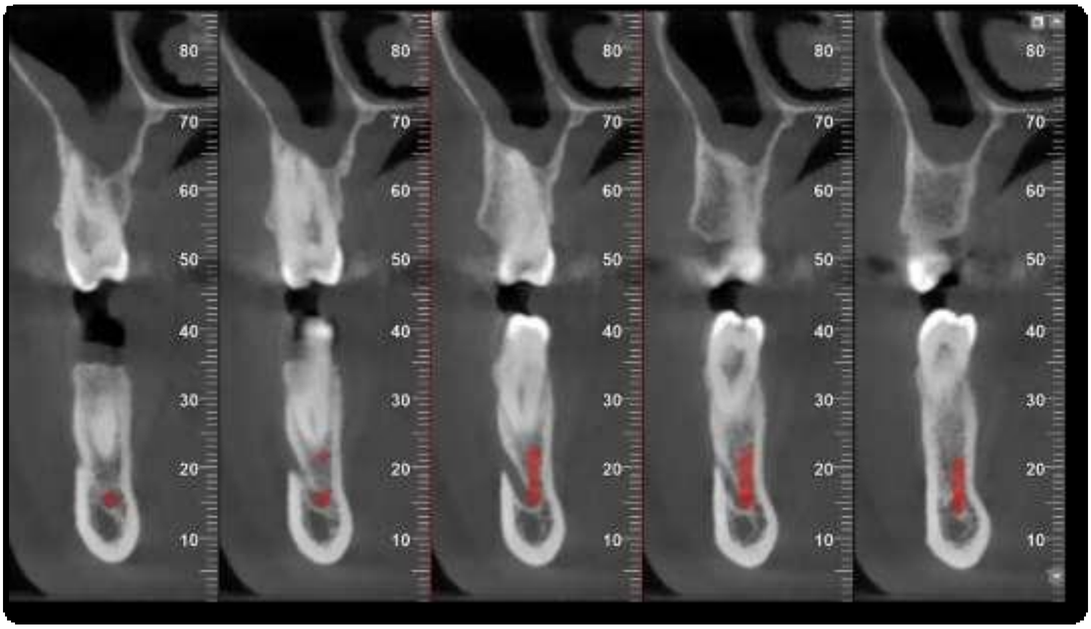


Figure 4: No. of slice ANL seen (right side)

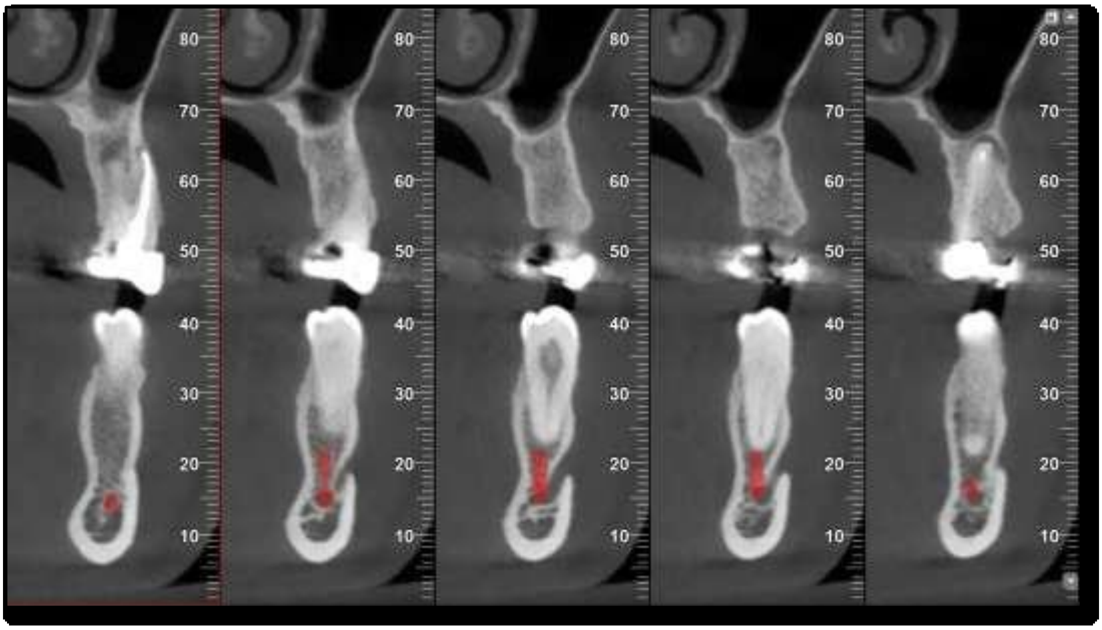


Figure 5: No. of slice ANL seen (left side)

Data Collection:

All records were taken good software specifically for CBCT image analysis, ensuring careful and trustworthy data collection. The data were thoroughly categorized on the occurrence of the AL, the span of loop, and its position in relation to the MF. This approach allowed for exact analysis of the anatomical variations observed in the CBCT images observed in the CBCT scans.

Statistical Analysis

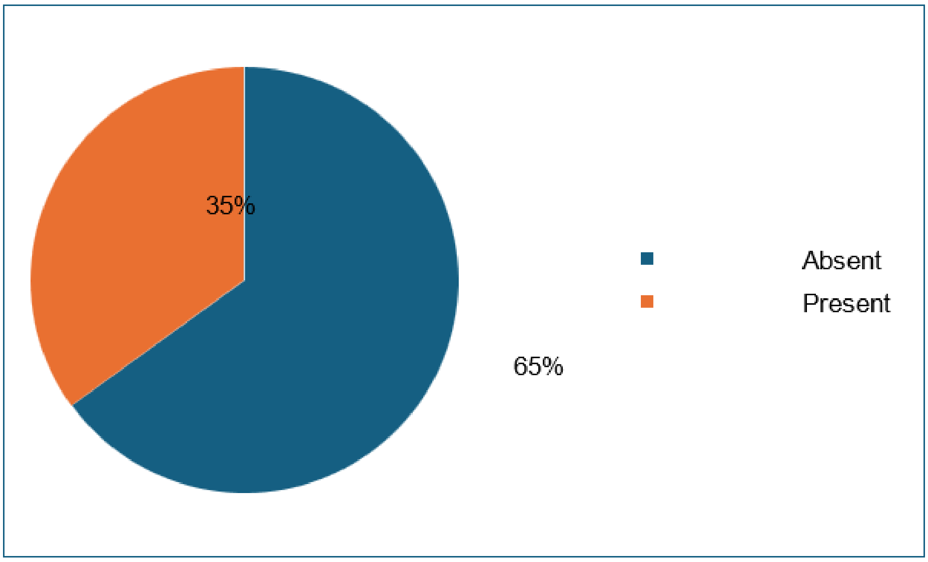
Microsoft Excel 2007 was used for data entry, and SPSS software version 23.0 was employed for statistical analysis. Descriptive statistics included frequency and percentage, along with mean and standard deviation. The level of significance for the current study was set at 5%.

4. RESULTS

Among the study subjects, the majority (65%) did not exhibit the presence of loops, with a total of 26 cases classified as absent. In contrast, 14 cases (35%) showed the presence of loops. This suggests that around two third of the subjects were not having the ANL, while only around one third proportion did exhibit nerve loops (table 1, pie chart 1).

Table 1: Intergroup comparison of presence or absence of loop among study subjects

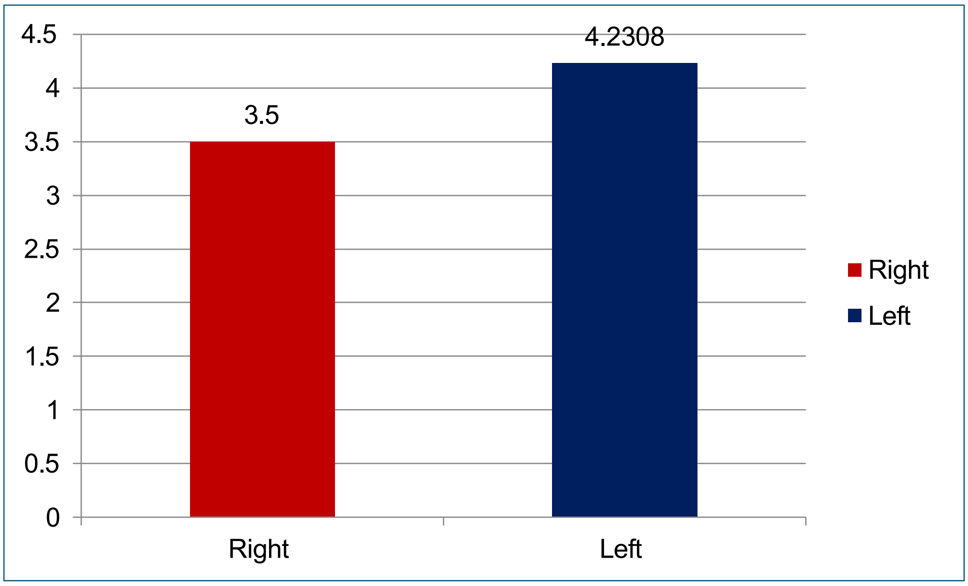
	Frequency	**Percentage**
Absent	26	65
Present	14	35.0



Pie chart 1: Loop present and absent

Table 2: Length of loop on right and left side			
	Mean	**Standard Deviation**	**Standard Error**
Right	3.5000	.84984	.26874
Left	4.2308	1.36344	.37815

Table 2 and graph 1 depicted the length of the loop on both sides. It indicated that in cases where the loop was absent, the mean length was 3.50 mm with a standard deviation of 0.84984 mm and a standard error of 0.26874 mm. In contrast, for cases where the loop was present, the mean length was 4.23 mm, with a higher standard deviation of 1.36344 mm and a standard error of 0.37815 mm. This suggests that the presence of the loop is associated with a greater mean length.

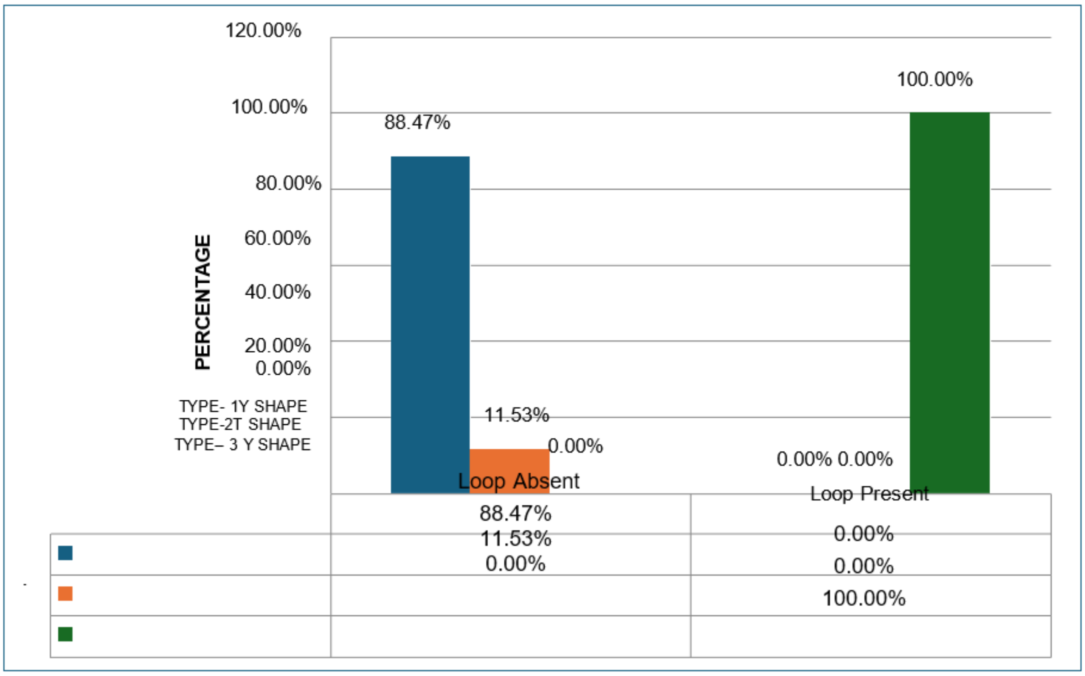


Graph 1: Loop length

Table 3: Position of AL with respect to MF

	Type -1 Y shape	Type- 2 T shape	Type -3 Y shape	P value	Significance
Loop absent	23	3	0	0.001	Significant
	88.47%	11.53%	0%		
Loop present	0	0	14		
	0%	0%	100%		

Table 3 and graph 2 showing the data as per various types of the loop. The position of the AL concerning the MF was categorized into three types: Type-1 Y shape, Type-2 T shape, and Type-3 Y shape. The data reveals a significant association (p = 0.001) between the presence of the loop and its classification. In the absence of the loop, Type-1 Y shape was present in the majority of cases (88.47%), Type-2 T shape was present in 11.53% of cases, and Type-3 Y shape was not present. On the other hand, all cases (100%) with the loop present were categorized as Type-3 Y shape; neither Type-1 nor Type-2 was found. These results show that the presence of AL is solely linked to with the Type-3 Y shape, whereas its absence is predominantly linked to the Type-1 Y shape and, to a lesser extent, the Type-2 T shape.



Graph 2: Data as per loop types

5. DISCUSSION

The ANL is a vital anatomical part of the mandibular nerve, specifically associated with the mental nerve. It represents the part where the mental nerve goes beyond the MF before looping to enter it. Located in the ventral mandible around the MF, the ANL varies in presence and length among individuals, making its identification crucial for surgical procedures. Some individuals may have a clearly defined ANL, while in others, it may be absent or difficult to detect.

Recognizing the ANL is essential during dental implant placement, bone grafting, and other surgical procedures in the anterior mandible, as improper identification may lead to nerve injury, resulting in temporary or permanent complications. The mental nerve, which contributes to the ANL, provides sensation to the lower lip, chin, and anterior gingiva. Any damage during surgery can cause paresthesia (numbness or tingling), dysesthesia (pain or discomfort), or complete loss of sensation, affecting speech, facial expression, and overall quality of life.

Precise localization of the ANL is necessary to prevent nerve compression and ensure optimal implant stability. If the nerve loop extends far anteriorly, placing implants too close to the MF can increase the risk of complications. Accurate mapping allows for proper implant positioning, minimizing post-operative issues such as persistent pain or discomfort. The use of CBCT has become essential in pre-surgical assessment due to its high-resolution, three-dimensional imaging for precise ANL visualization, which traditional two-dimensional radiographs often fail to achieve.

Given the variability in ANL's presence, length, and trajectory among individuals, studying its anatomy using CBCT is crucial for improving treatment planning, patient safety, and surgical outcomes. Understanding these anatomical differences helps to adjust implant depth and angulation, design flaps appropriately, and enhance overall surgical safety.

To minimize these consequences, a study by Debbarma H et al. (2025) [8] have tried to reposition teeth using orthodontics toward a neighboring atrophic edentulous alveolar ridge, effectively closing the gap and eliminating the necessity for implant placement [9].

This study provides significant insights into the presence, characteristics, and anatomical variations of loops among study subjects. The findings indicate that 65% of participants did not exhibit loops, while 35% had them, suggesting that while the majority remain unaffected, a notable proportion do exhibit loops, which may have clinical relevance. Anatomical differences or genetic predispositions could influence the variation in loop presence. This finding was consistent with the findings of Kheir MK et al. (2017) [10]

In terms of loop dimensions, a distinct disparity was observed in their length on both sides. The mean length of loops on the right was recorded at 3.50 mm, whereas on the opposite side, it was significantly higher at 4.23 mm. This suggests that when loops are present, they tend to be longer on the left side than on the right, indicating potential asymmetry in anatomical formations. The higher standard deviation and standard error values on the left side further support this observation, suggesting greater variability in AL length. The differences may be attributed to anatomical variability in the region of the MF [11].

A significant association ($p = 0.001$) was found between the failure of absence of an AL and its shape concerning the MF. In cases where the loop was absent, the most common shape was Type-1 Y shape (88.47%), followed by Type-2 T shape (11.53%), with no occurrence of Type-3 Y shape. However, in all cases where loops were present, 100% exhibited Type-3 Y shape. This suggests that the presence of an AL is exclusively linked to this specific shape, whereas its absence is associated with other morphological variations. These findings have crucial clinical implications, particularly in surgical procedures involving the MF, where variations in loop morphology must be carefully considered to minimize the risk of nerve damage. This finding was consistent with the findings of Balagopal PG et al (2012) [12]

Given the complex anatomical structure of AL, accurate visualization and measurement are essential. CBCT serves as an effective diagnostic modality, offering a three-dimensional assessment free from distortion, magnification errors, or blurriness, which are common limitations of panoramic radiography. Since the AL contains the mental and incisive nerves, surgical planning in the inter-foraminal region must be performed with caution to prevent nerve injury, which can lead to complications such as sensory disturbances or neuropathic pain [13].

Research on the occurrence of AL in different populations has reported varying results. Research on an Iranian population found AL in 32.8% of 180 radiographic projections. In Malaysia, a study identified AL in 34.4% of OPG [14]. Among the Indian population, Type III AL was observed in 50% of participants. A Belgian study estimated AL commonness between 22% and 28% [15], while research in Brazil reported its presence in 41.6% of the study group [16].

In the present study, the longest observed AL measured 7.5 mm. Additionally, research by Prakash O et al. reported mean AL lengths of 2.77 mm [16]. While Wong et al.'s study on the Malaysian population found mean AL lengths of 3.85 mm on one side and 3.69 mm on the other. These variations highlight the potential influence of genetic and environmental factors on AL morphology [17, 18].

The examination identified a higher chance of the AL in males in contrast to females. This suggests that anatomical variations may be influenced by biological factors. An age-related decline in AL visibility was also noted, with its prevalence decreasing as age increased. Similar trends were reported by Shao X et al. [19], who found that the AL was more usually present in young. The underlying mechanisms for this decline may involve age-related bone remodeling, resorption, or changes in neural structures. However, conflicting evidence from Fanhg H et al [20] suggests no significant correlation between age, gender, and AL lengths. These discrepancies highlight the need for further research to determine the precise influence of demographic factors on AL morphology.

Clinical implications

Anatomical variation in ANL has a major impact on treatment planning for dental implant placement. Symptoms like altered sensation or their absence in the areas supplied by the nerve are examples of neurosensory damage that can arise from improper implant placement close to the nerve loop. The nerve loop should be precisely identified with 3D imaging, which aids clinicians in choosing the safest implant placement zone while maximizing both functional and cosmetic results. Dentists can increase patient safety, reduce surgical risks, and increase implant success rates by incorporating CBCT evaluations into preoperative planning.

6. LIMITATIONS

Despite its valuable findings, the paper has certain drawbacks. The sample size may not depict the generality of the population, necessitating larger studies for more robust conclusions. Additionally, while CBCT provides superior imaging, variations in image interpretation and measurement techniques could introduce minor inconsistencies. The study primarily focused on anatomical observations without exploring potential functional implications of AL. Future research should aim to incorporate larger populations, longitudinal assessments, and histological analyses to further elucidate the clinical significance of these findings.

7. FUTURE SCOPE

Increasing the sample size in future studies will enhance the reliability and accuracy of the results by reducing variability and improving statistical significance. A larger sample size allows for a better representation of the population, minimizing potential biases and increasing the generalizability of the findings. This is particularly important in studies involving anatomical measurements, where precision is crucial for clinical applications.

The IANL tool should be introduced in CBCT for measuring its ANL to avoid minor inconsistencies. CBCT provides high-resolution, three-dimensional imaging that enables accurate visualization of anatomical structures. The use of an IANL tool in CBCT imaging ensures precise and standardized measurement of ANL, reducing errors associated with manual or subjective estimation. This is particularly beneficial in implant planning, nerve injury prevention, and maxillofacial surgeries, where detailed knowledge of nerve positioning is essential. By implementing the IANL tool in CBCT analysis, researchers and clinicians can improve diagnostic accuracy, enhance treatment planning, and ensure better patient outcomes [21].

The integration of the metaverse and AI can further enhance the precision and efficiency of anatomical studies by creating virtual environments for simulating and analyzing IANL measurements in real-time [22]. AI algorithms can process large datasets from CBCT scans, while the metaverse allows for immersive, interactive visualizations of anatomical structures, enabling clinicians to practice and refine surgical techniques in a risk-free, virtual setting [23,24]. This can improve diagnostic accuracy, reduce human error, and ultimately enhance patient outcomes in clinical practice.

8. CONCLUSION

CBCT is essential for accurate identification and measurement of the AL, offering superior 3D visualization. Around two-thirds of the subjects did not have the AL, while only about one-third exhibited the nerve loop. The presence of the loop is associated with a greater mean length. When the AL is present, it is exclusively linked to the Type-3 Y shape, while its absence is primarily associated with the Type-1 Y shape and, to a lesser extent, the Type-2 T shape. Differences in AL length suggest genetic, environmental, and anatomical influences, which necessitate population-specific surgical guidelines. Precise AL identification is crucial for dental implants, nerve repositioning, and surgeries, reducing risks such as paresthesia and enhancing patient safety and outcomes

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