Inferior Alveolar Nerve Transposition for Placement of Dental Implants - A Narrative Review

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Abstract

AIM: This article is a narrative review of inferior alveolar nerve transposition for the placement of dental implants in severely atrophied mandibles.

METHODS: Clinical reports on dental implants from leading scientific journals and comprehensive searches in PUBMED, QUINTESSENZ, and MEDLINE served as the basis for this review, which includes 190 sources from the literature. The relevant topics presented included nerve anatomy, arterial blood supply, innervations of the mandible, mandibular bone atrophy, factors influencing mandibular bone loss, nerve injury, and evaluation of inferior alveolar nerve disturbance. Methods to avoid inferior alveolar nerve injury were discussed, in conjunction with inferior alveolar nerve transposition for implant placement and various surgical techniques.

RESULTS: Inferior alveolar nerve repositioning should be performed by a skilled surgeon. Proper diagnosis and presurgery planning are essential to avoid nerve sensory disturbances. This technique can provide the additional bone required for an optimal implant anchorage while reducing the risk of nerve damage. Regeneration of a nerve injury is evidenced by the spontaneous return of normal sensation, depending on the severity of the injury and the nerve involved. Recovery should be monitored using sensory tests to determine the need for micro-reconstructive surgery, with continued monitoring indicated post-surgery.

CONCLUSION: Inferior alveolar nerve transposition can be safely and predictably performed with a lower risk to mental nerve sensibility.

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1 Introduction

The first case of inferior alveolar nerve repositioning was published by Alling (1977) in the context of prosthetic rehabilitation in patients with severe atrophy and the emergence of the nerve close to the alveolar crest. The first case of repositioning concerning osseointegrated implant placement was described by Jensen and Nock (1987), with the normalization of sensory function occurring five weeks after surgery. Jensen et al. were the first to introduce guidelines regarding the presence of bone above the canal of the inferior alveolar nerve.

The goal of this procedure is to relocate the inferior alveolar nerve buccally to permit the insertion of longer implants that can achieve anchorage in the basal cortical bone of the inferior mandibular border. However, there is a risk of nerve injury due to primary surgical trauma, which includes temporary or permanent loss of sensation resulting from inferior alveolar nerve injury. The complications may include slight hypoesthesia (reduced feeling), paresthesia (numb feeling), hyperesthesia (burning sensation), or dysesthesia (painful sensation), and in serious cases, complete and permanent anaesthesia (Spiekermann, 1995).

Other terms used to describe nerve injuries include neuropraxia, where there is no loss of continuity of the nerve, although it may be stretched or exposed to blunt trauma. In this situation, the paresthesia will subside and sensation will return within days to weeks. Axonotmesis, where the nerve is damaged but not severed, typically allows for feeling to return within two to six months. Neurotmesis, which involves a severed nerve, has a poor prognosis for the resolution of paresthesia. The prevalence of sensory alterations varies due to multiple factors, such as the location of osteotomy and the manner of surgery (Greenstein & Tarnow, 2006).

Inferior alveolar nerve transposition is a complex procedure with a high risk of sensory changes; however, it can be performed safely with a low risk of mental nerve injury. Each patient should be informed about the possibility of a permanent nerve defect, and alternative techniques should also be considered. Careful nerve manipulation and mobilisation are required to reduce this complication.

2 Methods

Clinical reports on dental implants found in leading scientific journals and thorough searches in PUBMED, MEDLINE and Google Scholar have served as the basis for this review. A total of 190 literature sources were reviewed. The topics presented include nerve anatomy, arterial blood supply, and innervations of the mandible; mandibular bone atrophy; factors influencing mandibular bone loss; and nerve injury. The evaluation of inferior alveolar nerve disturbances was undertaken. Methods to avoid inferior alveolar nerve injury were discussed. Additionally, inferior alveolar nerve transposition for implant placement and various surgical techniques were reviewed. The use of piezosurgery in dental implantology was also addressed.

The following PUBMED search strategy was used: ("Nerve Anatomy" OR "Arterial Blood Supply" OR "Mandible" OR "Mandibular Bone Atrophy" OR "Bone Loss" OR "Nerve Injury" OR "Inferior Alveolar Nerve" OR "Nerve Disturbances") AND ("Surgical Techniques" OR "Prevention" OR "Nerve Transposition" OR "Piezosurgery" OR "Dental Implantology"). The results were filtered by articles of the last 10 years, English language, Humans, Adult: 19+ years and preprints excluded.

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analytic techniques were not deemed suitable for the analytical framework.

3 Results

3.1 Nerve anatomy

The head and neck region possesses an abundant blood supply, characterized by numerous anastomoses. The vascular supply to both the mandible and maxilla is derived from the external carotid artery, which branches from the common carotid artery. The primary artery supplying the mandible is the inferior alveolar artery (IAA), which acts as a nutrient artery to the bone and other tissues within the lower jaw. It enters the medial aspect of the mandibular ramus and proceeds downward and forward within the mandibular canal to reach the body of the mandible. This artery branches in the premolar region to give rise to the mental and incisive arteries. The incisive artery continues medially within the mandibular body to anastomose with the artery from the contralateral side. The mental artery exits the body of the mandible through the mental foramen and supplies the region of the chin, while also anastomosing with the submental and inferior labial arteries. Therefore, lateral repositioning of the inferior alveolar artery may be necessary prior to implant insertion in certain cases to avoid compromising the blood supply to the bone in this region (Misch, 2008).

The inferior alveolar nerve (IAN) is a branch of the mandibular nerve (V3), the third division of the trigeminal nerve (cranial nerve V). It travels through the mandibular canal alongside the inferior alveolar artery (IAA) and its accompanying vein. The nerve is joined by dental, interdental, and interradicular branches from the mandibular posterior teeth, forming a dental plexus. In rare cases, two inferior alveolar nerves may be present on the same side, resulting in bifid inferior alveolar nerves. This phenomenon can occur unilaterally or bilaterally and may appear on a radiograph as a double mandibular canal, indicating the presence of more than one mandibular foramen. This variation should be considered when administering local anesthesia to the mandibular arch (Fehrenbach et al., 1996). As it courses through the canal, the IAN gives off several branches to the teeth, before producing the mental branch, which exits through the mental foramen (Misch, 2008). In the molar region, the IAN typically divides into the mental and incisive nerves (Bovi et al., 2010). The mental nerve is one of the two terminal branches of the IAN and emerges from the mental foramen in conjunction with blood vessels. It innervates the skin of the mental region, lower lip, mucous membranes, and the gingival surface from the corner of the mouth to the midline, extending as far posteriorly as the second premolar (Greenstein et al., 2006; Mraiwa et al., 2003). Additionally, the mental nerve may provide innervation to tissues adjacent to the canine and incisor regions (Pogrel et al., 1997). The shape of the mental foramen is typically round or oval, and it is usually found in a more coronal position than the mandibular canal, generally located at the apex of the second premolar or between the apices of the premolars. However, minor anatomical variations have been reported in Chinese populations, where the mental foramen may be located anterior to the canine or posterior to the first molar (Greenstein et al., 2006).

In rare cases (approximately 1% of the patients), the mandibular canal can bifurcate in the inferior - superior or medial - lateral plane. Consequently, a bifurcated mandibular canal can result in the presence of more than one mental foramen. This variation may or may not be observable on panoramic or periapical radiographs (Dario, 2002).

Medial to the mental foramen, studies have confirmed the existence of a true incisive canal, which acts as a continuation of the mandibular canal (De Andrade et al., 2001; Mraiwa et al., 2003).

In addition to the IAN, another important branch of the mandibular nerve (V3) in the posterior mandible is the lingual nerve, which follows a distinct anatomical course. The lingual nerve travels toward the base of the tongue and is positioned anteromedially to the IAN. It provides general sensory innervation to the anterior two-thirds of the tongue and carries taste fibers via the chorda tympani branch of the facial nerve. It is typically located immediately medial to the lingual cortical plate of the mandible, inferior to the alveolar crest, and posterior to the third molar region. It courses superficially beneath a thin oral mucosal layer, which requires special consideration during surgical procedures in this region (Al-Faraje, 2013, p. 138).

To avoid potential injury to the IAN or mental nerve, clinicians are advised to obtain a preoperative tomogram or computed tomography (CT) scan prior to implant placement. Greenstein et al. (2006) described the IAN extending anteriorly to the mental foramen and entering the canal as an anterior loop of the IAN, while others consider the anterior loop as a neurovascular bundle of the mental foramen traversing inferiorly and anteriorly to the foramen before turning back to exit the foramen. The IAN and its branches, along with the lingual nerve, play a crucial role for both the patient and the oral surgeon. Trauma to these nerves can result in symptoms such as numbness, tingling, altered sensation, loss of taste, or a combination of these symptoms. Trauma to the lingual nerve (LN) and inferior alveolar nerve (IAN) can also occur during the administration of local anesthesia (Steven et al., 2003).

3.2 Mandibular bone atrophy

After tooth extraction, a phase of remodeling occurs, which may result in extensive loss of alveolar bone height, particularly in the mandible (Carlsson & Persson, 1967; Tallgren, 1972). This phenomenon is significant as it was the observation of the "waste of the sockets of the teeth" by John Hunter in the 1750s that prompted him to consider bone as a material capable of remodeling, rather than as a permanent structure, as was previously thought (Cohen & Hunter, 1993). The healing of post-extraction sockets has been an area of interest to many oral surgeons and pathologists. Numerous investigators, including Atwood (1963) and Neufeld (1958), studied the process of healing extraction sockets. They discovered that both internal and external changes occur in the mandible following tooth loss.

Boyne (1982) explained that during the initial healing phase, the sockets become filled with blood clots. Osteoprogenitor cells from the ruptured periodontal ligament differentiate into osteoblasts, invade the coagulum, and form woven bone, which is later replaced by coarse cancellous bone. Concurrently, new bone formation is observed deep to, and some distance from the socket surrounding the inferior dental canal. Boyne also found that after extraction, no bone formation occurred during the first week. By the eighth day, new bone formation was evident throughout the alveolar bone, particularly beneath the socket wall, but not on the surface of the bone lining the extraction socket. By the twelfth day, new bone formation continued along the socket wall and in the trabecular spaces surrounding the extraction site. These findings indicate that, in humans, the first phase of extraction-socket healing is most likely characterized by osteoclastic undermining and rejection of the original socket wall into the healing socket.

Further investigations by Atwood (1963), Enlow et al. (1967), and Pietrokovski et al. (1967), demonstrated that the crest of the residual ridge narrows due to periosteal osteoclastic resorption, resulting in sharp edges of the alveolar processes. Meanwhile, endosteal apposition occurs, yet no new bone formation is seen on the periosteal surface of the residual ridge, which remains porous and never develops a complete cortical layer (Atwood, 1963; Neufeld, 1958; Pudwill & Wentz, 1975). Additional internal remodeling results in the loss of bone organization. As the bone height decreases due to periosteal osteoclastic resorption, there is thinning of the trabeculae (Neufeld, 1958; Pudwill, 1975). The mandibular alveolar process following tooth loss leads to alveolar bone remodeling, which includes osteoclastic resorption of the residual alveolar ridge. The rate of resorption varies among different individuals and within the same individual over time (Reich et al., 2011).

Most longitudinal studies regarding changes in the jaw bones, which were conducted through measurements either from serial study casts (Breham & Abadi, 1980; Likeman & Watt, 1974; Pietrokovski & Massler, 1967) or from radiographs (Carlsson & Persson, 1967; Cohen & Hunter, 1993; Tallgren, 1966; Wright & Watson, 1998), have shown that the loss in vertical height is greatest in the anterior region. Little change is believed to occur in the area of the superior genial tubercles or the mylohyoid and external oblique ridges, which become increasingly prominent and, in extreme cases, may necessitate surgical reduction for the provision of dentures (Neufeld, 1958; Osborne, 1963). Tallgren (1972) illustrated the pattern of bone loss and reported that the amount of bone loss occurring in the first year after tooth loss is nearly ten times greater than in the subsequent years, with an average loss of approximately 0.2 mm per year.

The majority of bone loss occurs from the buccal aspect in the maxilla, resulting in a reduction in palatal width, length, and height (Likeman, 1974). In the mandible, the majority of the loss occurs from the labial aspect anteriorly and from the lingual aspect posteriorly (Watt & MacGregor, 1986), which corresponds to the regions where the cortex is inherently more porous (Atkinson & Woodhead, 1968) and where the rate of bone turnover is higher (Kingsmill & Boyde, 1998b). Some resorption is also observed buccally (Enlow, 1976; Pietrokovski & Massler, 1967), yet the arch width of the edentulous mandible is greater than that of the edentulous maxilla (Parkinson, 1978).

In radiographic studies, the mental foramen is considered an anatomical landmark; the demarcation between alveolar and basal bone is typically identified at the level of the mental foramen (Wical & Swoope, 1974). However, the mental foramen has no direct relation to the teeth and may lie inferior or superior to the root apices in radiographic projections (Kingsmill, 1999). Furthermore, identification of the mental foramen and inferior dental canal becomes increasingly challenging in resorbed mandibles, particularly in advanced cases where the canal may be exposed due to the resorptive process (Gershenson, 1986; Ulm, 1993). It has been suggested that it is possible to observe the limit between alveolar and basal bone in the form of base alveolar sulci (Inke, 1972), and that when bones are separated along these lines, the basal parts resemble the shape of a remodeled edentulous mandible and maxilla. However, the sulci are often difficult to discern, potentially relating to the positions of muscle insertions or the limits of the attached gingiva, both of which serve as functional-anatomical divisions between alveolar and basal bone (Van Der Klaauw, 1952; Moss, 1972).

Nakamoto (1968) examined 263 jaw specimens, defining six separate segments of the jaw.

Each segment was assigned to one of the six stages of atrophy described by Atwood (1963; Cawood & Howell, 1988).

- **Stage 1:** Describes the physiological state of pre-extraction, during which the tooth is still in the alveolar socket, or the tooth is lost post mortem.
- **Stage 2:** This stage is assigned to tooth loss immediately before death, characterized by slight osseous reactions of new bone formation within the alveolus. The alveolus remains in good condition, with sharpened edges.
- **Stage 3:** The alveolus is completely refilled with newly formed bone. The original shape of the alveolus is no longer identifiable, and the top of the alveolar process becomes well-rounded due to early signs of resorption. However, there is no notable reduction in height.
- **Stage 4:** At this stage, the shape of the alveolar crest alters into a thin and sharp knife-edge, while the body of the jaw maintains adequate height and width.
- **Stage 5:** Further resorption leads to a low, well-rounded ridge that is flat but already reduced in height and width. The alveolar process is lost during this stage.
- **Stage 6:** Continued excessive atrophy of the residual crest results in a depressed bone level, where even the basal bone shows signs of reduction.

Atwood (1971) and Pietrokovski (1975) demonstrated that the cortical layer may not sufficiently close over the former alveolus and adjacent areas due to degenerative and resorptive processes of the alveolar crest. Consequently, the residual ridge displays trabecular bone extending over the entire length of the edentulous area.

As a result of the loss of several adjacent teeth, the bone tissue in this edentulous space often deteriorates, and bone fails to regenerate to the height of the former alveolar crest, resulting in a depressed level of the residual ridge. The original height of the alveolar process is maintained adjacent to the remaining tooth. This phenomenon explains the so-called concave depressions observed at the distal end of the dentate arch, as well as in edentulous spaces between remaining teeth. Ulm (1989) found that excessive resorption of the mandibular residual ridge can lead to a reduction of the alveolar crest towards the mandibular canal. In the final stage of resorption, the canal containing the mandibular nerve and blood vessels may even lie directly on the surface (Atwood, 1971; 1973).

Kingsmill (1999) discussed various factors, both local and systemic, that have been proposed to influence post-extraction resorption of the mandible. Local factors include anatomical, physiological, functional, and inflammatory factors, while systemic factors encompass nutritional aspects, calcium metabolism, age, gender, and a relationship with osteoporosis.

3.2.1 Local factors influencing mandibular bone loss

The influence of bone size, type, origin, composition, and bone cells is significant (Atwood, 1962; Kingsmill, 1999; Reich, 2010).

Bone size. It has been suggested that the original size of the mandible and the depth of the extraction sockets may influence ridge resorption (Atwood, 1979). However, with continued bone resorption of the residual ridge, the mandible has the capacity to become increasingly consolidated and more highly mineralised, improving its resistance to bending (Kingsmill & Boyde, 1998a, 1998b).

Many investigators, such as Kingsmill and Boyde (1998a, 1999) and Klemetti et al. (1993a), noted that cortical and cancellous bone respond differently to local and systemic influences. Additionally, others (Parfitt, 1962; Ulm, 1997) indicated that the number, arrangement, and distribution of bone trabeculae vary considerably in edentulous mandibles. Moreover, research has shown that following tooth loss, the ridge crest never develops a complete cortex (Atwood, 1963; Neufeld, 1958; Pudwill, 1975) and may therefore be more susceptible to age- or metabolic-related loss (Baxter, 1987). Further research proposed that the concentration of insulin-like growth factor differs between cortical and cancellous bone, which may affect the rate of bone turnover (Canalis & Agnusdei, 1960). Clinically, the primary stability of an implant is affected by the bone quality and quantity of the residual ridge (Rabel et al., 2007).

Bone origin. Bone tissue at different locations in the body varies in its rate of remodelling and response to mechanical strain (Jee et al., 1991). Histological studies by Couly et al. (1993) and Smith et al. (1994) revealed that alveolar bone may initially develop from basal bone in close association with the tooth germs. Furthermore, there is evidence that bone of dermal origin (membrane bone) differs in several aspects from bone of endoskeletal origin (endochondral bone).

However, the mandible is subjected to greater strains than the postcranial skeleton (Throckmorton et al., 1992). Research performed on bone of dermal origin demonstrated that it differs from bone of endoskeletal origin in its behaviour as a grafting material and in the levels of stored growth factors (Baylink, 1993; Smith, 1974). Further studies by Kasperk (1995) and Recker (1992) indicated that cultured human mandibular osteoblasts produce more fibroblast growth factor and insulin-like growth factor, but less transforming growth factor beta than human iliac cells. These differences have been attributed to the embryological origin of the bone cells.

Bone composition. Some investigators, including Waddington et al. (1989), consider that alveolar bone is less brittle than other bones due to its higher glycosaminoglycan content. Experimental studies by Shore et al. (1996) showed that a decrease in occlusal loading reduces the proteoglycan distribution and content in rat mandibles, which may be implicated in the strain-memory responses of bone (Davidovitch, 1991).

Additionally, some authors, such as Jones et al. (1995), Kingsmill and Boyde (1998b), and Landini (1991), advocated that the less mineralized a substrate is, the more easily it may be resorbed. Studies on functional loading by Akeson et al. (1987) and Short and Johnson (1990) showed that in groups with non-function and hypofunction, there was a reduction in the level of fiber mineralization; the fibers became larger and sparser compared with those in bone around teeth with normal function.

Bone cells. Atwood (1997) suggested that the aging of bone cells may contribute to their defective function. Further investigations by Frost (1960), Kingsmill and Boyde (1998b), and Tonna (1976) demonstrated that osteocytes, which are replaced only when bone is remodeled, are well-known to exhibit age-related changes and may become mineralised. The mineralisation of osteocytes is particularly evident in the elderly mandible.

Physiological factors affecting bone include bone turnover and blood supply. Bone turnover is influenced by many factors, notably the interaction between osteoblasts, osteoclasts, and osteocytes. Numerous studies by Carlsson and Persson (1967), Kingsmill (1999), and Maejima et al. (1997) suggested that osteoblasts are responsible for detecting and initiating cellular responses to changes in bone function. A significant number of osteocytes die following tooth extraction, resulting in many cell-free areas of bone during the initial stages of socket healing. This may account for the initial rapid phase of remodeling observed after tooth loss, as viable osteocytes may release factors that inhibit osteoclasis.

With age, the number of viable osteocytes tends to decrease, and the presence of 'overaged' bone becomes a frequent finding in the mandible (Kingsmill and Boyde, 1998b; Pudwill and Wentz, 1975). As turnover decreases, there is a reduction in the number of osteocytes (Atkinson and Hallsworth, 1983; Mullender et al., 1996).

Blood supply. The mandible has three sources of blood supply: The primary source arises from the inferior alveolar artery (IAA), a branch of the maxillary artery, which is itself a branch of the external carotid artery (ECA). The second source of blood supply, primarily to the distal part of the mandible, derives from anastomoses involving the sublingual branch of the lingual artery from the ECA, the submental branch of the facial artery (from ECA), and the mylohyoid branch of the IAA (from the maxillary artery, a branch of ECA).

The third source of arterial blood supply, mainly to the basal bone and the proximal part of the mandible, is provided by the surrounding muscles (including small arteries within the attached musculature) and the periosteum (musculoperiosteal source). The second and third sources of mandibular vascularisation are considered collateral (Tolstunov, 2007).

The directions of the mandibular blood flow depend on four major factors: the presence of teeth, age, degree of resorption of alveolar bone, and the presence of systemic disorders that cause atherosclerosis in the blood vessels (Eiseman et al., 2005; Tolstunov, 2007). Another study by Bradley (1975) postulated that the normal blood flow within the body of the mandibular inferior alveolar artery (IAA), along with its small dental arteries in early life, is centrifugal (from inside to outside). With aging, the direction of blood circulation may reverse; thus, a reduction or absence of flow in the inferior alveolar artery toward the alveolar ridge and teeth occurs, which may also be associated with tooth loss. The blood flow then becomes centripetal (from outside to inside), originating from the periosteum and muscles toward the bone.

When the inferior alveolar artery is interrupted for various reasons, a network of internal (inferior alveolar) and external arteries converges to provide vascularization to the anterior and posterior mandible (Bradley, 1975). These anastomoses are critical in cases involving mucoperiosteal flaps in the mandible (Misch, 2008). Anatomical studies by Castelli et al. (1975) have reported that changes in mandibular blood supply correlate with age. According to their findings, the inferior alveolar artery becomes obliterated in 50% of cases, while branches of the facial artery (submental and sublingual branches) persist and contribute more significantly to the blood supply (Bradley, 1975).

An experimental study conducted by Sake et al. (2002) demonstrated three different types of blood supply in the mandibular cortex. The cranial part of the mandible, including the condyle, is primarily supplied by endosteal blood vessels, whilst the caudal part of the mandibular body is supplied by periosteal blood vessels. The angle and ascending ramus receive vascular supply from both patterns. It has also been observed that if central vascularization through the IAA is dominant in the medullary area of the mandible, then periosteal vascularization is dominant in the cortical bone (Chanavaz, 1995). Changes in the pattern of blood supply to the atrophic mandible are of considerable importance to implant dentistry; a reduced blood supply may contribute to failure (Misch, 2008).

Functional factors. Functional factors include the frequency, intensity, duration, and direction of forces applied to bone, which result in either bone formation or resorption, depending upon the patient's individual resistance to these forces (Atwood, 1962). Forces applied within certain physiological limits to living bone bring about bone remodeling through a combination of resorption and formation. The traditional design of dentures encompasses many features aimed at reducing the amount of force on the ridge; consequently, residual ridge resorption is decreased. Various clinical studies conducted by Atwood (1962, 1979), Enlow et al. (1976), Baxter (1987), and Nemeth et al. (1998) have attempted to correlate one or more of these factors with the rate of residual ridge resorption. Their findings consistently indicate that bone loss occurs regardless of whether dentures are provided. It is known that implants can help maintain ridge height, although they may exacerbate bone loss in the opposing jaw. Functional changes occur when loss of teeth leads to a reduction in biting force. Tallgren (1967) conducted numerous studies on patients wearing dentures in both the maxilla and mandible. He attributed the higher rate of atrophy in the lower jaws to the smaller surface area and unfavourable shape of the mandibular ridge on which mechanical loads are applied to edentulous patients. In contrast, the maxilla resists loads from dentures more effectively due to the larger supporting surface of the hard palate. He posited that prosthetics cannot solely account for the higher degree of ridge resorption.

Inflammatory factors. Inflammatory factors include periodontal health and trauma. With respect to periodontal health, periodontal conditions lead to a reduction in the bony support of teeth due to microbial factors acting either directly or indirectly via the host's inflammatory responses (Henderson & Wilson, 1996; Jeffcoat, 1993). Some authors, including Atwood (1990) and Humble (1936), have suggested that microbial endotoxins from denture plaque and residual bone-resorbing factors may induce localized resorption of the alveolar ridge similarly. Investigations by Atwood (1971) elucidated a correlation between tooth loss and atrophy of the residual alveolar ridge, which has been demonstrated to be chronic, progressive, and cumulative, accompanied by reduction and exposure of the attached gingiva. Moreover, others such as Klemetti et al. (1993) have shown that bone atrophy and loss of attached gingiva are correlated, with bone loss being more pronounced. In such cases, it is advised to combine surgical and pre-prosthetic treatment prior to implant placement.

3.3 Systemic Factors Influencing Mandible Bone Loss

Systemic factors that influence mandibular bone loss encompass various nutritional (calcium metabolism), hormonal, and other metabolic factors that affect the relative activity of bone cells, including age and sex (Atwood, 1962).

Diet. Nutritional factors are predominantly associated with calcium metabolism. A reduction in calcium intake may occur due to internal causes such as short bowel syndrome or secondary hyperparathyroidism (Von Wowern et al., 1996), particularly in patients with renal osteodystrophy (Bras et al., 1982b). These conditions typically result in varying degrees of atrophy in the mandibular bone and a decrease in bone density (Kingsmill, 1999). It has been postulated that a low-calcium diet leads to mandibular bone resorption (Sones et al., 1986).

Several human studies have suggested that dietary calcium and vitamin supplements may assist in maintaining ridge size and mass one year post-extraction (Kribbs, 1992). However, the long-term effects remain uncertain. A retrospective analysis of calcium intake by Kribbs et al. (1989) demonstrated a weak correlation with mandibular bone density but no correlation with mandibular bone mass.

Additionally, a study by Syrjäläinen and Lampainen (1983) analysing dental panoramic radiographs of patients with secondary hyperparathyroidism found no correlation between serum calcium, inorganic phosphate, alkaline phosphatase, or parathyroid hormone with the radiographic parameters assessed, although patients were observed to have fewer trabeculae compared to controls. No association was identified between primary hyperparathyroidism and residual ridge reduction. However, in patients with significantly impaired nutrition, changes in mandibular bone may become evident (Lekkas, 1989).

Osteoporosis is the most common systemic bone disease, characterized by a decrease in bone mass coupled with structural changes that predispose individuals to fractures (Bras, 1982; Horner, 1992; Watt, 1986).

Age. Research has clarified that age-related changes in the mandible may exacerbate the difficulty of orthodontic tooth movement, extractions, or other surgical interventions (Grant & Bernick, 1972). Numerous radiographic studies conducted by Benson et al. (1991), Humble (1936), Kingsmill and Boyde (1998a), and Manson and Lucas (1962) have shown alterations in cortical thickness measurements with advancing age, indicating that the cortical bone becomes increasingly porous as individuals age.

Gender. Certain authors, including Bergman et al. (1971), Kingsmill and Boyde (1998b), and Winter et al. (1974), contend that males exhibit greater bone loss than females in the posterior mandible; this may be attributed to males possessing a higher biting force. Nonetheless, no gender difference has been observed in the level of mandibular bone mineralization at any age.

Relationship with Osteoporosis. The measurement of bone density, cortical thickness, and the trabecular pattern of the mandibular bone has been extensively investigated by various researchers as significant factors influencing the osseointegration of implants. There remains controversy regarding the measuring tools, correlations with other body bones, and the relationship between density and quality of mandibular bone.

Misch (2008) categorized the bone density of the edentulous areas of the maxilla and mandible as follows.

- D1 - dense cortical bone (anterior mandible);
- D2 - porous cortical bone at the crest, with coarse trabecular bone (anterior mandible, anterior maxilla, and posterior mandible);
- D3 - bone characterized by a thinner porous cortical crest and fine trabecular bone (anterior maxilla, posterior maxilla, posterior mandible);
- D4 - bone exhibiting minimal crestal cortical bone (posterior maxilla);
- D5 - very soft bone, with no mineralization and large intertrabecular spaces.

Bone density may be assessed via tactile sense during osteotomy preparation, general location, or radiographic evaluation, such as computed tomography.

It has been noted that panoramic and periapical radiographs are not effective for determining bone density (Kircos and Misch, 1999; Misch, 2008). Kirkos and Misch (2008) established a relationship between CT Hounsfield units and bone density at the time of surgery, categorized as follows: D1 - $\geq$ 1250 Hounsfield units; D2 - 850 to 1250 Hounsfield units; D3 - 350 to 850 Hounsfield units; D4 - 150 to 350 Hounsfield units; D5 - $\leq$ 150 Hounsfield units. Several studies by Homolka et al. (2002) and Ikumi and Tsutsumi (2005), correlating torque forces at implant insertion with bone density values from CT scans, have reported similar conclusions.

Hormones. A study by Schiessl et al. (1998) explained the importance of the relationship between muscle strength and bone mass, as well as the role of estrogen. They emphasized that not only are mass and strength related to the local mineralization densities in the buccal and lingual cortices distal to the mental foramen, but also that individuals with weaker muscles exhibit significantly lower bone mineral density values than those with stronger, more palpable masses. Mandibular bone mineral density is usually evaluated in the basal parts of the mandible, as this area can be influenced by muscular activity (Klemetti, Vainio, and Kroger, 1994d). Another study by Jacobs et al. (1996) reported that the radiographic density of the mandible increased in women taking hormone replacement therapy.

3.4 Inferior alveolar nerve injury

Inferior alveolar nerve (IAN) injury is one of the most common complications that may occur during oral maxillofacial surgery procedures. It may arise if important vital structures, such as the mental foramen and anterior mental loop, are not well identified preoperatively (Holmes et al., 2004).

Aetiological Factors. A possible aetiological factor of IAN injury has been attributed in the literature to mechanical trauma, which includes: the injection needle, implant drill, the implant itself, a hematoma in the mandibular canal (MC) below the implant, scalpel, soft tissue retraction instruments, removal of difficult impacted lower third molars, mandibular fractures, and orthognathic surgery.

Needle Injection. Although injury to the inferior alveolar nerve during local anesthetic injection is very rare, it has been well documented (Malamed, 2010). This may result from direct contact of the tip of the long and sharp needle with the nerve, which may rupture the Perineurium and herniate the endoneurium, which can lead to the transection of multiple nerve fibers. This could cause altered sensation (Pogrel & Thamby, 2000) and persistent paresthesia following injection of local anesthetics. In addition, it may be attributed to the barbing of the needle, which, when removed from the tissues, may damage any nearby structures, including nerves. Direct inferior alveolar nerve trauma can present as an electric shock, sometimes causing patients to suddenly jerk their heads. The practitioner should cease the injection immediately if this occurs (Malamed, 1990).

Implant Drills. These instruments are slightly longer than their corresponding implants. Nerve injury may occur during the use of twist drills, which can transect or lacerate the nerve as a result of over-penetration of the drill. Consequently, knowledge of the specific drill length is essential to prevent these complications.

For most implant systems, the drills are approximately 0.5 to 1.5 mm longer than the implant being placed. For example, when using a 10-mm drill for a 10-mm implant, the actual drilled depth can range from 10.5 to 11.5 mm, depending on the implant system.

This discrepancy occurs because manufacturers typically do not account for the cutting edge of the drill. As a result, the implant surgeon may inadvertently risk injury to nerves or blood vessels if this extra length is not considered (Al-Faraje, 2021, p. 162).

Nerve injury can also occur due to the low resistance of spongy bone, which may cause the drill to glide, even in the hands of a skilled surgeon (Worthington, 2004). Furthermore, it is important to determine the location of the mandibular canal, which is the most significant anatomical structure in the mandible as it contains the neurovascular bundle. A study by Basa and Dilek (2011) assessed the risk of perforation of the mandibular canal by implant drills. They investigated the bone resistance surrounding the mandibular canal during the preparation of the implant bed. Their results indicated that the average density and thickness of the bone encasing the mandibular canal were not sufficient to resist the implant drill. Therefore, they recommended the use of drills with guards to ensure full control during drilling.

Dental Implant. Injury from implant is caused by direct mechanical injury or indirect postoperative trauma, such as ischaemia and periimplant infection, which lead to encroachment or laceration of the nerve. When the implant is fully inserted into the canal, the nerve endings may undergo retrograde degeneration in most cases. Partial implant intrusion into the canal can result in IAN injury due to compression and secondary ischaemia of the neurovascular bundle. Therefore, to avoid nerve injury, a thorough evaluation of clinical data and biomechanical analyses is recommended (Samartino et al., 2008). A study by Khawaja & Renton (2009) indicated that cracking of the IAN canal, due to its close proximity to the preparation of the implant bed, can cause haemorrhage into the canal or compression within the canal, leading to primary ischaemia.

Extraction of Lower Third Molar. Compression injuries to the IAN may occur during the elevation of third molars that lie in close proximity to the mandibular canal. Transection injuries are likely to occur when the nerve passes between the roots of a third molar (Holmes et al., 2004). Ylikontiola et al. (1998) have explained additional possible causes of IAN injury during various oral surgical procedures, such as in cases of difficult impactions of lower third molars, osteotomies, or when the IAN comes into contact with a rotary instrument. Additionally, mandibular fractures occur in the area traversed by the mandibular canal. Orthognathic surgery may also lead to sensory disturbances immediately post-operatively. Paresthesia in the lower lip and chin following bilateral sagittal split osteotomy is common and reported in 80 to 100% of cases. There is a risk of IAN injury at all stages of surgery, including incision, dissection, retraction, bone osteotomy, mobilization, and mandibular fracture fixation with compression screws. Damage can also arise as a consequence of inferior alveolar nerve lateralization or transposition.

Chemical Nerve Injury. Chemical nerve injury may be related to specific chemical substances, components of local anesthetics (LA), the type of agent, agent concentration, buffers, and preservatives. Elian et al. (2005), Malamed (2006), and Pogrel and Thamby (2000) compared articaine and lidocaine local anaesthetic solutions in adults. They found that articaine caused more injuries than lidocaine; it has been reported that 54% of nerve injuries during mandibular block anaesthesia were associated with articaine.

The degree of the inflammatory reaction to local anaesthetics has been studied, and it was found that lidocaine is the least irritant, followed by articaine, mepivacaine, and bupivacaine (Jacobs et al., 2007). An in vitro study by Perez-Castro et al. (2009) demonstrated that local anaesthetics can cause rapid cell death, primarily due to necrosis. They postulated that lidocaine and bupivacaine can trigger apoptosis with either increased exposure time or increased concentration. These effects may be related to postoperative neurologic injury.

Lidocaine, which is linked to the highest incidence of transient neurological symptoms, was not the most toxic local anaesthetic, whereas bupivacaine, a drug causing a very low incidence of transient neurological symptoms, was the most toxic in their cell model. This suggests that cytotoxicity-induced nerve injury may have different mechanisms for different local anaesthetics and may target other cell types aside from neurons.

Some authors, including Heraud et al. (1996), recommended that during the insertion of implants in the mandible, local infiltration should be used instead of mandibular block anaesthesia to avoid inferior alveolar nerve injury. This technique is not generally accepted, as the bone contains sensitive nerve endings, which could cause discomfort for patients during surgery.

Hematoma Formation. Hematoma formation occurs when a needle traumatizes the epineurial blood vessels, leading to hemorrhage from these vessels and subsequent compression of nerve fibers, ultimately causing localized neurotoxicity. (Pogrel et al., 2000; Stacy and Hajjar, 1994). This damage may extend up to 30 minutes after injection; the release of blood and its products from the epineurial blood vessels into the epineurium during hematoma formation may lead to reactive fibrosis and scar formation.

Thermal Stimuli. Thermal stimuli result in indirect postoperative trauma to the inferior alveolar nerve. The increase in temperature during excessive drill speed produces necrosis, fibrosis, osteolytic degeneration, and an increase in osteoclastic activity. The thickness of the necrotic area is related to the amount of heat generated during the surgery. Some studies, such as Fanibunda and Whithworth (1998), have reported that temperatures up to 47°C are possible. In the preparation of implant beds, the use of bone drilling with conventional internal or external irrigation has been shown to be very important in reducing thermal changes.

Infection. Sussman and Moss (1993) reported a case of osteomyelitis that developed around an implant adjacent to a non-vital tooth exhibiting periapical infection. This introduced the concept of implant periapical pathology, which corresponds to an infectious, inflammatory process around the implant apex that may lead to an IAN injury. Various authors have mentioned causative factors, such as overheating of bone during drilling, contamination of the implant surface during implant instrumentation, and pre-existing bone disease (Peñarrocha Diago et al., 2006).

Paraesthesia has been reported in patients related to implants inserted in proximity to the mental foramen, accompanied by signs of peri-implantitis, leading to complaints of neurosensory disturbances. Therefore, if the implant is situated on top of the nerve, the nerve can be stimulated recurrently each time the patient bites or chews. It is likely that such chronic stimulation may lead to chronic neuropathy (Jacobs et al., 2007).

Stretch Injury. In cases of extreme mandibular bone atrophy, the mental foramen has been found on the surface of the alveolar bone and directly beneath the gum, which may lead to stretch injuries during surgical flap retraction (Ulm et al., 1993). Other causes of IAN dysfunction include idiopathic sensory neuropathy related to the second and third branches of the trigeminal nerve, which can cause facial numbness (Blau, 1969; Peñarrocha

Diago et al., 2006), viral infections such as herpes simplex (Fisher, 1983), or herpes zoster (Goor & Pngerboer De Visser, 1976). Additionally, osteomyelitis, tumors, and cysts of the mandible, as well as their surgical treatment, may cause neurological disturbances of the inferior alveolar nerve (Ylikontiola et al., 1998).

3.5 Classification of inferior alveolar nerve injury

Sensory disturbances can occur to varying degrees depending on the extent of the injury: paraesthesia, hypoesthesia, hyperesthesia, dysesthesia, or anaesthesia of the teeth, mucosa, lower lip, and surrounding skin of the chin (Greenstein & Tarnow, 2006).

Steven and Redford (2003) explained Seddon's classification for nerve injury (1943) as follows: Neuropraxia is a conduction block resulting from traction, stretching, compression of the nerve trunk, and mild trauma to the endoneurial capillaries, which causes paraesthesia and intrafascicular oedema without axonal nerve damage. This paraesthesia will subside and return within days or weeks.

Axonotmesis is a more severe injury with preservation of the nerve sheath; however, there is afferent fibre axonal degeneration and incomplete sensory recovery, with possible neuroma formation. Sensation returns within 2 to 6 months, but improvement leading to complete recovery may take up to 12 months. The psychophysical response to axonotmesis is an initial anaesthesia followed by paraesthesia during the recovery phase.

Neurotmesis is characterised by severe disruption of the connective tissue components of the nerve trunk, resulting in compromised sensory and functional recovery. This condition has a poor prognosis, especially if the nerve courses through soft tissue; however, regeneration may occur in bone (Greenstein, 2006; Steven & Redford, 2003). The psychophysical response to these injuries is immediate anaesthesia followed by paraesthesia or chronic pain (Jacobs et al., 2007).

Steven and Redford (2003) also mentioned Sunderland's classification of nerve injury based on the degree of tissue damage: **First-degree injury**, *Type one:* Neuropraxia results from manipulation of the nerve trunk, mild traction, or mild compression and is thought to reflect transient ischaemia. If blood flow is restored, nerve function usually returns to normal; with more prolonged ischaemia, permanent injury and anaesthesia may occur. *Type two:* Results from more prominent traction or compression that produce intrafascicular oedema, decreased blood flow, and conduction block; recovery is variable. *Type three:* Injuries resulting from severe nerve traction or compression cause segmental mechanical disruption of the myelin sheaths and demyelination. Recovery is delayed, and sensory loss may be permanent.

Second, third, and fourth-degree injuries correspond to those of Seddon's classification. **Second degree:** The efferent fibres are damaged, but endoneurium, epineurium, and perineurium remain intact. Surgical decompression may be necessary, and recovery requires axonal regeneration. **Third-degree** injury occurs when axons and endoneurium are damaged. If there is poor clinical recovery, surgical reconstruction may be needed. **Fourth-degree** injuries involve damage to all components, with only the epineurium remaining intact. The prognosis is poor, and surgical reconstruction may be indicated. **Fifth-degree** injuries refer to nerve transection. Surgical approximation may be required (Steven & Redford, 2003).

However, the presence of numbness does not indicate nerve severance. If complete numbness improves gradually, this is indicative of a first- or second-degree injury. This is in agreement with Rood (1983), who correlated histological findings with clinical data and found that the clinical symptom is most reflective of the degree of initial injury. Moreover, inflammation around the nerve caused by infection or foreign bodies may also alter function and increase pain (Tal, 1999).

3.6 Evaluation of inferior alveolar nerve disturbance

The evaluation is based on subjective and objective sensory tests. Ylikontiola et al. (1998) conducted an extensive study that described the mechanism of nerve injury and various nociceptive tests for assessing free nerve endings. Moreover, the study outlined different methods for monitoring IAN function, including subjective and objective sensory tests.

Subjective clinical sensory testing is divided into two categories: mechanoceptive and nociceptive, according to the stimulated receptors through cutaneous contact. Each test assesses certain types of receptors and axons. Mechanoceptive tests include static light touch detection, two-point discrimination, and brush stroke direction, while nociceptive tests focus on tactile discrimination and thermal discrimination.

Static light touch detection evaluates the integrity of cells innervated by myelinated afferent A-beta axons, which adapt slowly, with pressure as their putative sensory modality. The large myelinated A-beta fibres are highly susceptible to compression injury. In this test, the patient closes their eyes and indicates "yes" whenever they feel a light touch on the face, pointing to the exact spot where they felt the touch. Brush directional discrimination assesses proprioception and the integrity of the large A-alpha and A-beta myelinated axons, with the sensory modalities for these receptors being vibration, touch, and flutter. The patient reports whether a sensation is detected and in which direction the filament or brush moved.

Two-point discrimination assesses the quantity and density of functional sensory receptors and afferent fibres. If sharp points are used, the small myelinated A-delta and unmyelinated C-afferent fibres are assessed, whereas if blunt points are used, the larger myelinated A-alpha afferent fibres are evaluated. This test involves measuring the distance between two points using an appropriate instrument, with the patient's eyes closed. The test is initiated with the points nearly touching, allowing the patient to discriminate only one point.

Finally, pin pressure nociception assesses the free nerve endings and the small A-delta and C-fibres that innervate the free nerve endings responsible for nociception. This test is performed using an instrument called an algesimeter, which has a sharp point for testing nociception and a blunt end for assessing pressure. The magnitude of force necessary to perceive the sharpness of the unaffected area is recorded as the nociceptive threshold for the affected area. An exaggerated response to pin pressure relative to an unaffected area is termed hyperalgesia. In contrast, a reduced response (touch) relative to an unaffected area is termed hypoalgesia. No response is defined as anaesthesia. Thermal discrimination (TH) is a test of sensation that assesses the integrity of small myelinated and unmyelinated fibres, similar to those tested with pin pressure.

3.7 Methods to avoid inferior alveolar nerve injury

Many surgeons recommend assessing risk factors prior to implant surgery as follows:

1. Clinicians should perform a neurosensory examination to evaluate the function of the inferior alveolar nerve (IAN) before implant placement, to determine whether any pre-existing altered sensation is present (Juodzbalys et al., 2011).

2. It is also important to obtain accurate information about the mandibular vital structures prior to implant insertion. During the treatment planning phase, the implant site is typically evaluated through visual inspection, palpation, and the use of suitable radio-

graphic imaging techniques to ensure safe implant placement and avoid injury to adjacent anatomical structures (Juodzbalys & Wang, 2010).

Radiographic images provide valuable information about the topography and location of anatomical structures, as well as estimations of the quantity and quality of alveolar bone. Several imaging modalities are employed to localize the inferior alveolar nerve (IAN) during treatment planning. These include intraoral radiography, panoramic radiography, tomography, computerized tomography (CT), and cone beam computed tomography (CBCT) (Juodzbalys & Wang, 2010).

Another method involves the surgical exposure of the mental nerve through blunt dissection to allow direct visualization of the nerve and to estimate the distance between the mandibular ridge crest and the IAN. However, the irregular intraosseous course of the nerve limits the reliability of this method (Kumar & Satheesh, 2021). Due to the limitations of direct nerve exposure, alternative non-invasive imaging techniques are preferred.

Computed tomography (CT) has been widely used for assessing the mandibular canal, offering three-dimensional imaging that enhances the accuracy of implant placement. It is particularly effective in evaluating the buccolingual dimensions of bone and the position of the inferior alveolar nerve (IAN), which aids in avoiding nerve damage during surgery (Alhassani & AlGhamdi, 2010). A 2-mm safety zone between the apical part of the implant and the superior border of the IAN canal is widely recommended in the literature to minimize the risk of nerve injury (Al-Faraje, 2021, p. 162). However, CT is associated with higher radiation exposure and greater cost, limiting its routine application in implantology (Alhassani & AlGhamdi, 2010).

In contrast, cone beam computed tomography (CBCT) was introduced to provide high-resolution cross-sectional images with a reduced radiation dose and has become the preferred imaging modality for pre-implant assessment. Its ability to accurately identify anatomical landmarks and assist in surgical planning has been widely recognized in the literature (Juodzbalys & Wang, 2010).

Conventional radiographic techniques, such as panoramic or periapical imaging, provide only two-dimensional views, which limits their ability to assess the buccolingual dimension of the alveolar ridge. To compensate for this limitation, clinicians may use additional methods like palpation or bone sounding under local anesthesia to estimate the ridge width more accurately (Alhassani & AlGhamdi, 2010).

The available bone height can be calculated using the following formula: clinical bone height equals radiographic bone height divided by the magnification factor. The radiographic bone height is defined as the distance from the crest of the alveolar ridge to the superior border of the inferior alveolar nerve (IAN) canal, as visualized on the radiograph. The magnification factor is a known value based on the magnification of the X-ray machine (Alhassani & AlGhamdi, 2010; Worthington, 2004).

However, to optimize measurement accuracy, some authors recommend placing an object of known dimensions in the patient's mouth prior to radiographic exposure, particularly when the magnification factor of the machine is unknown or variable. Clinicians should also ensure that this object is properly incorporated within the radiographic field during pre-implant assessment.

Following the calculation of clinical bone height, it is essential to subtract a 2-mm safety margin between the apical end of the implant and the superior border of the inferior alveolar nerve (IAN) canal. Additionally, clinicians should carefully evaluate the alveolar crest, as it may consist of a thin cortical plate that does not provide adequate support for implant placement (Alhassani & AlGhamdi, 2010).

Karlis et al. (2003) emphasized the importance of informing all patients about the potential risk of IAN injury before implant surgery. A comprehensive risk assessment should be conducted to explain possible complications and offer alternative treatment options. This discussion must be documented, and patients must sign an informed consent form prior to surgery. Furthermore, careful site selection and attention to anatomical landmarks are crucial to minimize the risk of nerve injury (Juodzbalys et al., 2011; Pogrel & Thamby, 2000).

3.8 Inferior alveolar nerve transposition

Implant rehabilitation is widely used in partially edentulous patients. In cases of severe alveolar bone resorption, a standard procedure must be adopted to place the implants with satisfactory results. In instances of severe bone atrophy, long fixtures cannot be placed without encroaching on the IAN. Therefore, various solutions should be considered (Anibal et al., 2008).

Kan et al. (1997) and others clarified that the quantity and quality of bone superior to the IAN canal are often insufficient for the placement of fixtures of appropriate length. Some authors, including Anibal et al. (2008), Chrcanovic and Custódio (2009), Morrison et al. (2002), and Proussaefs (2005), recommended alternative surgical procedures to increase alveolar ridge height, such as mandibular bone augmentation with or without inferior alveolar nerve transposition (IANT), onlay grafting, distraction osteogenesis, and the use of short implants.

The inferior alveolar nerve transposition has emerged as an alternative to augmentation procedures for the placement of dental implants in patients who cannot tolerate removable dentures (Figure 1A and 1B). However, nerve transposition is a complex procedure with a high risk of sensory disturbances. This technique has previously been employed for several purposes, including alveolar ridge plasty, orthognathic surgeries, and mandibular resections, prior to being introduced for implant placement. A minimum amount of remaining bone above the mandibular canal (approximately 8 mm) is recommended for this technique (Morrison et al., 2002; Peter, 2010). Jensen and Nock (1987) were the first to publish the technique for the translocation of the mental foramen.

Regardless of the surgical technique employed, thorough clinical and radiological examinations are essential (Tallgren, 1972). In addition to conventional X-rays (panoramic radiography), three-dimensional examinations using computed tomography (CT) or cone beam computed tomography (CBCT) are required. Consequently, it is possible to obtain a three-dimensional image of the course of the inferior alveolar nerve in the mandible beforehand.

In recent years, the integration of artificial intelligence (AI) with digital diagnostic imaging has significantly advanced the field of implant dentistry. AI algorithms, when combined with imaging techniques like CT and CBCT, help enhance treatment planning by predicting implant placement with greater precision. They also assist in identifying critical anatomical structures, such as the inferior alveolar nerve, minimizing the risk of nerve damage during surgical procedures. These innovations allow implantologists to improve the accuracy of the treatment process, resulting in more predictable and successful outcomes (Rutkowski, 2024).

The positioning of the buccal bony window should be given special consideration during surgical planning. Moreover, study casts, diagnostic wax-ups, and surgical stents are important (Peleg et al., 2002).

Preoperative discussions with the patient regarding postoperative neurosensory complications are essential, as this helps many patients decide whether the procedure would be tolerable. In certain selected cases, inferior alveolar nerve repositioning can be performed under local anaesthesia and/or intravenous sedation; however, general anaesthesia is usually preferred (Del-Castillo-Prado-De-Vera et al., 2008; Peter, 2010).

According to the literature, Abayev and Juodzbalys (2015) describe two main inferior alveolar nerve repositioning techniques: transposition and lateralization (Figure 1).

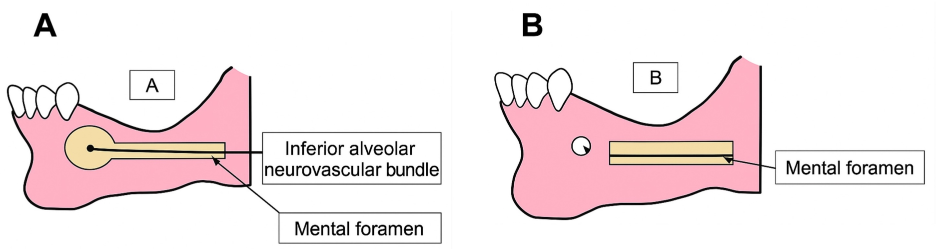

Figure 1. Schematic drawing showing the inferior alveolar neurovascular bundle transposition (A) and lateralization (B), adapted from Abayev & Juodzbalys (2015).

Both techniques commence with the administration of local anaesthesia. A small incision of approximately 5 mm is made buccally below the alveolar crest, accompanied by a vestibular releasing incision near the mental foramen. Mucoperiosteal flaps are raised: one lingual flap is created to access the alveolar crest and another vestibular flap for the subperiosteal dissection of the inferior alveolar nerve (Del-Castillo-Prado-DeVera et al., 2008; Peter, 2010). Subsequently, an osteotomy is performed using one of the following techniques: transposition or lateralization (Abayev & Juodzbalys, 2015).

The inferior alveolar nerve transposition (IANT) described by Chrcanovic and Custodio (2009), follows the standard mucosal incision and flap elevation described earlier. The mental nerve is exposed, and the periosteum is carefully separated from the surrounding mandibular bone. A unicortical lateral osteotomy is then performed around the mental foramen, ensuring that the incision extends inferiorly and anteriorly to prevent interference with any nerve loops during the procedure (Figure 1A). Minimal retraction of the nerve is required, and there is no need for additional dissection as it enters the soft tissue of the lip and chin.

A curette is gently inserted into the mandibular canal in the proximal direction, positioned between the nerve and bone to protect the nerve. The corticocancellous bone is then removed using a small round bur. The buccal bone is resected by approximately 2 to 3 mm, after which the curette is reinserted into the canal, and this process is repeated posteriorly along the canal. Once the cortical bone is removed, any remaining bone over the nerve is carefully cleared using instruments, and the neurovascular bundle is gently mobilized and atraumatically separated from the canal walls. Subsequently, the incisive branch is sectioned with a scalpel, enabling the mental nerve and proximal portion of the IAN to be freed from the canal.

These steps are illustrated in the intraoperative photographs presented in Figure 2.

At this stage, implants can be placed under direct vision through the canal, either into or through the inferior cortex. The excised bone is then repositioned laterally around the implants as a bone graft, with the inferior alveolar nerve (IAN) lying passively alongside. Essentially, this technique results in the posterior relocation of the mental foramen.

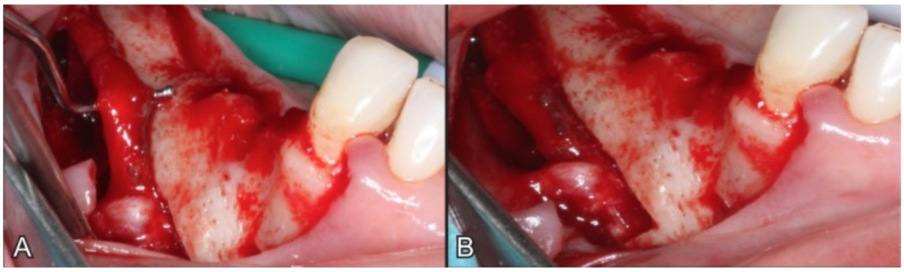

Figure 2. Intraoperative photographs showing inferior alveolar neurovascular bundle during transposition: (A) before transposition; (B) after transposition (courtesy of Dr. Dainius Razukevicius, Kauno Implantologijos Centras, Kaunas, Lithuania).

Inferior alveolar nerve lateralization (IANL) involves the preparation of a cortical bone window posterior to the mental foramen, without engagement of the mental nerve or sectioning of the incisive branch (Del Castillo Pardo de Vera et al., 2008). This procedure is typically performed via osteotomy or sequential drilling (Figures 1B and 3). The nerve is then carefully separated and gently retracted outward using a vessel loop while the implants are positioned. To achieve optimal primary stability, the implant must be sufficiently long to pass through the mandibular canal and engage the basal bone located below it (Abayev and Juodzbalys, 2015). After implant placement, the vessel loop is removed, and the nerve is repositioned into its original location. To prevent direct contact between the nerve and the implants, the application of a resorbable membrane between the nerve and the bone window has been recommended (Abayev & Juodzbalys, 2015; Del Castillo Pardo de Vera et al., 2008). The mucoperiosteal flap is then repositioned and sutured.

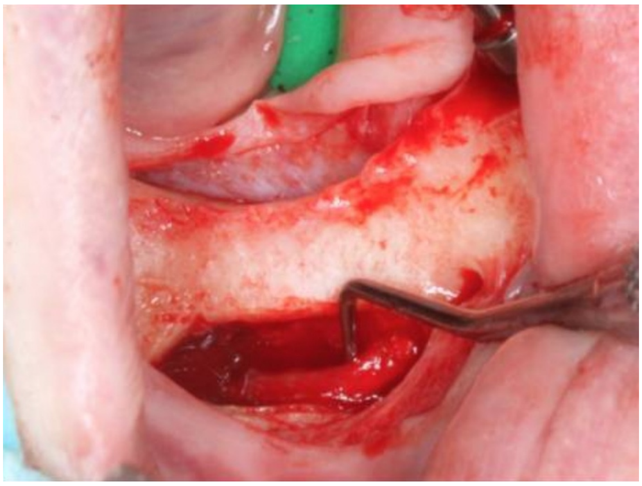

Figure 3. Intraoperative photograph showing the inferior alveolar neurovascular bundle during lateralization (courtesy of Dr. Dainius Razukevicius, Kauno Implantologijos Centras, Kaunas, Lithuania).

In addition to standard lateralization and transposition approaches, Peleg et al. (2002) described another modified technique for inferior alveolar nerve lateralization with simultaneous implant placement.

A crestal incision was performed with anterior and posterior releasing incisions. The incision line extends approximately 1 cm beyond the planned osteotomy site. This was followed by careful elevation of a full-thickness mucoperiosteal flap to expose the alveolar ridge and buccal cortex. During flap elevation, special attention was given to preserving the integrity of both the periosteum and the neurovascular bundle at the level of the mental foramen. Dissection was conducted below the neurovascular bundle as it exited the mental foramen to increase flap relaxation and improve exposure.

Subsequently, two osteotomies were performed using a surgical bur: one was a rectangular osteotomy posterior to the mental foramen extending 1 to 2 cm towards the most distal implant site; the second was a circumferential osteotomy performed around the mental foramen (Fig. 4a and 4b).

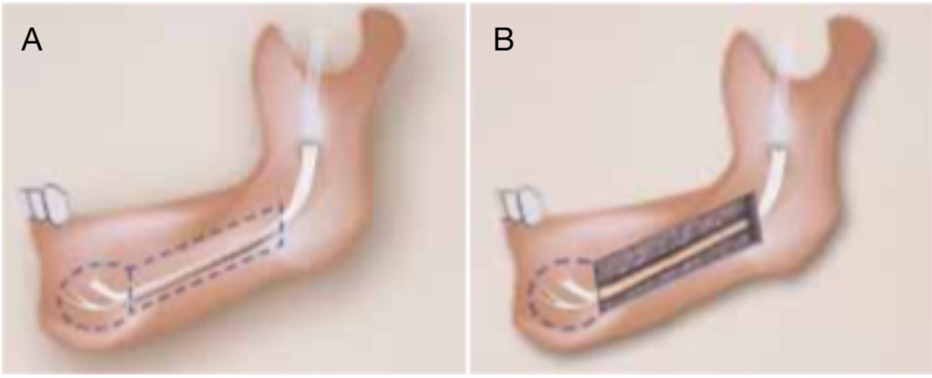

Figure 4. (A) and (B) Technique involving the use of two osteotomies: one in the posterior edentulous area and the other around the mental foramen. Reprinted with permission from Peleg et al., (2002).

A small curved osteotome was used to elevate the posterior segment of cortical bone over the IAN, and the anterior round segment was also removed. Care must be taken to minimize trauma to the neurovascular bundle; therefore, small blunt curettes were used meticulously to remove the medullary bone lateral to the neurovascular bundle, eliminating all sharp edges of bone along the window that could lacerate the bundle. Once the osteotomy was completed, the neurovascular bundle was carefully isolated from the inferior alveolar canal using a nerve retractor and small blunt curettes.

To minimize trauma, retraction instruments should remain in place throughout the procedure, as repeated insertion and removal may increase the risk of injury to the neurovascular bundle. While the neurovascular bundle was retracted laterally, the endosseous implants were placed using standard surgical techniques.

Cylindrical non-threaded implants were preferred in this technique to avoid potential neurosensory complications when placed in close proximity to the neurovascular bundle. Some surgeons prefer to use demineralized freeze-dried bone allograft (DFDBA) between the implant and the nerve after implant placement to avoid direct contact. Many authors, including Del Castillo Pardo de Vera et al. (2008) and Peleg et al. (2002), recommended the application of a collagen membrane lateral to the nerve for ridge augmentation and to cover any dehiscence in the buccal segment where fixtures were inserted. A releasing horizontal incision was made in the periosteum to enable optimal wound closure without tension. The new location of the neurovascular bundle should be documented in the medical record to ensure appropriate planning for any future surgical procedures.

Although nerve repositioning procedures, such as lateralization and transposition, have traditionally employed rotary burs for bone cutting as described by Del Castillo Pardo de Vera et al. (2008) , Chrcanovic and Custodio (2009), Abayev and Juodzbalys (2015), and Peleg et al. (2002), a refined alternative was introduced by Khoury through the development of the MicroSaw® system. Designed for bony lid osteotomies, this system utilizes a thin diamond disk with soft tissue protection, allowing more precise cuts and minimizing the risk of injury compared to traditional rotary instruments (Khoury and Khoury, 2007, pp. 126, 196; Hanser and Doliveux, 2018).

Following this mechanical innovation, piezoelectric bone surgery emerged as a subsequent advancement in the field, offering a method of performing precise bone cuts using ultrasonic microvibrations rather than rotary motion. Developed by Italian oral surgeon Tomaso Vercellotti in 1988, this technique was designed to overcome the limitations of traditional instrumentation in oral bone surgery (Hanser & Doliveux, 2018). Numerous studies have demonstrated histological and histomorphometric evidence of wound healing and bone formation in experimental animal models. This system for cutting bone with microvibrations is characterized by an oscillation frequency of 20,000 cycles per second and an oscillating motion of 20–200 µm (micrometres). It cuts hard tissue smoothly without harming the nerve and soft tissue, providing an alternative to conventional drilling that is feasible in inferior alveolar nerve transposition (Chrcanovic & Custodio, 2009; Metzger et al., 2006). The tissue response is more favorable in piezosurgery than in conventional bone-cutting techniques such as diamond or carbide rotary instruments (Vercellotti et al., 2005). Shock waves in the fluid environment assist in reducing bacterial levels, providing a disinfecting effect (Walsh & Laurence, 2007).

The main advantages of piezosurgery include soft tissue protection, optimal visibility in the surgical field, decreased blood loss, reduced vibration and noise, increased patient comfort, and protection of tooth structure. In contrast, the use of conventional burs in inferior alveolar nerve transposition may cause neurological disturbances due to mobilization and overstretching of the nerve. Tearing of the axon occurs when it is overstretched (Gregg, 2002).

A study of 10 cases involving inferior alveolar nerve transposition demonstrated that the piezosurgery device enables the oral surgeon to avoid overstretching of the nerve by creating a small window and using an apicoronal inclination of instruments to capture the neurovascular bundles (Bovi et al., 2010). Another study reported that a 74-year-old female patient underwent transposition of the mental nerve by piezosurgery; post-operatively, she complained of pain and neurological disturbances in the lower lip, which resolved after two months (Sakkas et al., 2008). Thus, inferior alveolar nerve transposition with a piezoelectric device may be considered as a safe and effective method.

However, the main disadvantage of piezosurgery is its comparatively longer operating time (Peter, 2010). An experimental study by Bovi et al. (2010), comparing piezoelectric devices and conventional drilling on hard tissue, showed that the rotary bur cuts faster and produces a deeper cut than a piezoelectric device. The authors found that the cutting efficiency of a piezoelectric device depends on the position of the instrument tip, with the highest efficiency achieved when the tip is kept flat, while the efficiency of the rotary bur was independent of adjustments.

The effect of piezosurgery on the inferior alveolar nerve involves roughening of the epineurium without affecting deeper structures. However, the degree of nerve injury was lower than that observed when using the rotary bur (Metzger et al., 2006). Regarding wound healing, smooth surfaces in the periosteum created by the rotary bur appear to be more conducive to regeneration. Several studies reported no significant difference in wound healing after 42 to 90 days. The lesion of the epineurium is accompanied by morphological changes.

4 Discussion

Cases of atrophied mandibles represent a challenge for surgeons when placing intraosseous implants of adequate length. This difficulty arises primarily due to the proximity of the inferior alveolar canal to the alveolar crest. In resorbed mandibles, the position of the inferior alveolar canal is considered the most critical anatomical limitation. Therefore, the degree of bone resorption and the anatomy of the mental nerve must be carefully evaluated to avoid inferior perforation of the cortical plate or impingement on the mental nerve. Less frequent anatomical considerations include anterior looping of the mental nerve and the presence of the lingual foramen, which may pose additional challenges (Kingsmill & Boyde, 1998a; Proussaefs, 2005). In assessing patients and determining implant length and position, individual variations may also encompass the presence of bifid mandibular canals, accessory mental foramina, and the incisive branch (Chrcanovic & Custodio, 2009).

Numerous anatomical challenges associated with atrophied mandibles have been reported in the literature (Reich et al., 2011). To overcome these challenges, various surgical solutions have been proposed, including standard-length implants, autologous bone grafting followed by endosseous implant placement, transposition of the inferior alveolar nerve and artery, distraction osteogenesis, and short endosseous implants. The selection among these strategies is guided by the severity of alveolar ridge atrophy (as classified by Cawood and Howell), the anatomical site, and the clinician's level of experience (Al-Faraje, 2021, p. 203).

Among these options, ridge augmentation or reconstructive procedures using autologous bone or allografts are notable. Autogenous bone grafts have been employed for many years in ridge augmentation and remain preferable in certain cases. The use of autogenous bone grafts with osseointegrated implants was first discussed by Branemark et al. (1977), who utilized the iliac crest as a donor site. Additionally, autogenous bone grafts can be harvested from the mandible, featuring advantages such as adjacency between donor and recipient sites, adequate surgical access, reduced donor site morbidity, and lower costs (Pikos, 2005).

In a study by Ferrigno et al. (2005), 15 patients underwent inferior alveolar nerve transposition procedures prior to the placement of a total of 46 implants, resulting in cumulative survival and success rates of 95.7% and 90.5%, respectively, over a mean follow-up period of just over four years. However, nearly 25% of the patients (four) experienced disturbances in sensation as a consequence of the procedure. While autogenous bone grafts facilitate stress distribution around the implant bodies, nerve injury may still occur. Furthermore, there is a limitation on the volume of bone that can be harvested intraorally. In contrast, bone harvesting from extraoral donor sites, such as the iliac crest, typically necessitates hospitalization, general anesthesia, prolonged surgical duration, and extended recovery. Additionally, it requires a secondary surgical site for harvesting autologous bone, which increases patient morbidity.

The resulting alveolar crest augmentation is also challenging to predict due to the risk of wound dehiscence and the high rate of graft resorption (Del Castillo Pardo de Vera et al., 2008). This resorption is influenced by multiple factors, including the grafting technique, anatomical location, type of surgery, muscular forces, and soft tissue pressure. Furthermore, the quality of both the graft and recipient bone, the degree of revascularization and revitalization, and even genetic predispositions can affect the severity of bone loss. The interplay of these variables makes it difficult to accurately predict the final volume of the grafted area (Khoury & Khoury, 2007, p. 198).

The decision to perform either vertical bone grafting or lateralization of the mandibular nerve depends on the available prosthetic space and the relationship between the implant length and the crown. If the prosthetic space between the maxillary teeth and the mandible is significantly wider than the normal length of the dental crown, vertical augmentation using an onlay bone graft is typically performed. However, if this space is reduced, such as in cases where the antagonist teeth are elongated, lateralization of the mandibular nerve should be considered to allow for safe implant insertion (Khoury & Khoury, 2007, p. 196).

Distraction osteogenesis of the alveolar crest is another option that has gained increasing popularity in recent years. It is a technique for gradual bone lengthening, allowing the body's natural healing mechanisms to generate new bone to augment alveolar ridge height (Rachmiel, 2001; Uckan, 2002). This technique enables the reconstruction of both hard and soft tissues of the alveolar crest in a one-stage surgery and has been associated with a relatively low complication rate. Additionally, the effect of creating new bone from living tissue allows early implant placement and functional loading (Zöller, Lazar,& Neugebauer, 2007, p. 280). Although in some instances the technique can be performed under local anesthesia and without the need for graft harvesting, it requires strict patient cooperation and involves multiple surgical steps (Del Castillo Pardo de Vera et al., 2008).

Furthermore, it has been recommended that, for proper fixation of the distractor, a minimum of 8–10 mm of residual bone height is required to ensure stability and preserve the vascular integrity of the transport segment (Nickenig, Zöller, & Kreppel, 2023). In such cases, an implant length of 10–13 mm is required to ensure adequate osseointegration (Nickenig, Zöller, & Kreppel, 2023; Rachmiel, Srouji, & Peled, 2001).

Despite its effectiveness, several studies by Uckan et al. (2002) and Gaggl et al. (1999) have noted potential applications and complications of vertical distraction techniques in patients treated with implants. Allias et al. (2007) reported that the prolonged presence of the distraction device in the area, encompassing the healing, distraction, and consolidation periods, can cause patient discomfort. In their study, 46% of patients experienced difficulty activating the device, and 10% required assistance. Additionally, discomfort associated with the activation rod was reported in 52% of cases. Complications may occur during different stages of treatment and include soft tissue dehiscence, infection, and mandibular fractures, particularly in cases with insufficient basal bone volume that had not been stabilized or when the osteotomy was positioned too far distally. The most critical complication, however, is the loss of vector control during distraction, which may lead to improper formation of the newly generated alveolar crest. Although rare, technical failures such as fracture of the device may result from improper patient handling, such as turning the device in the wrong direction or during the adaptation of the distractor plate prior to placement.

Post-distraction complications can also include implant failure, particularly when implants are placed too close to the osteotomy site. Failures occurred in all cases where the distance between the implant and the vertical osteotomy line was less than 4 mm. Furthermore, resorption of the distracted segment can occur after implant placement, especially in cases where the vertical gain is less than 4 mm or implant placement is delayed. Therefore, to prevent collapse of the regenerated bone, implant placement should occur no later than two weeks after removal of the distraction device (Zöller, Lazar, & Neugebauer, 2007, pp. 293–295).

Later in the literature, alternative implant lengths and diameters were introduced in response to clinical demands. Taking into account the vertical discrepancy between the arches, short implants, which have demonstrated high success rates in many cases, emerged as a viable solution (Chrcanovic & Custodio, 2009; Grant et al., 2009). The classification of short implants remains controversial, as some studies have considered implants shorter than 10 mm, while others have proposed stricter definitions, classifying them as less than 8 mm, 7 mm, 6 mm, or even 4 mm in length (Sáenz-Ravello et al., 2023).

Several researchers have reported that short dental implants, which were immediately loaded, demonstrate high survival rates and that implant length and diameter were not limiting factors for implant success (Degidi et al., 2007; Maló et al., 2007). Nevertheless, biomechanical factors related to prosthetic design are directly associated with implant survival. The use of short implants, particularly in combination with dentures exhibiting excessive lever arms, may contribute to failure (Chrcanovic & Custodio, 2009). Furthermore, placing short implants to avoid vital anatomical structures often results in increased crown-to-implant ratio, which is considered a biomechanical risk factors (Grant et al., 2009), and can act as a vertical cantilever, leading to crestal bone loss and potential implant failure (Jain et al., 2016).

One such complication is the bending overload in the posterior region. Rangert et al. (1995) concluded that prostheses supported by one or two implants that replace missing posterior teeth had an increased risk of mechanical failure due to excessive load forces. Guichet et al. (2002) demonstrated better sharing of occlusal loads and stress distribution with splinted versus individually restored implant designs.

In addition to these biomechanical factors, poor bone quality has also been identified as a particularly significant factor in the reduced success of short implants, as it compromises implant stability during placement and healing (Jain et al., 2016). Despite these limitations, short dental implants remain a beneficial treatment option, as they eliminate the need for additional surgical procedures such as autogenous bone grafting and inferior alveolar nerve transposition, thus avoiding donor-site morbidity and sensory complications, while also reducing costs and improving patient comfort (Grant et al., 2009). However, prospective long-term data on the clinical performance of these short implants remain limited, particularly in relation to their success under occlusal loading, unfavorable crown-to-implant ratios, and placement in sites with poor bone quality (Jain et al., 2016). In situations where these factors limit the use of short implants, more invasive techniques may be required to allow implant placement in the atrophic posterior mandible to better tolerate biomechanical complications. (Morrison et al., 2002).

The inferior alveolar nerve transposition technique is an option for the prosthetic rehabilitation of patients with moderate or even severe bone resorption. It has been suggested as an alternative treatment for the placement of longer fixtures and to engage two cortical plates for initial stability (Vasconcelos et al., 2008). These features are especially useful when placing one-stage implants (Morrison, Chairot,& Kirby, 2002).

Vasconcelos et al. (2008) reported that the inferior alveolar nerve transposition technique offers biomechanical advantages by increasing resistance to occlusal forces and promoting a favorable implant-to-prosthesis ratio. However, they also noted that the technique does not correct the increased interarch distance and is contraindicated when the crown-to-implant ratio is unfavorable. In addition, it may pose the risk of permanent damage to the nerve bundle. The degree of neurosensory disturbance (prolonged or permanent) has been related to the extent of compression of the inferior alveolar nerve (Peleg et al., 2002). Further damage to the mental nerve can occur as a result of the overstretching of the mucoperiosteal flap in the premolar area. Another cause of this complication is the lack of bone remodeling at the surgical site, due to insufficient revascularization as a consequence of canal obstruction (Chrcanovic & Custódio, 2009).

In the literature, two nerve repositioning techniques have been described. The "true" transposition technique involves the removal of the outer cortical bone, including the mental foramen, and the region designated for implant placement in one piece. This approach creates a large bone segment that may be difficult to manipulate and could increase the risk of permanent mental nerve injury.

The other technique, known as inferior alveolar nerve lateralization (IANL), creates a window posterior to the mental foramen without engagement of the mental nerve or sectioning of the incisive branch (Del Castillo Pardo de Vera et al., 2008). However, IANL requires greater stretching of the inferior alveolar bundle to allow implant placement (Peleg et al., 2002). According to Abayev and Juodzbalys (2015), this approach results in fewer neurosensory side effects compared to the transposition technique.

A third approach, introduced by Peleg et al. (2002), is a modified two-osteotomy technique involving one osteotomy anterior and another posterior to the mental foramen. This technique minimizes nerve stretching, thereby reducing the risk of complications such as neuropraxia, paresthesia, and anesthesia. It also avoids mobilization of the mental foramen, further decreasing the risk of nerve injury. Nerve function typically recovers more rapidly within 4 to 6 weeks when this technique is performed (Peleg et al., 2002).

The decision between lateralization and transposition techniques primarily depends on the surgeon's clinical experience, as both approaches require precise handling of the inferior alveolar nerve to avoid complications (Toledo-Filho, Marzola, Sánchez-Toro, & Toledo-Neto, 2008).

Morrison et al. (2002) recommended the use of general anaesthesia during inferior alveolar nerve transposition (IANT) to minimise patient movement and facilitate surgical access. However, special attention should be given to patients with systemic conditions, such as myotonic dystrophy (DM), which presents additional anaesthetic risks. According to Campbell, Brandom, Day, and Moxley (n.d.), these patients may experience airway obstruction, aspiration, or life-threatening cardiac conduction disturbances under anaesthesia. As a result, thorough preoperative evaluation and meticulous intraoperative monitoring are essential to ensure patient safety during IANT procedures.

According to an extensive study by Chrcanovic et al.(2009), the incidence of neurosensory disturbance of the mental nerve following inferior alveolar nerve transposition (IANT) is not always low, and that nerve conduction after partial and total lateral inferior alveolar nerve transposition had similar effects on inferior alveolar nerve recovery over six months post-surgery.

Nerve paresthesia following lateralization of the inferior alveolar nerve can also occur as a result of direct contact between the IAN and the sharp titanium implant thread. Thus, cylindrical implants are recommended when performing this procedure (Peleg et al., 2002). However, non-threaded implants have a lower surface area, which may reduce implant stability at the implant site (Abayev & Juodzbalys, 2015).

Regarding the effect of neurosensory disturbance in relation to sex and age, studies have shown that females are at a higher risk of developing postoperative complications than males, and primarily women and older individuals experience the most severe discomfort following nerve damage. The process of nerve regeneration after compression or minor crush injuries typically requires several weeks to six months. If no sensory recovery occurs during this period, permanent loss of continuity in the nerve trunk should be anticipated (Chrcanovic & Custódio, 2009). The clinical evaluation of these changes, in the case of inferior alveolar nerve injury, varies from simple methods that can be performed with readily available instruments in the operatory to more sophisticated procedures that require high-technology equipment. The simple clinical neurosensory tests are classified into mechanoceptive tests and nociceptive tests. Each test should be performed while the patient closes his or her eyes and is in a comfortable position, away from distractions. The clinician should use the contralateral side as a control, and the results must be accurately recorded (Alhassani & AlGhamdi, 2010).

Chrcanovic and Custodio (2009) concluded that inferior alveolar nerve transposition can be performed using panoramic radiography and clinical examination, without the need for advanced imaging techniques. Additionally, the procedure allows for the placement of longer implants and engagement of both cortical plates to enhance primary stability. However, it carries a major risk of neurosensory disturbance to the mental nerve. Loss of sensation in the lower lip and chin also results in the loss of sensation of its terminal incisive branch. This is of no consequence for individuals who are edentulous in the anterior mandible, but it may cause some disturbance to the residual dental and periodontal sensibility in any remaining anterior teeth (Morrison et al., 2002).

Greenstein and Tarnow (2006) mentioned that nerve damage may occur due to stretching or crushing of the mental nerve by the retractor. This may happen because of direct contact with the nerve or if the retractor presses on the flap containing the mental nerve. To avoid retractor slippage, Moiseiwitsch (1995) suggested performing a groove with a bur in the bone at the apex of a premolar, coronal to the mental foramen, thereby providing a positive seat for the retractor. It is safer to create a groove lateral to the foramen to avoid nerve injury due to retractor slippage.

Most investigators and clinicians (Kraut and Chahal, 2002; Luna et al., 2008) confirmed that preoperative planning is very important before implant placement. Neurosensory disturbances and haemorrhages, even in the anterior mandible after implant placement, may lead to trauma to any of the branches of the inferior alveolar nerve, mental, and lingual nerve.

In addition to neurosensory complications, other risks that may be associated with inferior alveolar nerve transposition include infection and pathological fracture of the mandible after implant placement (Karlis et al., 2003). Chrcanovic and Custodio (2009) also presented reports of rare mandibular fracture following IAN transposition and implant placement in the posterior region of an atrophic mandible. As this region is a flexion point and is subjected to mechanical stress during function, its structural integrity may be further compromised by the placement of multiple implants. This risk is also increased by extensive buccal bone removal and the presence of abandoned osteotomy sites. Although placing implants near the lower border of the mandible may enhance stability, care must be taken not to compromise mandibular continuity (Luna et al., 2008).

To minimize such complications, preoperative evaluation of bone volume is essential, and autogenous bone grafting should be considered when the remaining bone height is less than 6–8 mm (Proussaefs, 2005). In addition, performing precise and minimally invasive osteotomies is critical to preserving bone integrity (Chrcanovic & Custódio, 2009). Careful technique and the use of modern surgical tools, such as piezosurgery and the MicroSaw® system, play a crucial role in reducing complications and preserving both nerve function and bone integrity. In recent years, innovative techniques have been developed to minimize the risk of nerve damage and to improve the accuracy and safety of bone osteotomies. Among these advancements, piezosurgery and the MicroSaw® system have gained significant attention as alternatives to traditional rotary burs. Piezosurgery and MicroSaw perform better than conventional rotating instruments such as fissure burs, offering greater control and precision during bone cuts (Hanser & Doliveux, 2018).

Both the MicroSaw® and piezosurgery have emerged as valuable tools for bone osteotomies, particularly in anatomically sensitive regions like the retromolar area. The MicroSaw® was originally introduced in 1984 for creating bony lids in apical resections and for various osteotomy procedures. Its design features a thin 8 mm diamond disk and an integrated soft tissue protector that enhances cutting precision while minimizing soft tissue trauma (Khoury & Khoury, 2007, p.126; Hanser & Doliveux, 2018).

The indications for piezosurgery have increased in oral and maxillofacial surgery as well as in other medical specialties such as otorhinolaryngology, neurosurgery, ophthalmology, traumatology, and orthopedics. Although the piezoelectric device is more invasive to the bone than conventional burs, the degree and risk of injury with the piezoelectric device are lower than those with conventional rotary burs. Piezosurgery requires less hand pressure than rotary burs. This results in enhanced operator sensitivity, control, and precision for the cutting action due to the microvibration of the cutting tip. The cut is safe because the ultrasonic frequency used does not cut soft tissue. The cutting action is less invasive, producing less soft tissue damage, resulting in better healing (Aro et al., 1981; Vercellotti et al., 2001).

Quantius (2010) recommended the use of piezosurgery for bone incision and preparation of the inferior alveolar nerve because it is safer for soft tissue and reduces the risk of nerve damage. Therefore, when using piezosurgery or the MicroSaw system near the inferior alveolar nerve, it is essential to consider the anatomical course of the nerve, especially when osteotomies are performed below its level (Hanser & Doliveux, 2018).

In the literature, it has been clarified that inferior alveolar nerve transposition causes sensitivity disturbances in the area supplied by the inferior alveolar nerve. This is due to the mobilization and the associated stretching of the nerve, which can be stretched by about 10% to 20% before structural changes develop. Tearing of the axon occurs only when it is overstretched. However, the prognosis of these lesions after inferior alveolar nerve lateralization or transposition is reported to show very good healing, between 80% and 100% (Sakkas et al., 2008).

Conclusions

Inferior alveolar nerve repositioning should be performed by a skilled surgeon. Proper diagnosis and presurgical planning are essential to avoid nerve sensory disturbances. This technique is useful for providing the additional bone needed for optimal implant anchorage in such situations while reducing the risk of nerve damage or transection. Inferior alveolar nerve transposition can be safely and predictably performed with a lower risk to mental nerve sensibility. The regeneration of a nerve injury is evidenced by the spontaneous return of normal sensation, which depends on both the severity of the injury and the nerve involved. Recovery should be monitored using sensory tests to determine the need for micro-reconstructive surgery. Additionally, monitoring sensory recovery following micro-reconstructive surgery is indicated.

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Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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