Review Article

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Factors Affecting Primary Implant Stability: A Review

Ajinkya Wagh[1] Mahesh Gandhewar[2] Hemant Gadge[3] Priyadarshani Pawar[4] Aditya Kulkarni[5] Janhavi Rege[6]

[1]Senior Lecturer, Department of Prosthodontics, S.M.B.T. Institute of Dental Sciences and Research, Igatpuri, Ghoti Nashik, Maharashtra, India.
[2]Professor and Head, Department of Prosthodontics A.C.P.M. Dental College Dhule, Maharashtra, India.
[3]Reader, Department of Prosthodontics A.C.P.M. Dental College Dhule, Maharashtra, India.
[4]Reader, Department of Prosthodontics A.C.P.M. Dental College Dhule, Maharashtra, India.
[5]PG Student, Department of Prosthodontics A.C.P.M. Dental College Dhule, Maharashtra, India.
[6]PG Student, Department of Prosthodontics A.C.P.M. Dental College Dhule, Maharashtra, India.

ABSTRACT

Background: Dental implant therapy has a phenomenal rise and has occupied the summit in today's dentistry. Implant design, bone biology, primary stability, osseointegration, prosthetic options, etc., are the several issues taken into account for successful implant therapy. The factors which influence integration are the design of the implant, the material composition of implant, variance in the bone quality, and type of surgical procedure employed. The primary stability is the initial engagement between the bone and implant, and one has to ensure that it should be strong and paramount. Primary implant stability is influenced by three major factors, namely, implant-related factors, bone-related factors, surgical technique. For every patient in which we plan for an implant prosthesis all these factors need to be carefully gauzed, and a fine balance should be maintained, arrived on a best possible conclusion to get better primary stability which will further result in a predictable success. This article talks about these various factors involved in achieving successful primary stability.

Keywords: primary stability, factors, implant.

INTRODUCTION

Forty-five years ago, the first dental implant to replace a missing tooth in the human oral cavity was reported (Branemark et al. 1969)[1]. It was a sensational breakthrough in dentistry as it marked a new era to restore chewing function and aesthetics. Ever since, implant dentistry developed emphasizing aspects like dental materials, surface chemistry (Klokkevold et al. 1997[2], Salvi et al. 2004[3], Lazzara et al. 1999[4], Jansen et al. 1991[5]), surface characteristics (Buser et al. 1991[6], Abrahamsson et al. 2004[7], Carlsson et al. 1988[8]), as well as surgical soft and hard tissue biology.

The technique of placing titanium oral implants in healed edentulous sites and subsequently restoring the implant with a prosthesis has been recognized to be a highly predictive treatment for fully and partially edentulous patients. In general, the 5-year survival rate of implants is approximately 95%, and the 10-year survival rate is greater than 89% (Pjetursson et al. 2004[9]).

Primary implant stability has been acknowledged as an essential criterion for later achievement of osseointegration. Dental implant stability is a measure of the anchorage quality of an implant in the alveolar bone and is considered to be the consequential parameter in implant dentistry. Implant stability can occur at two different stages: primary and secondary [10]. It has been conclusively proved that stability both at placement and during function is an important criterion for the success of dental implants[11]. Primary stability is associated with the mechanical engagement of an implant with the surrounding bone, whereas bone regeneration

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***Correspondence Dr. Ajinkya Wagh.**
Department of Prosthodontics, S.M.B.T. Institute of Dental Sciences and Research, Igatpuri, Ghoti Nashik, Maharashtra, India.
Email: draj.wagh@gmail.com

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and remodeling phenomena determine the secondary (biological) stability to the implant[12,13].

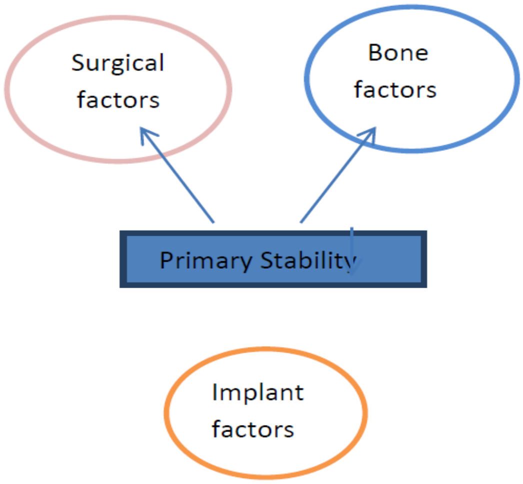


Fig 1: Factors affecting implant stability.

Primary implant stability at placement is a mechanical phenomenon that is related to FIG 1

1. local bone quality and quantity
2. implant factors
3. surgical technique.

Surgical factors:

Undersize drilling technique:

When evaluating whether the undersized drilling technique could enhance the primary implant stability, the two observational clinical studies [14,15] did not show a significant difference between the undersized drilling and the standard press-fit drilling techniques, but it was clearly in favour of the undersized group. The authors concluded that using thinner drills for implant placement in sites with poor bone density (posterior edentulous maxilla and mandible) is beneficial in enhancing primary implant stability. The higher primary stability of implants inserted after undersized drilling compared with those inserted after standard pressfit drilling might be interpreted by that the implants placed in undersized beds could compress the bone and increase its density, thereby enhancing the primary implant stability.

Osteotome Technique:

When evaluating what is the impact of using the osteotome in implant bed preparation on primary and/or secondary implant stability. Shayesteh et al. .[16] and Markovic et al. .[17] found a positive association between using the osteotome technique and the primary implant stability. This increase in primary stability could be due to changes in the micromorphology of peri-implant trabecular bone caused by apicolateral condensation by osteotome. So, the primary stability is enhanced in this low-density bone may be due to an increase in its density. In contrast, Padmanabhan and Gupta [18] demonstrated a statistically significant higher primary stability for implants placed with conventional drilling technique than those placed with osteotome in the maxillary anterior region.

Piezo surgery:

When evaluating whether using piezosurgery in implant bed preparation could influence the primary implant stability [19]. It demonstrated that there was no real difference in primary stability when implants were placed following the piezoelectric technique versus the conventional twist-drill technique.

Flapless surgical technique:

When assessing the influence of flapless procedure on primary and/or secondary implant stability[20]. Concluding from this study, there was positive association between the flapless technique and the primary and secondary implant stability at three months after surgery. Interpreting this finding, it can be assumed that raising a mucoperiosteal flap and having the bone denuded during a certain time causes a postsurgical reaction and may have an impact on the bone remodelling around the implant. While the opposite occurs with a flapless procedure where the bone remains covered by the periosteum; this may increase vascularity of the peri-implant mucosa, which furthermore appeared to be free from signs of inflammation.

Exposure of osteotomy site with infrared wavelength:

There was a study done with exposure of the osteotomy site with 830-nm low-level laser[21]. It concluded that there was no evidence of any effect of irradiating bone osteotomies with infrared wavelengths on either primary and secondary implant stability within 12-week follow-up in the posterior mandible.

Immediate loading:

It has been reported high survival rates with the immediate loading of dental implants, which are attributed to high primary stability[22]. A study evaluated the effect of immediate loading on the primary stability of endosseous implants placed in the anterior incisor region by mapping the stability over a period of time, using resonance frequency analysis. It was concluded that immediate loading of implants placed in the maxillary and mandibular incisor region did not seem to affect the osseointegration of the implants, which showed a high primary stability[23].

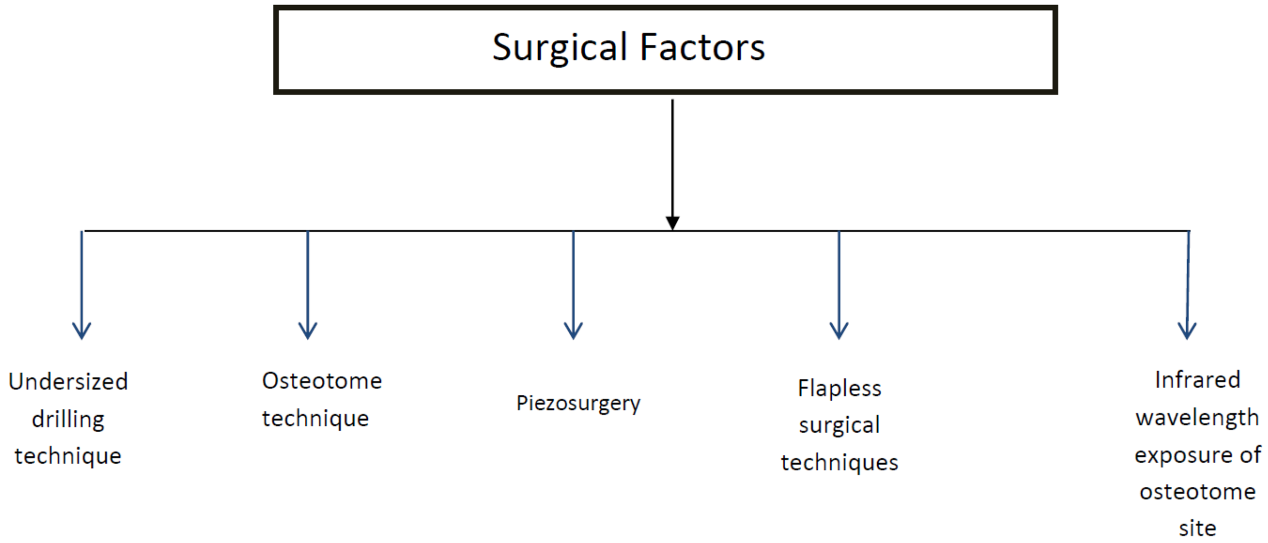


Table 1: Surgical technique.

Bone factors:

Bone quality is often referred to as the amount of cortical and cancellous bone in which the recipient site is drilled. A poor bone quantity and quality have been indicated as the main risk factors for implant failure as it may be associated with excessive bone resorption and impairment in the healing process compared with higher density bone[24,25]

A positive correlation was found between primary stability and cortical thickness of the artificial bone. In case of the poor supportive capacity of bone, compared with the implant diameter, a smaller drill diameter should be chosen, as from the findings of the present study, it can be assumed that the undersized drilling technique locally optimizes the bone density and consequently improves the primary stability[26].

Results by Miyamoto et al. .[27] demonstrated that dental implant stability is positively associated with the thickness of cortical bone thickness. In contrast to the previous studies, additional studies in the posterior mandible showed high failure rates due to the poor bone quality as well as other additional factors [28,29].

Computerized tomography (CT) has been regarded as the best radiographic method for analyzing the morphological and qualitative analysis of the residual bone [30]. It is also a valuable means for evaluating the relative distribution of cortical and cancellous bone[31]. Table 3

Bi-cortical anchorage was put forth from a clinical aspect, that is, the buccal (lingual) modality, in which a wide-diameter implant is suggested to be placed in a slightly buccal (lingual) position to engage buccal (lingual) compact bone. It is speculated that this pattern of anchorage has beneficial effects on stabilizing the immediately loaded implants against deteriorative micro-motion at the bone-implant interface in the initial phase of bone adaptation[32].

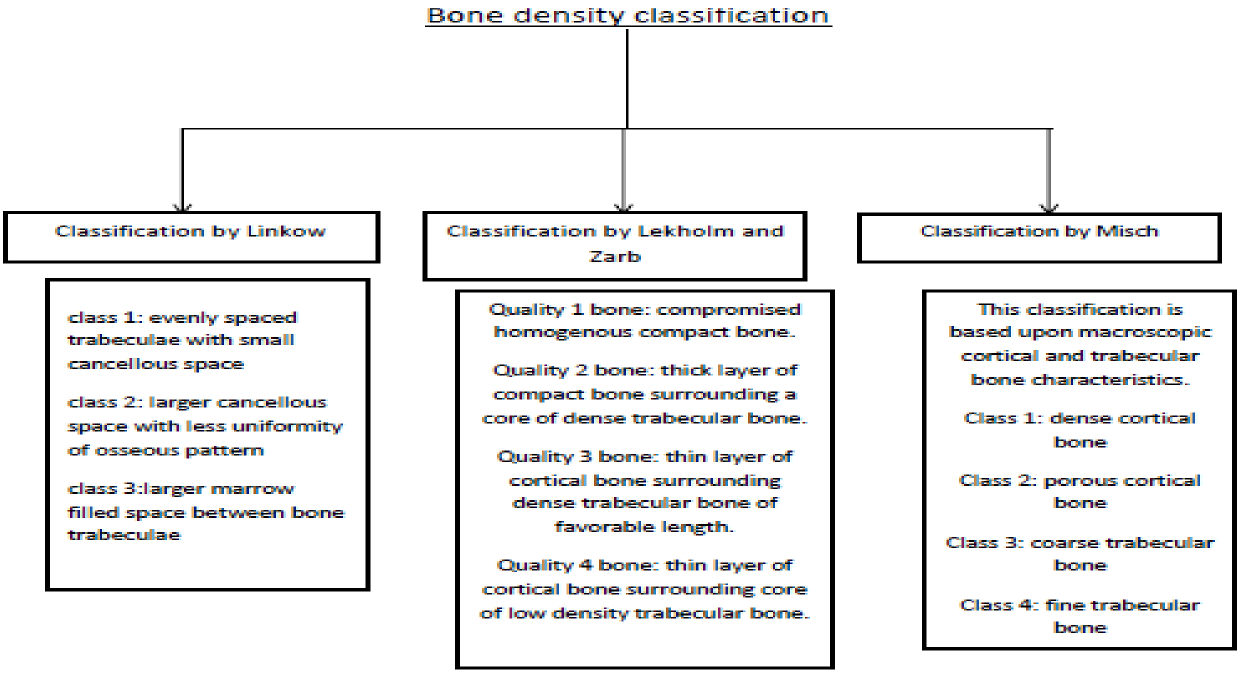


Table 2: Bone density classification.

Table 3: Bone density and common location

Bone type	D_1	D_2	D_3	D_4
Tactile sense	Oak or Maple	Pine or Spruce	Balsa wood	Styrofoam
Histology	Dense cortical bone	Dense to porous cortical & dense trabecular	Porous cortical & fine trabecular bone	Little cortical &fine trabecular
Usual location	Ant. Mandible 6% Post. Mandible 3%	Ant. Mandible 66% Post. Mandible 55% Ant maxilla 25%	Ant. Maxilla post. Maxilla	Post. Maxilla

Implant Factors:

Joe Merheb et al. in their study performed resonance frequency analysis (RFA) test at implant placement, and RFA and PTV were scored at loading. Bone density [Hounsfield (HU) scores] and coronal cortical thickness at osteotomy sites were measured from preoperative computerized tomography scans. They concluded that the implant length or diameter did not seem to influence primary stability when considered as single parameters. However, in a stepwise multiple regression analysis, both parameters became significant probably due to the elimination of the confounding influence of the cortical thickness and/or the impact of bi-cortical anchorage[33].

The implant diameter, however, was shown to affect the RFA scores significantly at loading and confirms therefore the tendency to use wider implants in zones of poor bone quality or poor anchorage to improve success by increasing the possible bone to implant contact. Implant design refers to the three-dimensional structure of an implant with all the components and features that characterize it. It has been reported that the implant design is a vital parameter for attaining primary stability[34]

Machined surface:

The first generation of osseointegrated implants had a relatively smooth machined surface[35]. The healing around the implant is characterized by an increase in bone-implant contact starting at the implantation while the biomechanical stability slightly decreases over the first weeks, possible due to inflammation and bone remodelling, and being fully recovered after 4 weeks in rat tibia[36]. Endosteal down the growth of bone tissue covering the implant threads occurs in the marrow cavity and reach up to 70% bone-implant contact after 16 weeks in rat tibia which could be compared to clinically stable oral implants retrieved up to 16 year after implantation where the bone-implant contact was measured to 56-85% [37]

Sand Blasting:

Increased roughness of an implant could be achieved by blasting the surface by small particles, usually called sandblasting or grit blasting. When the particles hit the implant surface, it will create a crater. The surface roughness is hence dependent on the bulk material, the particle material, the particle size, the particle shape, the particle speed and the density of particles. Implants blasted with 25 µm and 75 µm particles show higher removal torque compared to a machined implant surface after 12 weeks of healing in either rabbit tibia or femur[38].

Acid etching:

With acid etching, the surface is pitted by removal of grains and grain boundaries of the implant surface, as certain phases and impurities are more sensitive to the etching a selective removal of material is obtained. Significantly higher bone-implant contact was observed for acid-etched implants compared to machined implants in a rabbit model after 1 and 2 months, while no difference was found after 14 days[39]. Significantly increased removal torque was needed to remove acid-etched implants compared to the machined implant after 1, 2- and 3-months healing in rabbit while significantly lower removal torque was needed when comparing to titanium plasma-sprayed implants [40].

Acid etching + sandblasting:

Commercially available dental implants are usually both blasted by particles and then subsequent etched by acids. This is performed to obtain a dual surface roughness as well as the removal of embedded blasting particles. Significantly higher removal torque and higher bone-implant contact has been observed for blasted and fluoride modified implants compared solely blasted implants in a rabbit model after 1- and 3-months healing [41].

Anodized surface:

The structural and chemical properties could be tailored by varying different process parameters, such as anode potential, electrolyte composition, temperature and current[42]. Significant higher bone to implant contact has been reported as well as increased biomechanical removal torque values for phosphorous-containing anodized surfaces compared to machined surfaces in dog and rabbit[43].

Laser modified micro- and nano-structured surface :

The laser is an emerging field for use as a micromachining tool to produce a 3-D structure at micrometre and nanometer level. The technique is a method of choice for complex surface geometries. The technique generates short pulses of light of single wavelength, providing energy focused on one spot. It is rapid, extremely clean, and suitable for the selective modification of surfaces and allows the generation of complex microstructures/ features with high resolution. These advantages make the technique interesting for geometrically complex biomedical implants. The Branemark BioHelix Implant has surface modified with laser micromachining process to create micro- and nano-structured surface roughness in only the inner part of the thread. The inner part of the thread is believed to be more suitable for bone formation than the outer part[44]. Short-term, experimental in vivo studies of laser-modified titanium implants with nanoscale surface topographical features have demonstrated a significant increase in removal torque and different fracture mechanisms [45]. Some surface reactive materials have shown the ability to form an interfacial chemical bond with surrounding tissues through a series of biophysical and biochemical reactions, causing 'bioactive fixation' of the implant[46].

Bioactive materials can be biostable (i.e. synthetic hydroxyapatite) or bioresorbable (i.e. bioactive glasses and glass-ceramics). Some bioactive ceramics like bioactive glasses of certain compositions have been claimed to have a real chemical bonding ability with soft tissues[47]. Calcium phosphate ceramics are integrated within bone following a well-known sequence of events (Frayssinet, et al. 1993)[48]. They are considered to be bioactive and osteoconductive.

High bone quality and presence of cortical bone are indispensable for good primary stability, which is believed to also be influenced by implant-related factors such as morphology, length, diameter, surface structure and distance between threads[49, 50]

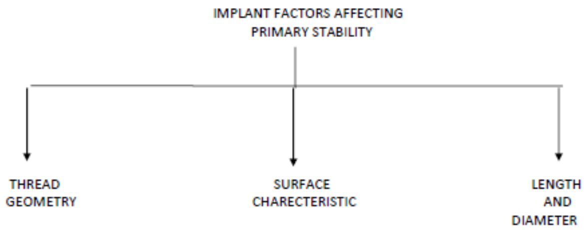
Chang (2012), and his associate concluded that an implant with a square thread profile might provide the best primary stability under immediate loading[51]. Erslan *et al*. (2010) concluded in their study that the maximum von Mises stress value of the square thread type was lowest. [52]

Thread pitch is defined as the distance between two neighbouring threads, measured on the same side of the axis. It also refers to the number of threads per unit length. Therefore, when implants have the same length, a smaller pitch indicates more threads, leading to greater surface area[53]. Orsini *et al*. 2012 conducted an animal study placing "narrow-pitch" (0.5 mm) and "wide-pitch" (1.7 mm) implants in a sheep iliac crest model. The findings suggested that the greater BIC gained by reducing thread pitch could improve initial anchorage and primary stability in cancellous bone[54]. Chun *et al*. In their FEA study have conclusively proved that Stress decreased as thread pitch decreased [55]

Lan and his colleagues recommended 1.2 mm and 1.6 mm as the optimal thread pitches of triangular- and trapezoidal-threaded implants, respectively. For V-shape threads, the implants with a 0.8-mm pitch produced the most favourable stress distribution. Thus different thread design has a different optimal pitch value when stress is considered [56, 57]. Tread depth and width clinically influence implant insertion and surface area. The shallower the tread depth, the easier the implantation procedure, especially in the high-density bone. It may be able to eliminate the need for tapping during the surgery. On the contrary, deep threads increase the functional surface area at the bone-implant interface, which can improve primary stability in the low-density bone or the region with high occlusal load[58]

Winter et al. .2010 found a positive correlation between implant length and PS after implant insertion in reduced bone quality. This is in agreement with the investigations of Barikani et al. .2013, who inserted tapered implants of different lengths (10 and 13 mm) and three different diameters (3.4, 4.3, and 5.0 mm) into bone block types D1 and D3. They demonstrated an increase in implant stability by a selection of longer implants.[59,60]. In contrast, S.C. Mohlhenrich et al. 2013 found in there study that, the diameter of an implant has a greater influence on primary stability than length. In particular, in the case of poor bone quality, a variation of implant geometry can lead to significant improvement in primary stability[61]

Table 4: Implant factors affecting primary stability.



DISCUSSION

Surgical, bone and, implant factors should be evaluated, thoroughly by the clinician to arrive at a best possible treatment plan for implant restoration so that the outcome of the treatment is positive, according to Bilan et al. (2010) who did there study focusing on primary stability and have concluded that in cancellous bone, partially conical dental implants with a wide diameter placed with a modified surgical technique, including under-dimensioned implant bed preparation and preservation of the cortical layer to obtain better primary stability can be recommended [62].

According to buccal bi-cortical anchorages could significantly increase both bending and axial NF values of dental implants, but extra-buccal cortical bone engagement could not produce considerable increments of NF (natural frequency) values as anticipated. Increasing implant diameter could result in limited increases of NF values in case of implants being bi-cortically anchored [32]. According to Dominic O'Sullivan, the tapered self tapping type of design as used in the study has appeared to maintain a high primary stability even in Type 4 bone. Author has further stated that, concern must be that the taper may lead to high compression forces during placement. With high compression, disturbance of the local microcirculation may occur, leading to necrosis of the osteocytes and bone resorption. It is reasonable to imagine that there is a balance point at which the degree of taper is such that there is an optimum level of primary stability without inducing resorption in the local bone [63]. Thus again the point of maintaining a balance of the influencing factors is rightly brought out in this study.

According to the data obtained from a in vitro study by, tilted implants with a progressive thread design and 10- degree angulation seem to have a greater PS than implants placed in the common axial direction (i.e., 0-degree angulation). This is a finding specifically for bone qualities type II and IV, which were observed using the ISQ values. Similar results were found with the Periotest device, explaining that the PS for tilted implants with a progressive thread design has better stability when compared with the conventionally placed implants. This may be explained because of the configuration of the instruments during the osteotomy preparation, which allows a better condensation in the middle and apical parts of the osteotomy. Furthermore, the middle and apical areas of the osteotomy contain more cancellous bone, which can increase the bone quality leading to a higher percentage of bone-implant contacts. Clinical studies of tilted implants with various designs allow higher stability and long-term success. This concept of implant placement can be used in areas with anatomical limitations (ie, sinus floor, mental foramen, etc.), providing an improvement of the stability due to placement of longer implants, when implants are tilted [64].

Although clinical evidence is limited, it is possible to conclude that the thread shape plays an important role in stress transfer between the implant and the surrounding tissue and determines the primary stability of the implant. The square thread profile may provide the best primary stability in an immediate loading situation. When primary stability is a concern, implants with smaller pitch are beneficial by increasing BIC (bone-implant contact) [65].

As far as the surgical technique are considered according to a recent systemic review summarized by Rola Muhammed Shadid et al., have concluded on following facts, There was weak evidence suggesting that using the osteotome technique to prepare implant beds in poor bone density could enhance the primary and secondary implant stability. There was weak evidence suggesting that ultrasonic implant site preparation by piezoelectric inserts does not affect the primary mechanical stability but could fasten the bone healing process and increase the secondary implant stability, earlier than the traditional drilling technique. There was weak evidence suggesting that a flapless procedure could enhance the primary and secondary implant stability.

There was insufficient evidence supporting or confuting the efficacy of irradiating bone osteotomies with infrared wavelengths for enhancing the primary or secondary stability of the implants [66]. The author has rightly pointed out that there is a need for more RCT with respect to these techniques having a larger sample size. Bone factors cannot be manipulated. So in a compromised situation such as the poor bone density of bone, the other 2 factors play a major role in the success of treatment. For e.g. Osteotome technique advocated by Summers is indicated to increase the density around the implant and to increase the bone to implant contact to improve the primary stability. In Underprepared osteotomy increase in moment of force is for placement of the implant into position. This moment of force is referred to as insertion torque. By increasing the insertion torque, it is possible to improve an implant's primary stability[67]. High implant insertion torque produces compression and distortion of the peri-implant bone; this has been claimed to induce deleterious effects on the local microcirculation, which may lead to bone necrosis and possible failure of implant. In order to achieve good primary stability, without creating excessive compression in the peri-implant bone, it has been suggested that implants be inserted with a torque of at least 30 Ncm.[68] Maintenance of low implant micro-movement, is essential in early healing periods, for growth of bone around implant surface, to achieve good primary implant stability[69]. Primary stability can be improved by adapting to good surgical technique and implant surface. For instance, the use of thinner drills and wider and tapered implant designs will result in high primary stability. This improvement is due to lateral compression of the bone trabeculae and an increase of the interfacial bone stiffness[23].

Two methods are usually employed to measure the clinical stability of an implant, namely, the Periotest (PT) and resonance frequency analysis (RFA) measurement using the Osstell device. Periotest uses a device which is an electrically driven and electronically monitored tapping head that percusses the implant a total of 16 times. The entire measuring procedure takes about 4 sec. The instrument includes a tapping rod that impacts the abutment/implant assembly. The rod is drawn by a propulsion coil toward the impacting surface and essentially moves at a constant velocity from the moment it leaves the handpiece until it impacts the surface.

This means that over a certain distance (approximately 4 mm), the tapping rod is moving at the same velocity and is designed to impact the surface at any time during this constant velocity travel. The end of the rod inside the handpiece is rigidly connected to an accelerometer, which produces an output proportional to its acceleration. PT values include a narrow range over the scale of the instrument and, thus, provide comparatively less sensitive information concerning implant stability [70]. It has been suggested that the measurement of the moment of force or torque (required for seating an implant in the bone) can also be used to measure the primary stability of an implant[71]. The RFA device measures the resonance frequency of a transductor attached to the implant body, which is stimulated by different frequencies. According to a study by Sul et al. [72], RFA is a reliable indicator for identifying implant stability with assurance.

Healing of long fractured bone is facilitated by maintaining absolutely no movement between the fractured ends[73]. If movement occurs, even at the micrometre range, it can induce stress or strain that may hinder the formation of new cells in the gap. The same phenomenon is applied at the bone-to-implant interface [74].

The induction of micromotion during functional loading may primarily be responsible for the failure of osseointegration and ultimately, implant loss [75]. Micromotions above 50–100 micrometres may negatively influence osseointegration and bone remodelling by forming fibrous tissues and inducing bone resorption at the bone-to-implant interface [76,77]. Therefore, high initial stability is essential for successful osseointegration of dental implants. A well-controlled micromotion positively influences the bone formation[28 78,79], in clinical situations of immediate loading of implants either in healed ridges or in extraction sockets.

Table 5: Primary stability and factors affecting.

Factors	Influence on primary stability
1. Bone quality and quantity Cortical bone > trabecular bone Bone is post. Mandible > bone in posterior maxilla Bone in male > bone in female 2. Implant characteristics Threaded > smooth surface Tapered wide > non tapered long implant short implant acid etched > mechanical surface Acid etched +sandblasted > only acid etched 3. Surgical technique undersize drilling technique osteotome technique piezosurgery flapless surgery exposure to infrared wavelength	Favorable Favorable Favorable More favorable More favorable Less Favorable More favorable Favorable Favorable in low density No different from conventional twist drill technique Favorable No effect

CONCLUSION

Primary implant stability is a fundamental factor in obtaining osseointegration. Patients increasingly are demanding implant-placement protocols that deliver functional and aesthetic implant-supported restorations quickly and economically, without requiring the use of a removable prosthesis. In order to meet these expectations, clinicians must find ways to place implants that have a high level of primary stability as well as rapid osseointegration. Clinical and radiographic evaluation of the bone quality and of primary stability remains essential. Early surgical approaches aimed at improving the amount of bone to implant contact. New implant designs, surface textures and surgical protocols have increased predictability in poor bone quality.

This literature review highlights the importance of achieving successful primary stability for successful implant integration. Bone quality and quantity, implant geometry, and surgical technique adopted may significantly influence initial implant stability and overall success rate of dental implants. Implant dentistry is a rapidly changing science. It is still evolving, and many new concepts, technique, are bound to come up, which will further increase the success rate of the implant.

CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

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