

REVIEW ARTICLE

Immediate loading: From biology to biomechanics. Report of the Committee on Research in Fixed Prosthodontics of the American Academy of Fixed Prosthodontics



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The concept of immediate loading has become popular in implant prosthodontics because of reduced treatment time and patient acceptance.¹ Much has been written on this topic, including a number of prospective clinical trial reports. In spite of the high success rates in most reports of immediately loaded dental implants, not all treatment modalities demonstrate consistently high clinical success rates.²⁻⁵ In addition, an understanding of underlying biologic and biomechanical mechanisms is lacking. In this report, the biologic and mechanical mechanisms of the success and failure in patients with immediate loading are summarized. More specifically, bone physiology, biomechanics, and characteristics of the bone implant interface are examined to identify potential critical factors for the success of immediate loading. Clinical recommendations for the immediate loading of dental implants are provided based on these analyses. For the purpose of this review, the definitions of different loading protocols in the latest *Cochrane Review* are adopted.⁶ “Immediate” loading is defined as an implant put into function within 1 week of its placement; “early” loading as those implants put into function between 1 week and 2 months; and “conventional” (also termed “delayed”) loading as those implants loaded after 2 months.

ABSTRACT

One of the key issues of modern implant rehabilitation is the overall shortening of treatment time. High survival rates for immediately loaded implants have been reported in many but not all treatment modalities. In recent years, considerable evidence for the successful immediate loading outcome has been documented in both animal and human studies. The mechanical force generated by immediate loading may explain the favorable biologic response of bone and surrounding tissue when the design is biomechanically sound. However, in certain treatment modalities, including but not limited to immediately placed maxillary anterior single implants, immediately placed single molar implants, unsplinted implants in overdentures, and implants in maxillary anterior partial fixed dental prostheses, loading dental implants indiscriminately and immediately is not safe because of potentially unfavorable stress distribution and a negative cellular response under such high stress during early healing. (J Prosthet Dent 2015;113:96-107)

ANALYSIS OF IMMEDIATE LOADING SUCCESS

Immediate loading was originally implemented in the anterior mandible⁷⁻¹⁰ and had excellent success rates with cross-arch stabilized fixed prostheses. This treatment protocol was applied to the edentulous maxilla and also had excellent success rates.¹¹⁻¹⁵ The immediate loading of single implant restorations also has enjoyed great success. A meta-analysis of 13 prospective trials with various prosthetic modalities revealed a failure rate of immediately loaded implants similar to that of conventionally loaded implants.¹⁶ Because of the high success rates across these modalities, clinicians frequently choose to immediately load implants to decrease treatment time,^{17,18} increase patient acceptance, and maintain optimal soft tissue esthetics.¹⁹ The biologic evidence and mechanisms of the success of this treatment modality were reviewed.

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Biological Evidence of the Success

To achieve a high success rate in implant therapy by using the immediate loading approach, understanding how periimplant hard and soft tissues respond to different loading conditions is critical. Both animal studies and human studies that found favorable periimplant tissue response to immediate loading are summarized.

Animal studies

Periimplant bone responds similarly to a titanium (Ti) implant surface (osseointegration) in different loading conditions. Romanos et al^{20,21} compared bone implant contact (BIC) and bone area around immediately loaded, delayed loaded, and unloaded implants in monkeys. Immediate loading was found to stimulate osseointegration in a manner similar to that of delayed loading. Compared with unloaded implants, both immediately loaded and delayed loaded implants had similar levels of BIC and bone area within the threads and around the apices of the implants (3.5-mm-diameter Ti implants with a progressive thread design). A more recent study was designed to compare immediately loaded versus standard 2-stage loaded implants in dogs.²² Polycarbonate shell crowns were relined with acrylic resin and cemented on Ti implants (Biohorizon) placed in healed mandibular premolar areas immediately after the surgical placement of these implants. The occlusion was relieved from centric and lateral contacts (nonocclusal loading). After 3 months of loading, the BIC, implant stability quotient, bone type within 2 mm of the implant surfaces, and marginal bone loss were all similar when compared with standard 2-stage loaded implants.

A few studies reported a better or faster osseointegration in immediately loaded implants compared with early loaded or unloaded implants. Piattelli et al²³ compared immediately loaded (metal suprastructure was cemented after 3 days of implant placement) and unloaded implants on both maxilla and mandible in monkeys. Immediately loaded implants had significantly greater BIC than unloaded implants, and no fibrous connective tissue was present at the interface. Moon et al²⁴ reported higher bone formation in immediately loaded implants compared with early loaded or unloaded implants in dog mandibles. Immediate placement of dental implants in fresh extraction sockets cannot prevent the alveolar ridge resorption that happens naturally after tooth extraction in animal models.²⁵⁻²⁷ Whether immediate loading can help maintain marginal bone level around implants is uncertain because the previous evidence found a more favorable osseointegration (higher BIC, bone area, and bone density) compared with the delayed loading protocol. Blanco et al²⁸ used a dog model to test this hypothesis but failed to prove that immediate loading can prevent the buccal bone

resorption that occurs after tooth extraction without immediate implant placement. Immediate loading and delayed loading had a similar amount of buccal marginal bone resorption in this study.

Berglundh and Lindhe²⁹ stated that implant transmucosal attachment consists of a barrier epithelium (approximately 2 mm) and a zone of connective tissue (approximately 1.3 to 1.8 mm). These parameters also were determined to be similar to implants placed immediately after extraction when using similar histometric analyses.^{25,30} Biologic width is a stable dimension in both natural teeth³¹ and around dental implants.³² In a recent study, the barrier epithelium, connective tissue, and the biologic width dimensions were found to be comparable around immediate implants with immediate loading versus immediate implants without loading.³³ The immediate loading animal studies that investigated the periimplant hard tissue response included in this review are summarized in [Table 1](#).

Human studies

Early studies of human participants were case reports of retrieved implants from autopsies. Four Ti plasma-sprayed screw implants were placed and immediately loaded with a bar-supported overdenture for 12 years.³⁴ Implants were retrieved at autopsy, and histologic analysis was performed. The BIC was 70% to 80% at the interface, with active bone recasting. Romanos and Johansson³⁵ reported a patient with 12 grade-2 Ti implants placed (6 in the maxilla and 6 in the mandible) and immediately loaded with acrylic resin restorations followed by metal ceramic restorations 4 months after insertion. When the patient died 7 months after the implants had been placed, all of the implants had successfully osseointegrated, in spite of the patient being a heavy smoker. The BIC was 46%, and bone volume was 47%. Proussaefs et al³⁶ reported 79% to 84% of BIC on hydroxyapatite-coated implants in canine areas after 7 years of service in 1 patient. Degidi et al³⁷ reported on 11 implants (7 in the mandible and 4 in the maxilla) that served as the distal abutments of provisional partial fixed dental prostheses and were subjected to immediate occlusal loading in the posterior jaws of 6 patients. After 10 months of loading, all the implants were retrieved for histologic examination. Mature bone was present at the interface of all the implants. The BIC ranged from 60% to 65% for all the implants. The results from multiple individuals confirmed that osseointegration of dental implants does occur during immediate loading. A systematic review, including a total of 29 retrieved implants with different designs and surfaces after 2 to 10 months of loading had satisfactory histologic and histomorphometric results.³⁸

A few clinical studies (immediately loaded implants versus delayed or unloaded implants) have been done

Table 1. Summary of cited immediate loading (IL) animal studies

Study	Year	Animal Species	Site Status	Type of Implant	Type of Prosthesis	No. Implants and Animals	Loading (functioning) Period	Implant Survival Rate (%)	Periimplant Bone Tissue (BIC%)
Piattelli et al ²³	1998	Monkey	Healed (MX and MN)	Plasma-sprayed Ti	Splinted cast metal crowns (centric occlusion)	48 (24 IL and 24 UL) in 6 animals	9 mo	IL, 100; UL, 100	IL, 67.3 (MX), 73.2 (MN); UL, 54.5 (MX), 55.8 (MN)
Romanos et al ²⁰	2001	Monkey	Healed (MN)	Ankylos, Dentsply	Splinted acrylic resin crowns followed by splinted metal crowns (centric occlusion)	36 (18 IL, 18 DL) in 6 animals	3 mo	IL, 100; DL, 100	IL, 64.3; DL, 67.9
Romanos et al ²¹	2003	Monkey	Healed (MN)	Ankylos, Dentsply	Splinted acrylic resin crowns followed by splinted metal crowns (centric occlusion)	48 (21 IL, 21 DL, 6 UL) in 9 animals	3 mo	IL, 100; DL, 100; UL, 100	IL, 64.3; DL, 67.9; UL, 50.2
Moon et al ²⁴	2008	Dog	Healed	Osstem	Splinted composite resin crowns	50 (20 IL, 20 EL, 10 UL) in 5 animals	16 wk	IL, 100; EL, 100; UL, 100	New bone formation rate (%): IL, 73.5; EL, 75; UL, 62.0
Blanco et al ²⁸	2011	Dog	Fresh extraction Sites	Straumann	Splinted acrylic resin crowns (occlusal contacts)	24 (12 IL, 12 UL) in 6 animals	3 mo	IL, 100; UL, 100	Bone resorption on either side of implants were measured and found no significant difference between IL and UL implants
Rismanchian et al ²²	2012	Dog	Healed (MN)	Biohorizon	Polycarbonate crowns relined with acrylic resin (no occlusion)	12 (6 IL and 6 UL) in 3 animals	3 mo	IL, 100; UL, 100	IL, 51.3; UL, 44.4

IL, immediate loading; BIC, bone-to-implant contact; MX, maxilla; MN, mandible; Ti, titanium; UL, unloaded; EL, early loading; DL, delayed loading.

but often with only 1 individual. Testori et al³⁹ reported on an individual who received 11 Ti implants in the mandible with Type IV soft bone (6 were immediately splinted and loaded with an interim prosthesis, and the other 5 were submerged). After 2 months, 2 submerged implants and 1 immediately loaded implant were retrieved and analyzed histologically. All 3 implants had successful osseointegration (BIC, 38.9% for the submerged implants and 64.2% for the immediately loaded implants). In another case report, 2 Ti implants were immediately placed in postextraction sockets in symmetrical quadrants in 1 patient.⁴⁰ One implant was immediately loaded with an acrylic resin crown in occlusion, and the other implant was not loaded. After 6 months, both implants were retrieved and compared histologically. The BIC was similar in the 2 implants. More compact, more mature, and better-organized periimplant bone, with many areas of recasting and some osteons, was found around the loaded implant, whereas only thin bone trabeculae were found around the unloaded implant.

Studies with more than 1 participant are available, but the sample size is still very small. Rocci et al⁴¹ reported a study with 9 oxidized Ti implants in the posterior mandibles of 5 participants. Implants were either loaded immediately or after 2 months of healing. The loading time ranged from 5 to 9 months. Analysis of the results found the undisturbed healing of soft tissue and bone tissue with no apparent differences between responses to immediately and early loaded implants. Donati et al⁴² reported a study of 13 participants in need of single tooth replacement. Each of these individuals received 1 immediately loaded implant on one side of the jaw and 1 unloaded implant on the other side of the jaw. Two healing times (1 and 3 months) were included in the study. Analysis of the results (BIC) found that immediate loading of implants did not influence the osseointegration process. The density of newly formed periimplant bone at the immediate loading implant sites seemed to be greater than that at the unloaded control implant sites. The immediate loading human studies included in this review are summarized in Table 2.

Table 2. Summary of cited immediate loading (IL) human studies

Study	Year	Type of Study	Site	Type of Implants	Type of Prosthesis	No. Implants and Participants	Loading (functioning) Period	Implant Survival Rate (%)	Periimplant Bone Tissue (BIC%)
Ledermann et al ³⁴	1998	Case Report	Anterior edentulous MN	TPS Straumann	Bar-supported overdenture	4 Implants in 1 participant	12 y	100	76.4 (range, 73.4-82.9)
Proussaefs et al ³⁶	2000	Case report	MX canine area	Hydroxyapatite-coated root form	Single crowns	2 Implants in 1 participant	7 y	100	79-84
Testori et al ³⁹	2002	Case Report	Edentulous MN (soft and normal bone)	Osseotite, Biomet 3i	Screw-retained acrylic resin with metal-reinforced provisional FDP	6 IL and 5 UL implants in 1 participant	2 mo	IL, 100; UL, 100	IL, 64.2; UL, 38.9
Degidi et al ³⁷	2003	Case series	Posterior MX (4) and MN (7)	Frialit2, Dentsply (7), IMZ screw type (2), IMZ cylindric (2)	Provisional FDPs, bar-supported overdenture	11 Implants in 6 participants	10 mo	100	Histologic bone loss: 0.7-2.6 mm; BIC, 66.8 (Frialit2), 64.5 (IMZ screw type), 54.2 (IMZ cylindrical)
Rocci et al ⁴¹	2003	Clinical Trial	Posterior MN	Branemark oxidized	Provisional acrylic FDPs	9 Implants in 5 participants	5-9 mo	IL, 100; EL, 100	IL, 92.9; EL, 81.4
Romanos et al ³⁸	2005	Case Report	Edentulous MX and MN	Ankylos, Dentsply	Provisional acrylic FDPs followed by ceramometal FDPs	6 Implants in MX and 6 implants in MN in 1 participant	7 mo	100	46
Guida et al ⁴⁰	2008	Case report	Posterior MX (third molars)	PHI Ti plasma sprayed	Acrylic resin crown	2 Implants in 1 participant	6 mo	100	IL, 52; UL, 58
Donati et al ⁴²	2013	Clinical trial	Unknown	Astra Tech	Acrylic resin crown	26 Implants in 13 participants	1-3 mo	100	At 1 mo: IL, 25.6-32.0; UL, 24.7-30.8; and at 3 mo: IL, 41.5-51.2; UL, 40.6-49.6

IL, immediate loading; BIC, bone-to-implant contact; MN, mandible; TPS, titanium plasma sprayed; FDP, fixed dental prosthesis; MX, maxilla; IMZ, intra mobil cylinder; EL, early loading; UL, unloaded; PHI, primary healing implant; Ti, titanium.

Biomechanical Analysis of Immediate Loading Success

The key to successful outcomes with immediate loading is the control of micromotion or the reduction of strain at the healing bone-implant interface.^{43,44} To minimize this strain, prostheses must be engineered to minimize both the magnitude and mechanical advantage of applied forces. A common solution is to splint multiple implants rigidly together around an arch form with minimal cantilevers.⁴⁵ Early success with immediate loading was predicated on these design characteristics and is well documented.⁴⁶ The success of this prosthetic modality depends on controlling the bending moments of individual implants and maximizing the bone-implant interface area with the use of multiple implants.⁴⁷

Other prosthetic modalities also had excellent success rates with immediate loading, including single tooth restorations and posterior 3-unit fixed dental prostheses.^{2,48-60} These modalities do not possess inherent bending moment protection from cross-arch splinting,^{43,61} which necessitates the careful management of applied forces to limit the strain on the healing bone-implant interface. Other critical factors in these prosthetic

modalities are bone quality, implant design, diameter, and length.⁶²⁻⁶⁴ All of these factors have been linked to strain at the bone-implant interface, which must be controlled to achieve predictable osseointegration.⁶⁵

Biologic Mechanism of the Favorable Response of Bone-Implant Surface to Immediate Loading

The bone mass is regulated by the balance between bone resorption and bone formation. Bone resorption is carried out by hematopoietically derived osteoclasts. Mesenchymal stem cell-derived osteoblasts build the bone by producing a matrix that then becomes mineralized. Some of the osteoblasts are embedded in the bone matrix and become osteocytes, which are the long-lived bone cells. In the adult skeleton, osteocytes make up more than 90% of all bone cells compared with 4% to 6% osteoblasts and 1% to 2% osteoclasts.⁶⁶ Importantly, osteocytes have a mechanosensory function and can regulate osteoblast and osteoclast function. Mechanical loading plays a critical role in maintaining skeletal integrity and in recasting the bone. Proper loading is known to increase bone mass, and the frequency, intensity, and timing of loading are all

important determining factors.⁶⁷⁻⁶⁹ Osteocyte cell bodies are embedded inside the bone tissue and are surrounded by fluid-filled spaces known as lacunae.⁷⁰ Osteocytes have long dendritic processes, which travel through the bone in tiny canals called canaliculi and form a network that connects the neighboring osteocytes and the cells on the bone surface, such as osteoblasts and osteoclasts.⁷¹ The lacunae, canaliculi, osteocytes, and dendritic processes form the lacuna-canalicular network.⁷² Osteocytes are dispersed throughout the mineralized matrix and are connected to each other and cells on the bone surface through dendritic processes in the lacuna-canalicular network.⁷³ The mechanical loading of bone causes fluid flow in the lacuna-canalicular network, and osteocytes sense this signal and convey it to osteoblasts, osteoclasts, and bone-lining cells.⁷⁴ In response to this signal, osteocytes send out bone remodeling signals to both osteoblasts and osteoclasts (Fig. 1).⁷⁵⁻⁷⁷ Mechanical loading can significantly reduce the sclerostin (a negative bone formation regulator) expression in osteocytes, thereby enhancing bone formation.⁷⁵ In response to shear stress, osteocytes can also rapidly release prostaglandin,⁷⁸ which can induce new bone formation and, therefore, help mediate mechanical loading-induced bone formation.⁷⁹ By contrast, on mechanical loading, osteocytes send signals that inhibit osteoclast activation.⁸⁰ Altogether, in response to mechanical loading, osteocytes can orchestrate the signal cascade to enhance bone formation and inhibit bone resorption.

Dental implants transmit mechanical stress into the surrounding bone. One of the most critical factors in the successful osseointegration of an implant is the primary stability at the time of placement.⁸¹ The loss of primary stability is known to be faster than the development of secondary stability (established by new bone formation), which causes a gap between the 2 processes and results in a stability dip.^{82,83} The stability dip is the foundation of the historical clinical recommendation that implants should be unloaded until the dip has passed. Clinically, implant stability can be evaluated by cutting force resistance analysis, reverse force test, Periotest measurement, and resonance frequency analysis. However, no definite method of evaluating implant stability has yet been established.⁸³ The mechanobiology discussed here is based on the assumption that good primary stability is achieved and that the high strain caused by the applied load does not cause material (bone) failure. Mechanically anchored implants are mostly surrounded by bone, and any stress applied to implants will deform the surrounding bone. As mentioned previously, osteocytes inside the bone can sense this signal through the fluid flow change in the lacuna-canalicular network. In response to this signal, osteocytes can send out signals to osteoblasts to enhance new bone formation and to osteoclasts to inhibit bone resorption. Of note, both bone formation

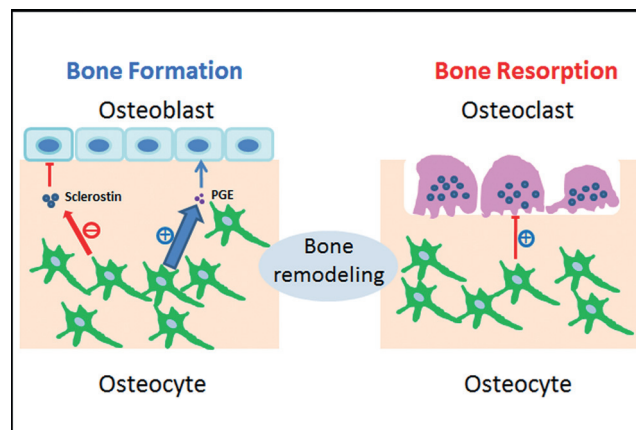


Figure 1. Mechanical stress promotes bone formation by osteoblasts and inhibits bone resorption by osteoclasts through mechanosensory function of osteocytes. Mechanical loading can reduce sclerostin (negative bone formation regulator) expression in osteocytes and increase prostaglandin (PGE) production (positive bone formation regulator), thereby, enhancing bone formation. In addition, osteocytes send signals to inhibit osteoclast activation in response to mechanical loading. +, mechanical signal promotes this process; –, mechanical signal inhibits this process.

and bone resorption will occur in the bone remodeling process during the osseointegration process. However, the signals sent out by osteocytes in response to mechanical stress may favor bone formation, thus the net effect may be that bone formation is more than (or at least equal to) bone resorption. This favorable bone formation over bone resorption in response to mechanical load partly explains the biologic basis for the success of dental implant immediate loading. In contrast, the proper amount of micromotion in the bone-implant interface generated by immediate loading may serve to recruit osteoprogenitor cells from the surrounding tissue. Leucht et al⁸⁴ elegantly reported (by using a micromotion device) that a defined physical stimulus dramatically enhances bone formation in the periimplant tissue.

Implant surface types can affect cellular responses.⁸⁵⁻⁸⁷ Human osteoblasts cultured on machined Ti spread more and are flatter than cells cultured on rough Ti. However, blasted surfaces had increased messenger RNA expression of osteopontin, bone sialoprotein, and Runx2, which are osteoblast differentiation markers.⁸⁶ More interestingly, Sato et al⁸⁵ reported that osteoblasts respond to mechanical stimulation on Ti with different surface topographies differently than osteoblasts on acid-etched Ti surfaces. Mechanical stimulation can better promote osteoblast differentiation on an acid-etched surface, which suggests that implant topographies can play important roles in the cellular response to immediate loading.

In addition to the implant topography, chemical modification, fluoride treatment, and ultraviolet light

treatment on the implant surface can modulate osseointegration.⁸⁸⁻⁹⁰ Of these, the photofunctionalization of Ti implants has attracted considerable interest.⁹¹⁻⁹⁵ The photofunctionalization of Ti implants increased the bone-implant contact from 55% to 98.2% in an animal model.⁹² Suzuki et al⁹⁰ reported that immediately loaded photofunctionalized implants achieved very high stability, without the typical stability dip and regardless of the initial implant stability. Advanced surface technology may expand the use of the immediate loading protocol to challenging clinical scenarios.

CLINICAL SCENARIOS WITH CONFLICTING OUTCOMES

Single Anterior Implant

Studies have documented the excellent short-term survival of this immediate loading modality, both with and without occlusal contact on the provisional restoration.^{59,96-102} A limited number of studies reported diminished success rates (<95%), and these studies contain valuable information on identifying risk factors.^{5,99,100,103-105} A critical variable may be the combined therapy of immediate placement and immediate loading. If 95% implant survival is set as a benchmark for implant success, then multiple clinical studies that used this combination therapy failed to meet the requirement.^{5,99,104-106} The risk-benefit of immediate loading in scenarios in which support and stability from the recipient site is diminished must be critically evaluated because of the difficulties in achieving esthetic outcomes after failure.

Single Posterior Implant

Several studies examined the success of the immediate restoration of implants placed in healed molar sites. Early studies that used machined surface implants reported lower success rates.¹⁰⁷ Subsequent studies that used enhanced implant surfaces reported excellent immediate load success rates in healed sites.⁴⁸⁻⁵⁵ Vandeweghe et al¹⁰⁸ reported an 89.7% implant survival rate with an immediate loading protocol, in which 27 of 29 implants were immediately placed in molar sites. Atieh et al⁴ are the only investigators who have specifically documented the unique combination of both immediate placement and immediate loading for molar restorations. The results were discouraging, with a 33% failure rate. Of note, very large diameter implants (8 to 9 mm) were used in this study with intra-septal placement, which reflects the dimensional challenges of a molar extraction site to obtaining adequate primary stability for immediate loading. The characteristics of the included immediately loaded, single molar implant studies are summarized in Table 3.

Implant-Supported Partial Fixed Dental Prosthesis

Extensive case studies and prospective trials reported encouraging success rates for the immediate loading of partial fixed dental prostheses. High success rates

Table 3. Summary of cited immediate loading studies on single posterior implant

Study	Year	Site Status	No. Implants	Loading (functioning) Period (mo)	Implant Survival Rate, %
Glauser et al ¹⁰⁷	2001	Healed	30	12	73.3
Calandriello et al ⁴⁹	2003	Healed	50	6-12	100
Rao et al ⁵⁰	2007	Healed	51	12-36	94
Payer et al ⁵¹	2008	Healed	19	24	100
Guncu et al ⁵²	2008	Healed	12	12	91.7
Schincaglia et al ⁵⁴	2008	Healed	15	12	93.3
Meloni et al ⁵³	2012	Healed	40	12	100
Levine et al ⁵⁵	2012	Healed	21	60	100
Vandeweghe et al ¹⁰⁸	2012	Socket	27	6-34	89.7
Atieh et al ⁴	2013	Socket	12	12	66

have been reported for the posterior maxilla and mandible,^{56-60,109} and even for the posterior maxilla with simultaneous sinus augmentation.¹¹⁰ Studies have reported better survival for partial fixed dental prostheses compared with single implant restorations when immediately loaded, which is attributed to splinting and reduced micromotion.^{41,61,103,111} The overall success rates for the immediate loading of partial fixed dental prostheses seem favorable; however, documentation for the anterior maxilla and anterior mandible is deficient. Current evidence for these regions is sporadic and appears only in immediate loading studies that do not focus on these areas.^{57,58,60,103,111-113} More specific studies need to document the success rates and risk factors for these regions.

Implant-Retained Overdenture

Another controversial treatment option for immediate loading is implant overdentures. Immediate loading in this application initially involved a splinted approach on 2 intraforamenal implants in the mandible.¹¹⁴ A bar would be fabricated within 48 hours of placement, and several studies reported success with this method.¹¹⁴⁻¹¹⁶ Cooper et al¹¹⁷ in 1999 was the first to challenge the need for splinting by immediately loading 2 implants with healing abutments and soft reline material within the overdenture. Subsequent studies have increased loading by adding abutments to the implants and definitive attachments to the overdenture. This has produced conflicting results. Success rates in overdenture studies are defined simply as the presence or loss of implants. Marzola et al¹¹⁸ placed ball abutments with definitive attachments and achieved a 1-year success rate of 100% (34 implants in total). Roe et al¹¹⁹ used Locator attachments on the day of surgery and achieved a 100% (16 implants in total), 3-year success rate. Liddel and

Henry¹²⁰ loaded a single, anterior mandibular implant with a ball abutment and found no failures (25 implants in total) at 1-year recall. However, Kronstrom et al³ reported a 1-year, 81.8% (55 implants in total) low survival rate when using a laboratory relined to incorporate ball attachments in the denture on the day of implant placement. Thus, to what extent this treatment modality is successful remains to be determined.

The immediate loading of maxillary overdentures is not a common procedure, presumably because of poor bone quality and the desire for splinting. Two studies undertook this challenge with the fabrication of bars for maxillary overdentures in a short time after placing 4 to 5 implants.^{121,122} No studies have been conducted on the immediate loading of unsplinted implants for maxillary overdentures.

ANALYSIS OF THE FAILURE OF IMMEDIATE LOADING

The diminished success rates of immediate loading modalities focus on implants that are not splinted or face challenging bending loads. Both of these issues led to increased micromotion and unsuccessful osseointegration of the bone-implant interface. The mechanisms of this failure are elucidated in the following mechanical and biologic analysis.

Biomechanical Analysis of the Healing Bone-Implant Interface

The common theme of the clinical modalities with reduced success rates is the inability to control bending loads that arise from nonaxial forces. Providing mechanical leverage to nonaxial forces elevates stress at the bone-implant interface, which increases bone strain, the potential for micromotion, and the possible fatigue failure of supporting bone. Nonaxial loads are considered by several investigators to challenge the stability of the bone-implant interface.¹²³⁻¹²⁵ If this concern is valid for osseointegrated implants, then the immature bone-implant interface during immediate loading will be more susceptible to these challenges. Cochran¹²⁶ defined osseointegration as the “direct structural and functional connection between ordered living bone and the surface of a load-carrying implant.” To transmit force through the bone-implant interface, 2 parameters must be examined: the amount of BIC and the nature of this contact (friction interface or bonded interface). Osseointegration is analogous to bonding the implant to the surrounding bone.¹²⁷ A bonded interface is able to transmit force under compression, shear, and tensile stress states. An unbonded interface is unable to support a tensile stress state and can only support a shear stress state through friction between the implant and surrounding bone (Fig. 2). Finite element analysis (FEA) studies modeled bonded and/or unbonded scenarios,

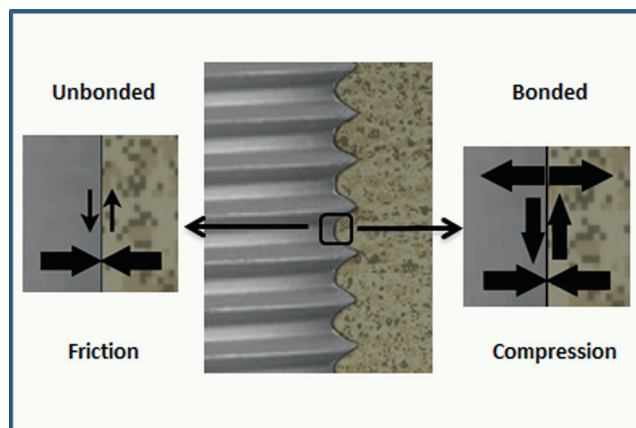


Figure 2. Load interactions at bone implant interface during healing (unbonded) and when osseointegrated (bonded).

and consistently found a significant difference on the microstrain in the surrounding bone between these 2 interfaces.¹²⁸⁻¹³⁰ An excellent comparison of resultant bone-implant interface strain between bonded and unbonded interfaces can be found in Mellal et al.¹³¹

For an immediately placed implant without a bonded interaction with the bone, when a nonaxial force is applied, significant tensile stress forms in the bone along the entire length of the implant. This distribution emphasizes the importance of the length of implants for immediate loading to distribute stress.¹³² After osseointegration, a functional connection is established between the implant and the surrounding bone. Stress now localizes in the cortical layer and, to some degree, at the apex of the implant. The walls of the osteotomy are no longer in a tensile stress state because of the change in stress states at the bone-implant interface. Therefore, significant BIC at the time of implant placement (unbonded) does not translate to assumed force transmission ability when compared with similar BIC after healing (bonded).

Biomechanical Analysis of Clinical Scenarios of Immediate Loading with Conflicting Outcomes

In addition to the general biomechanical disadvantage of healing bone-implant interface compared with healed bone-implant interface as described above, the healing bone-implant interface may have other scenario-specific biomechanical disadvantages.

Immediate placement and immediate loading of single implant

Several FEA studies examined bone strain in the immediate loading of incisors.^{128,132-134} However, only Pessoa et al¹³⁴ specifically addressed the immediate placement–immediate load combination therapy discussed earlier. Ideal positioning of maxillary anterior

implants produces a horizontal facial defect, which yields less bone support for facially directed loads. Only the most apical portion of the implant beyond the socket is available for support, and the extensive bone-implant contact on the palatal aspect offers no support against a facial bending moment. The differences between implant support in a healed site and implant support in an extraction site after positioning recommendations for esthetics are presented in Figure 3.^{135,136}

The studies of Pessoa et al^{128,134} focused on bone strain differences created by implant design, but the most significant finding was in the clinical scenario. The immediate placement scenario produced maximal equivalent strains, 75% higher than those encountered in a healed site. These studies demonstrate the mechanical challenges posed by the immediate placement and loading due to the reduced contact and supporting surfaces. Consistent with this analysis, the previously mentioned clinical studies reported higher failure rates for immediately placed and loaded, maxillary anterior, single implants than for immediately loaded implants in healed sites. The lack of clinical success with immediate placement and immediately loaded molars seems to be due to the large socket and lack of supporting structures, even for large implants. The contrasting success of immediately loaded molar implants placed in healed sites would indicate that the applied loads are not a problem but the supporting osseous structure is.

Maxillary anterior partial fixed dental prosthesis

The lack of specific clinical trials for this treatment modality with immediate loading is a cause of concern. The anterior maxilla generates significant nonaxial forces on implants due to the angle of these implants in the alveolus. In addition, eliminating eccentric contacts on this prosthesis is difficult. The more anterior teeth restored, the more protrusive contacts are involved with the prosthesis. Altering the prosthetic contours to eliminate eccentric contact, depending on the incisor relationship of the patient, may prove esthetically detrimental, which may preclude immediate loading.

The FEA study by Hasan et al¹²⁹ demonstrates the risk of immediately loading partial fixed dental prostheses in the anterior maxilla because of nonaxial forces. Calculated strain at the bone-implant interface of an immediately loaded implant is beyond the stimulatory levels proposed by Frost¹³⁷ and could lead to fatigue damage of supporting bone and increased micromotion. However, once the implants have integrated and the bone-implant interface is treated as bonded, the strain values are reduced by a factor of four.¹²⁹ Although the casting of the bone-implant interface is difficult, the simple mechanics of casting an osseointegrated (bonded) interface identifies a significant reduction in stress. This FEA model seems to confirm the

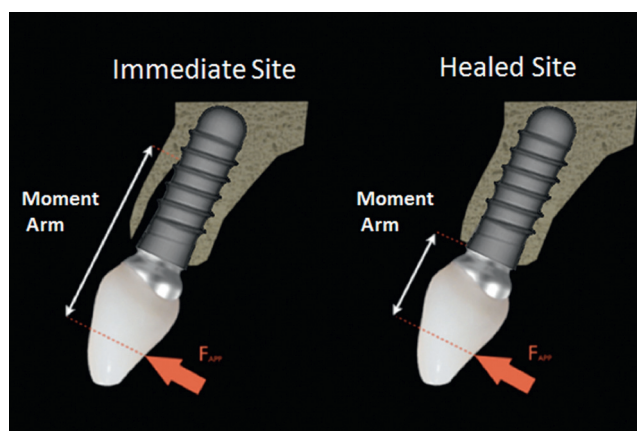


Figure 3. Mechanical leverage over bone implant interface is much greater with immediate placement because of palatal positioning.

apprehension of clinicians to document the immediate loading of maxillary anterior partial fixed dental prostheses.

Mandibular overdenture, unsplinted implants

When concerned about excessive micromovement, clinicians have been slow to adopt the immediate loading of unsplinted implants with overdenture attachments. The loading involved with this prosthetic modality has been well defined by Mericske-Stern,¹³⁸ who used intraoral instrumentation to assess the load magnitude and direction on unsplinted implants with attachments. The forces during mastication were elevated in an anterior direction, sometimes 300% more than the vertical forces on the implants and ranging from 50 to 100 N. In addition, this substantial anterior component of force was isolated in the implant ipsilateral to the mastication, whereas the contralateral implant displayed minimal loading. Providing this anterior force with a 5-mm lever arm (frequently the height of attachments from the crestal level¹³⁹) over the supporting bone crest would yield a bending load of 25 to 50 Ncm based on the recorded load range of this study.¹³⁸ The magnitude of this bending load is significant, when considering the implant measurements of other investigators who determined a 14 to 25 Ncm range during mastication on posterior 3-unit fixed dental prostheses.^{140,141} The frequency of this loading could also be a significant factor. The lack of bending support provided by the contralateral implant in this clinical study demonstrates the challenges of immediately loading this unsplinted prosthetic modality. The conflicting results of clinical studies leave the clinician with a difficult risk assessment when considering the use of definitive attachments for the overdenture on the day of implant placement.

Biologic Mechanism of the Failure of Immediate Loading

Although the mechanical force generated by immediate loading can stimulate osseointegration when the design is biomechanically sound and the force is below a certain threshold, excessive immediate loading force can be detrimental to osseointegration and result in implant failure. Isidor¹²³ created an implant overloading cast on monkeys by raising the occlusal table and found that 5 of 8 implants with excessive occlusal load lost osseointegration. However, it is difficult to know how much occlusal force was applied and also the exact direction. Esaki et al¹²⁹ used a dog model and lateral cyclic loading device to control these variables. Mild and excessive loading forces were applied to implants that were immediately placed in dog mandibles. Mild loading group implants had similar BIC and bone density around implants compared with the control unloaded group. However, excessive loading group implants had significantly lower values on both parameters. Thus, overloading increased the risk of implant failure and jeopardized bone healing, especially under immediate loading conditions with high load.

Drilling and cutting during implant surgery can damage bone. Typically, microgaps and macrogaps or spaces are found at the interfaces of implant and bone. A common feature of the space between bone and implant is that it will fill with a blood clot soon after surgery. If the implant is stable in the site, the bone heals in a process called intramembranous bone formation. In the first weeks to months after surgery, the interface will be made up of new woven bone as well as damaged and/or recasting bone. The intimate contact between the implant and surrounding bone provides the primary stability. The bone formation process will eventually fill most of the space within this environment. However, when the implants are "overloaded," this process will be interrupted, and clinical failure will result.

Compression and tensile testing of both cortical and trabecular bone have revealed that bone does yield at a critical point and mechanical damage can subsequently occur.⁶⁵ Although a single cycle overload of a bone-implant interface is conceivable, especially for implants in cancellous bone of poor quality, clinical failures are more associated with the cyclic loading condition.⁶⁵ In such situations, microdamage can occur in interfacial bone around a loaded dental implant, and this damage can trigger bone remodeling that may not be able to keep pace with accumulating damage, thus making fatigue failure and eventual bone loss more likely. For example, with cortical bone, macroscopic evidence of yielding occurs at a strain of approximately 0.75%.¹⁴² The resultant microdamage can stimulate bone resorption (to clear out the damaged bone) and contribute to increased bone fragility. Thus, a vicious cycle of microdamage, more

remodeling (more resorption), worsened strain state, more damage, and ultimate excessive micromotion begins. The absence of excessive micromotion is detrimental to osseointegration. Excessive micromotion can damage the tissue and vascular structures that are part of early bone healing. Excessive micromotion can interfere with the development of fibrin clot scaffolding and disrupt the reestablishment of a new vasculature to the healing tissue, which, in turn, interferes with the arrival of regenerative cells.

Eventually, the healing process moves toward repair by collagenous fibrous tissue instead of regeneration of bone. A delicate experiment was designed by Leucht et al⁸⁴ to illustrate the relationship between the magnitude of the effective strain and local osseointegration. The investigators compared the histology of the implant site and the strain measurement. As expected, robust new bone formation areas correlated with moderate values of effective strains. However, there is no matrix deposition where there are excessively large strains. Instead, fibroblasts and red blood cells accumulate in these high strain areas. The strong correlation between strain magnitudes and the fate of osteochondroprogenitor cells during bone-implant interfacial healing highlights the importance of biomechanical consideration when immediately loading implants.

SUMMARY AND RECOMMENDATIONS

Immediate loading is successful in many prosthetic modalities because of the favorable biologic response of bone to stress, as documented in both animal and human studies. The desirable biomechanical design and resulting controlled strain at the healing bone-implant interface contribute positively to the success of immediate loading. However, the bone-implant interface in immediate loading is different from that in delayed loading both biologically and biomechanically. In the scenario of immediate placement and immediate loading, the resulting strain will be even higher because of the limited bone-implant contact. The documented, unfavorable clinical results for the immediate placement and immediate loading of single anterior maxillary implants and single molar implants warrant the careful attention of the practitioner when these treatment options are considered. Biomechanical analysis of unsplinted implants in overdenture treatment reveals potential risk because of the lack of bending support provided by the contralateral implant.

The lack of conclusive clinical data makes it difficult to know whether immediate loading for unsplinted implants in mandibular overdentures is a safe protocol. Immediately loading unsplinted implants in maxillary overdentures is not recommended. The lack of specific clinical data and unfavorable biomechanical analysis results do not support the general practice of immediate

loading for maxillary anterior partial fixed dental prostheses. Based on the analyses and within the limitations of this review, immediate loading is a sound protocol in most treatment modalities. However, it is not safe to indiscriminately and immediately load dental implants in the following clinical scenarios: immediately placed maxillary anterior single implants, immediately placed single molar implants, unsplinted implants in overdentures, or implants in maxillary anterior partial fixed dental prostheses.

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