

Computational Modeling of Bone-Implant Construct Osseointegration: Advantages and Shortcomings

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Abstract

Background: Osseointegration (OI), the direct structural and functional connection between living bone and implants, remains poorly understood despite being critical for implant success. Current bone implant designs lack optimization due to limited understanding of the multifactorial mechanical, chemical, and biological processes which govern the OI process.

Methods: This systematic review analyzed studies published in English using numerical/mathematical methods to model OI. A PubMed search was conducted up to July 2025, and full-text articles were screened for keywords including "osseointegration," "healing," "bone generation," "computer simulations," "finite element models," and "mechanobiological model." The selected studies encompassed various species, tissue types, and computational procedures. Articles were categorized by modeling approach: mechanical, biological, and compound models.

Results: Seventeen articles met the inclusion criteria. Ten studies had employed mechanobiological algorithms simulating bone formation around implants, focusing on mechanical factors. Four studies had developed bioregulatory algorithms, targeting biological aspects. Three studies had created compound models integrating both mechanical and biological factors. Current models successfully predicted key mechanical influences but showed limitations in capturing complete biological complexity.

Conclusion: Mathematical models of OI face significant challenges in accurately considering both biological and mechanical factors simultaneously, often oversimplifying one aspect, while focusing on the other. Their key limitations include unrealistic boundary conditions, computational constraints, and incomplete understanding of biophysical signal translation. Moreover, most models rely on animal studies with interspecies differences and adapt bone healing algorithms rather than developing OI-specific approaches. Despite these challenges, mechanobiological models offer promising insights for optimizing implant design, though developing comprehensive models requires substantial experimental investment and computational resources.

Keywords: Osseointegration; Prostheses and Implants; Bone-Implant Interface; Fracture Healing; Computer Simulation; Finite Element Analysis

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Background

Since Brånemark, the renowned Swedish physician known as the father of modern dental implantology, coined the term osseointegration (OI) to describe the process by which a dental implant integrates with its surrounding bone, this term has been widely used in orthopedic and dental applications (1). According to the original definition, OI is a process by which a direct structural and functional connection is formed between a living, organized bone and the surface of a load-bearing implant (1). This multi-step process, which encompasses a variety of interrelated biological processes, begins with the insertion of the implant into the osteotomy site (2). Drilling creates a void between the implant surface and the surrounding bone wall, which is filled with blood (Figure 1a, b). Platelets that adhere to the implant surface secrete growth factors that signal MSCs to migrate toward the implant surface. A fibrin network forms around the implant, trapping various blood components, such as platelets, red blood cells, neutrophils, and macrophages thus forming the coagulum (Figure 1c) (3). Meanwhile, new capillaries grow into the interface zone through a process known as angiogenesis (Figure 1d) (4). Some regions of the host bone undergo necrosis due to the

pressure and heat generated by the drilling tip, as well as local ischemia caused by rupture of the surrounding capillary network (Figure 1d) (5). The fibrin network facilitates the migration of MSCs toward the implant surface, where they can differentiate into osteoblasts under appropriate conditions (Figure 1d, e) (6, 7). This can be boosted by the presence of growth factors (8) and is also influenced by the mechanical condition of the interface zone. Osteoblasts begin depositing new bone tissue on the implant surface and advance toward the host bone surface in a process known as contact osteogenesis (Figure 1e) (9, 10).

Another group of stem cells on the surface of the surrounding bone differentiate into osteoblasts. These cells initiate bone formation from the surface of the host bone and move towards the implant surface, in a process called distance osteogenesis (Figure 1e) (9, 10). Contact and distance osteogenesis contribute to the formation of bone bridges that integrate the implant with the host bone, enabling it to undergo functional loading (Figure 1e, f). Meanwhile, the necrotic host bone wall is gradually replaced by new bone tissue. At 2 weeks the remodeling process begins and replaces woven bone tissue with more organized, stiffer, lamellar bone tissue (11). This entire process is referred to as OI process (12).



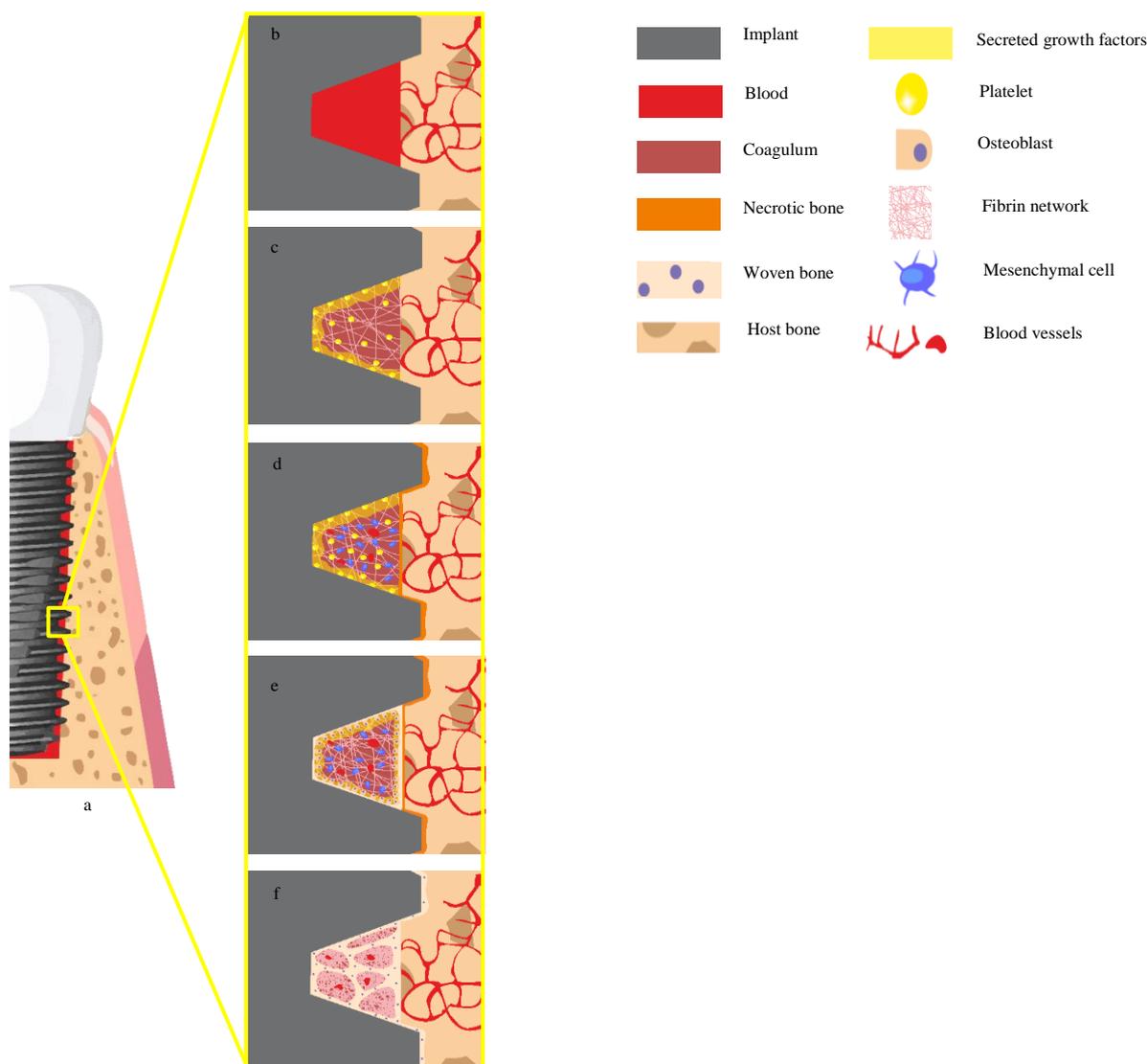


Figure 1. Various stages of bone implant osseointegration process

While OI process is primarily associated with dental implants, the underlying biological and mechanical principles are also largely applicable to cementless orthopedic prostheses and screws (13). Both dental and orthopedic implants aim to establish a strong, durable bond with the surrounding bone. In other words, the OI process for both dental and orthopedic implants involve similar stages, i.e., blood clot formation, inflammation, cellular proliferation and differentiation, and bone formation. However, there are some key differences between OI in orthopedic implants and dental implants (14). For instance, mechanical environment, size, and the shape of the implant can vary significantly between dental and orthopedic implant (15).

These differences lead to different rate and extent of OI between orthopedic and dental implants.

Is osseointegration the same as bone fracture healing process?

Although OI and bone fracture healing have been considered analogous processes, governed by similar biological principles, by most researchers to date, there are some key differences between the two processes. In the

treatment of a bone fracture, a medical implant is typically inserted to stabilize the broken bone and support the natural healing process. Moreover, in the case of bone fracture healing, biological processes involved in the healing process aim at connecting the fractured segments of the bone, i.e., the ultimate goal is to make bony bridges between the broken bone fragments. On the other hand, in OI, biological processes try to make a bony connection between an implant, such as a dental implant, and its neighboring bone, either from bone to implant or from implant to its neighboring bone. It should also be noted that the gap where OI process occurs is much smaller than the existing space between two bone fragments in fractured bone healing. Moreover, in the bone fracture healing process, endochondral and/or intramembranous ossifications can occur (16). However, reportedly in OI process, stem cells primarily only differentiate into osteoblasts, resulting solely in intramembranous ossification (17, 18). In other words, based on the current literature, no discernible population of chondrocytes, indicative of endochondral ossification, was observed between the implant and surrounding bone in the OI process (17, 18).

OI of bone implants can be evaluated using different methods, such as experimental (including histological, radiological, and clinical methods) and theoretical (including computer simulations) methods. Experimental methods can be divided into invasive methods (such as pull-out and removal torque tests), and non-invasive methods (such as percussion test and resonance frequency analysis) (2). While experimental studies offer invaluable insights in this field of research, they are constrained by ethical considerations, time-consuming protocols, high costs, and more importantly the difficulty of controlling complex biological and mechanical factors involved in OI process. These limitations can hinder our understanding of the intricate interplay between bone implant and host tissue response. Computational simulations complement experimental studies by compensating for their shortcomings (13).

The goal of this work was to provide a review on some computational models of implant OI, recent advancements in the field, models' strengths and weaknesses, and delineate future directions of research regarding OI process. The intention behind reviewing some models in this article was to shed more light on the obscure features of OI, and, consequently, to pave the way for the development of more effective and reliable bone implants.

Methods

This review only included English essays that used numerical and/or mathematical methods to model OI. A PubMed search was conducted up to July 2025, using the terms "implant" and "osseointegration". Full-text articles were then screened for the keywords "osseointegration", "healing", "bone generation", "bone ingrowth", "computer simulations", "finite element models", and "mechanobiological model". The selected articles were reviewed, summarized, and categorized based on the considered aspect of OI (mechanical, biological or both, i.e., compound models).

Results

Seventeen articles, in which OI was simulated from different perspectives, met the inclusion criteria. Ten articles have used mechanobiological algorithm models to study how bone forms around implants (19-28). Four studies have focused specifically on the biological aspects of OI and tried to develop bioregulatory algorithms to simulate bone formation around implants (29-32). Only three studies tried to develop compound models that consider both mechanical and biological factors (33-35). In the following sections, each group of articles is reviewed.

Mechanobiological Models: In 1997, Prendergast et al. performed a numerical simulation of bone tissue regeneration around implants (19). They used a biphasic finite element model to explore whether or not certain biophysical stimuli, i.e., fluid flow velocity and octahedral shear strain, could influence tissue differentiation. Their two-dimensional (2D) axisymmetric model featured a cylindrical implant placed inside a bone chamber, surrounded by granulation tissue. Their findings showed that fluid flow velocity and octahedral shear strain could initiate cellular biochemical responses, ultimately driving tissue differentiation. This research served as the foundation for the biphasic mechanobiological algorithm later developed by Lacroix and Prendergast (36), which has since become widely used in studies on modeling bone

healing and OI processes.

In 2003, Geris et al. (22) explored the capacity of the biphasic mechanobiological algorithm, proposed by Lacroix and Prendergast (36) to simulate tissue differentiation around implants (Figure 2). A titanium implant was placed inside a bone chamber within a rabbit's tibia and exposed to controlled loading conditions. To evaluate the effectiveness of the algorithm and to compare the influence of 2 different modeling approaches, they developed 2 finite element models: one using a 2D axisymmetric design, and the other using a full 3D representation. Displacement-controlled loadings of 50 and 160 μm , similar to those reported in experiments, were applied on the implant and stem cells migration into the chamber was modeled using a diffusion equation. Simulation results of their study exhibited good qualitative agreement with their histological findings, indicating that the implemented algorithm effectively predicted tissue differentiation within the bone chamber. Moreover, the results revealed the significant influence of the loading magnitude on the resulted tissue type. Under lower loads, i.e., displacement of 50 μm , granular tissue differentiated into bone, whereas for the higher displacement, i.e., 160 μm , fibrous tissue was formed. Moreover, the strong similarity between the results of the 2D and 3D simulations demonstrated that both 2D axisymmetric and 3D models could effectively predict tissue differentiation around implants.

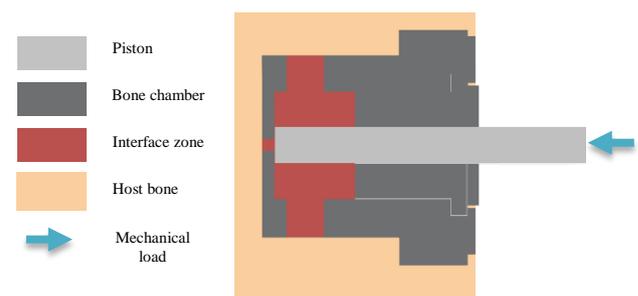


Figure 2. A 2D representation of the cylindrical bone chamber setup of the study by Geris et al. (22) (Piston undergoes loading cycles and model equations are solved at the interface zone, i.e., at the interface of piston and bone chamber.)

In 2004, Geris et al. (25), using the results of their previous experimental study, compared the ability of biphasic (36) and single-phase mechanobiological algorithms (23) to simulate bone growth around implants (Figure 2). Their previously developed 2D axisymmetric finite element model (22) was employed in this investigation. The results of the new study indicated that biphasic model not only directly influences the magnitude of the mechanical stimulation at the interface zone, but also affects its distribution (25). In the single-phase model, all implant displacements were concentrated in the tissue placed right adjacent to the implant surface. In contrast, the biphasic model, which includes a fluid phase, distributed the deformation across the entire implant environment, which led to a distinct differentiation outcome. In the experimental setup, due to vein rupture, the entire chamber was filled with blood and stem cells (25). They also assumed that the movement of the implant during loading cycles leads to a uniform distribution of these cells. To further refine their analysis, they examined two different scenarios: one that incorporated the stem cell diffusion equation in the bone chamber model, and another one, which excluded it (25).

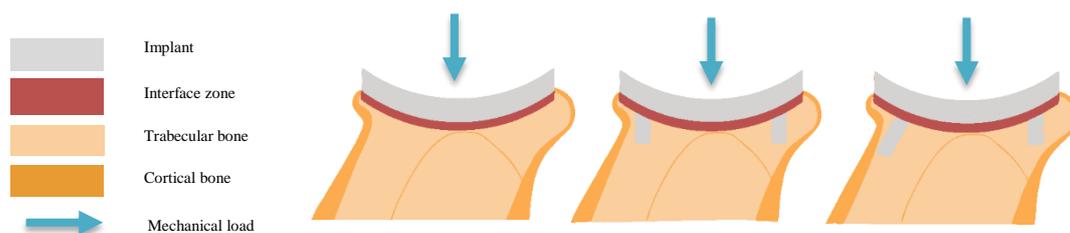


Figure 3. Shoulder joint implant of the study by Andreykiv et al. with different configurations of implant pegs that results in different implant primary stability (25) (Implant undergoes loading cycles and model equations are solved at the interface of glenoid component of shoulder joint implant and host bone.)

Their simulations showed that the predicted differentiation patterns obtained without considering the diffusion of MSCs were similar to those obtained when the diffusion equation was included. However, the models without diffusion equation converged much faster (25).

In 2005, Andreykiv et al. (24) employed a biphasic mechanobiological algorithm, i.e., the Lacroix and Prendergast model to simulate bone growth around glenoid components of shoulder joint implants under 3 different initial stability conditions due to different implant configurations (Figure 3). Their results showed that insufficient initial stability is detrimental to OI, favoring cartilaginous tissue formation over bone. Conversely, high primary stability facilitated complete bone growth via intramembranous ossification. However, since their study was based on 2D models, it may overestimate interfacial strength and underestimate micromotion.

Until 2007, a model that simultaneously incorporates damage and healing mechanisms for living bony interfaces had not been developed. Moreo et al. aimed to develop a mathematical model to understand the evolutive behavior of living interfaces, focusing on destruction and ingrowth of bone tissue (28). Their findings indicated that the level of patients' activity, implant's surface topography, and stem stiffness significantly affect the outcomes of the OI process (Figure 4) (28).

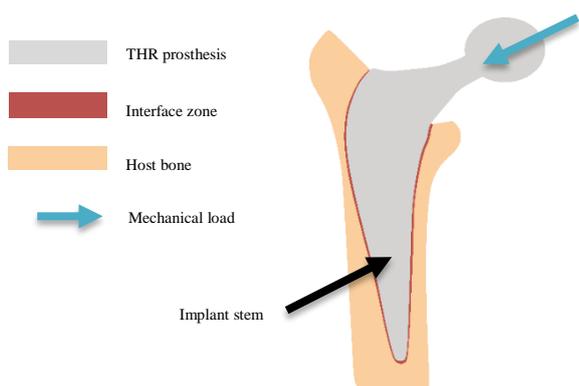


Figure 4. A 2D section of the 3D THR prosthesis-bone construct of the study by Moreo et al. (28) (loading cycles and model equations are solved at the interface of implant stem and host bone.)

In 2008, Liu and Niebur (26) utilized biphasic tissue differentiation algorithm (36) and added bone remodeling to it in a simplistic manner (26). It is well known that bones are continuously remodeled through a coupled process of bone resorption and formation, which is called bone remodeling. There are numerous models on bone remodeling process, some based on the continuum

mechanics approach (27-39). In their study, Liu and Niebur developed a 2D finite element model to investigate bone ingrowth on porous implant surfaces (Figure 5) (26). In their model, interface zone parts, which differentiated into bone tissue, were subjected to a bone remodeling algorithm, while the other regions stayed under healing algorithm. Compared to the original algorithm, the modified version, which incorporated bone remodeling, showed better agreement with experimental data, particularly in capturing the temporal progression and spatial distribution of different tissue types.

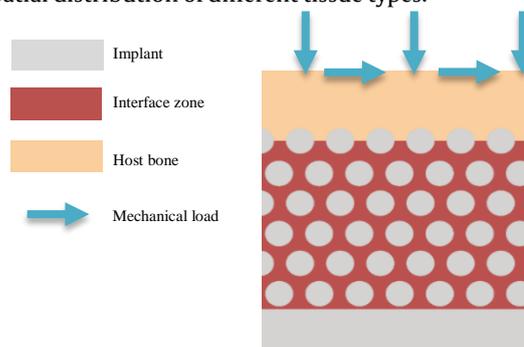


Figure 5. 2D model of porous implant surface of the study by Liu and Niebur (26). [Implant undergoes loading (normal and shear stresses were applied at the top surface of the model) and model equations are solved at the interface zone, i.e., within the porous space between the implant surface and the host bone.]

Additionally, their algorithm predicted more stable results, while the original algorithm (36) exhibited fluctuations between different tissue types. They have also reported that excessive micromotion hinders bone ingrowth and favors soft tissue formation. This study marked the first attempt to incorporate both remodeling and healing processes in OI simulation.

Chou and Müftü investigated OI of immediately loaded dental implants using biphasic tissue differentiation algorithm (20, 40). The main limitation of their model was that implant threads were not in contact with the surrounding bone. They evaluated the influence of various parameters, including immediate loading magnitude in terms of micromotion, thread design, and osteotomy hole size, on peri-implant tissue healing. They concluded that controlling micromotion is essential for optimal OI.

In 2020, using biphasic algorithm and a 2D axisymmetric finite element model, Irandoust and Müftü studied OI of dental implants, and the consequent remodeling process of the surrounding tissue (Figure 6) (21). Their research primarily examined how different levels of micromotion influence OI, and how this leads to different remodeling results. In their simulation, the implant threads were not in contact with the surrounding

bone, which is an important limitation of their work. Their results indicated that bone initially formed within the implant threads during the healing period (days 1 to 30) but was resorbed during remodeling phase. This underscores the need to account for not only OI, but also the remodeling process in treatments of dental implants.

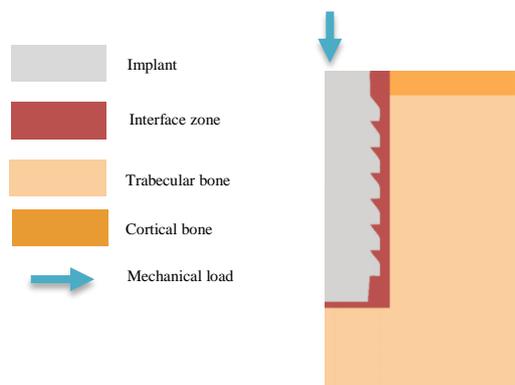


Figure 6. Dental implant in the study by Irandoust and Müftü (21) (Implant undergoes loading cycles and model equations are solved at the interface of implant and host bone.)

In 2024, Babayi et al. used a modified mechanobiological model based on distortional and dilatational strains to investigate the effects of loading type, i.e., immediate versus delayed, on cell differentiation around dental implants (27).

A 2D finite element model of an implant placed between two healthy teeth was developed. They observed that delayed loading resulted in greater bone formation, compared to immediate loading. In the immediate loading scenario, osteoblast accumulation was primarily observed at the base of the implant threads, whereas in the delayed loading scenario, bone formation occurred further away from the implant and closer to the surrounding bone. This study highlighted the importance of loading scenario, post-implantation, for optimizing OI.

Bioregulatory Models: The models reviewed in the previous section have narrowly focused on the mechanical aspects of OI that frequently assumed that it is the same as of the bone fracture healing process, which can be a place of serious debate. In this section, a quick review is made on some bioregulatory models in which biological factors, instead of mechanical stimuli, were assumed to drive the OI process.

In 2006, Ambard and Swider introduced a new mathematical framework to simulate the tissue differentiation process around orthopedic implants, by focusing entirely on biological factors (29). Their multiphase model included bone matrix, extracellular fluid, osteogenic cells, and growth factors. Nonlinear convection-diffusion equations were developed to simulate cell migration, growth factor diffusion, cell proliferation/differentiation, and bone formation. The model's predictions were qualitatively validated against *in vitro* histological data. The study demonstrated that both the initial spatial distribution of osteoblasts and the heterogeneity of the surrounding tissue markedly affect the healing process, with healing outcomes showing pronounced sensitivity to osteoblast density (29).

In 2009, Amor et al. (30) used a growth factor-based OI model to analyze a not loaded titanium dental implant inserted into the jawbone of laboratory dogs (8). Using a 2D finite volume code, this model simulated various

cellular activities, including migration, proliferation, and differentiation of stem cells and bone formation. The driving force of the cellular activities was considered to be the growth factors, which were present around the implant. The initial and boundary conditions and the values of the model's various parameters were changed relative to the original model in a way to correctly predict the temporal and spatial patterns of bone tissue, similar to those observed in their experiment. The effect of implant surface roughness was mimicked by considering a source of osteogenic growth factor on the implant surface. Both contact and distance bone formation were observed in their results (30).

In 2009, Moreo et al. aimed at developing a mathematical model that could comprehensively reproduce the biological features of a bone implant OI (32, 41). Using a system of reaction-diffusion equations and 2D FE analysis, their model simulated a dental implant with two different surface roughness levels. For the first time, the effect of platelet concentration, which plays a crucial role in the early stages of OI, was considered in model equations. Since various signaling molecules and growth factors mediate bone tissue formation, incorporating all of them would significantly increase the model's complexity and computational cost. Moreover, sufficient experimental data to accurately determine all relevant parameters is lacking at the moment. Therefore, all factors involved in the OI process were divided into two main categories: growth factors, associated with platelet release, and signaling molecules, secreted by osteogenic cells. The primary stimulus initiating bone formation in this model was implant surface roughness, simulated by the concentration of proteins adsorbed to the implant surface. Numerical results showed that the model could qualitatively reproduce features, such as contact and distance bone osteogenesis, depending on the level of surface roughness, similar to what has been observed in experiments (9, 32). The effect of mechanical stimulation and implant loading was not directly considered in this study (32). Therefore, the researchers limited the validity of their model to low and moderate mechanical stimuli (41).

In 2011, Amor et al., in another effort to further develop their previous model (31), incorporated chemotaxis and release of growth factors from platelets adhering to the implant surface to investigate the effect of implant surface roughness on surrounding bone formation (31). Surface-related parameters were assigned to the model based on existing data with appropriate adjustment. The predicted spatial and temporal patterns of OI aligned with histological findings from animal studies conducted with different surface roughness levels. Their results showed that SLA (micro-rough) surfaces promoted greater bone density and faster early bone formation than turned (smooth) surfaces. Contact osteogenesis occurred only with a strong initial supply of osteogenic growth factors, highlighting the pivotal role of surface topography in enhancing implant integration (31).

Compound Algorithms: As already mentioned, creating a comprehensive model for OI is quite challenging due to the many mechanical and biological factors involved, the vast number of parameters that are at play, and the lack of sufficient experimental data to accurately define them. Despite these difficulties, some researchers have attempted to address both mechanical and biological aspects in their models, through making some simplifying assumptions, which are introduced in this section.

In 2011, Vanegas-Acosta et al. developed a mathematical model to simulate OI, considering biological and mechanical factors, and implant surface roughness (33). By solving the equations of the model using FE method, they tried to reproduce spatial and temporal distribution of various tissues at the sample bone-implant interface (Figure 7). The main focus of this work was on the initial stages of OI, including blood clot formation, fibrin network formation, granulation tissue formation, and mesenchymal cells migration. Moreover, the force exerted by these cells on the fibrin network was studied. This study showed that suitable surface roughness can contribute to a better OI through stimulating chemical agents, faster cells migration, and better adhesion of the fibrin network to the implant surface.

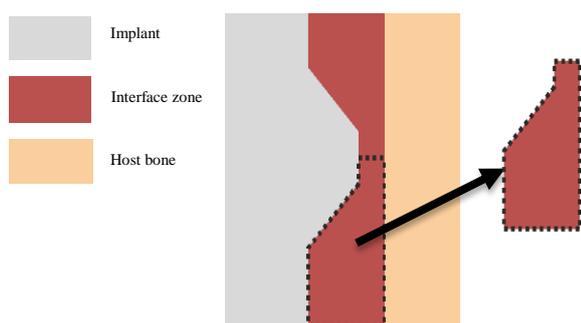


Figure 7. Bone-implant model of the study by Vanegas-Acosta et al. (33) (Model equations are solved at the (dashed) interface of implant and host bone.)

In 2012, Prokharau et al. developed a comprehensive model for tissue differentiation, incorporating a flexible mathematical framework, which allows researchers to study how various biological and mechanical factors influence stem cells differentiation into a limitless range of cell types (34). Inspired by the concept of cellular plasticity (42), differentiation was considered as an evolutionary process that is completed over time, and regulated by an arbitrary number of parameters. In this approach, for the first time, the process of cell differentiation was considered as a gradual and reversible process, and its state was characterized by a continuous variable. To investigate the functionality of the proposed model, the process of dental implant OI was simulated, and the results were compared with similar experimental work. A 2D axisymmetric FE model of the implant without a contact with the surrounding bone was created. The findings of this study indicated that large micro-motion, i.e., micromotions greater than 240 μm , caused high mechanical stresses in the tissue near the implant surface, and stem cells in these areas were differentiated into fibroblasts. Additionally, according to their numerical results, the amount of bone formed under low mechanical loading, i.e., for micromotions smaller than 30 μm , was higher than that of the unloaded condition, especially in the first few weeks.

Since osteoblasts cannot migrate, bone formation during the OI process occurs only on pre-existing surfaces (9). This was formulated as a moving boundary problem in a study by Prokharau et al. (35). The equations of the evolutionary differentiation model (34) were solved within this moving boundary domain (35). Since solving the equations for a problem with moving boundaries condition is quite complex, Prokharau et al. approached it using a 1D axisymmetric model (35). However, the 1D axisymmetric model does not fully capture the 3D nature

of the phenomenon. They successfully simulated two key aspects of OI, contact and distance OI, in dental implants in their work (35).

Discussion

OI is a complex, multi-stage, and adaptive process, influenced by numerous factors (13), which can be broadly categorized into biological and mechanical stimulus (2). To date, a limited number of studies have attempted to consider both biological and mechanical factors, albeit in a simplified manner. The goal of mathematical models and their validation against experimental data is to unravel the impact of different variables involved in the OI process. Improving bone implants' designs, refining treatment strategies, and shedding light on future experimental investigations are among the most significant applications of OI modeling.

Computational models in combination with mechanobiological algorithms, and experimental validation, present a promising avenue to simulate complex interactions between implant and bone tissue, which can present researchers with deep insights into the fundamental mechanisms governing implant OI (33). Furthermore, mechanobiological models and computational simulations help researchers assess the impact of various parameters, such as implant geometry (20, 40), implant surface topography and properties (41), and mechanical loading (21), without executing expensive and time-consuming experiments. Additionally, mechanobiological models can help identify critical factors influencing the success or failure of OI, ultimately leading to improved implant designs and treatment strategies (13).

Despite substantial advancements in this field of research over the past decades, significant limitations still persist in the currently available studies regarding OI process and its experimental and modeling aspects. For instance, in bioregulatory models proposed on OI so far, the influence of mechanical factors on the tissue differentiation process are either disregarded or are taken into account indirectly (31). Nonetheless, numerous studies have demonstrated that mechanical loading has a clear impact on OI outcomes (18). This limitation might be one of the reasons for unrealistic predictions of uniform bone formation at the implant-bone interface, observed in bioregulatory models of OI. Conversely, mechanobiological models often simplify biological factors and incorporate them indirectly (20, 22).

The main reason for making oversimplifications in one aspect of OI, when considering, is the incomplete understanding of the mechanisms by which biophysical signals are translated into cellular processes, including stem cells differentiation, migration, and proliferation, as well as the secretion of various molecules and growth factors in the OI process. Accounting for the numerous factors involved in the complex process of OI presents two main challenges in modeling and in solving the problem. First, accurately identifying all relevant parameters and assigning realistic values to them is practically impossible, due to the limitations in experimental measurements at the present time. Secondly, as the number of equations increases and the model becomes more complex, analysis becomes computationally more demanding, eventually surpassing the capabilities of currently available computational resources and numerical methods. To address this issue, by designing well-thought

experimental studies, it is possible to identify key factors influencing the OI process, and thus only employ them in mechanobiological models.

Experimental studies have shown that the initial stability of bone implants directly affects their long-term biological or secondary stability, the latter is the outcome of the OI process. Furthermore, numerical studies have demonstrated that variations in the micro-motion of bone implants, relative to their neighboring bone, lead to different patterns of tissue differentiation, and thus different OI process results. However, it can be argued that most simulations conducted so far have not accounted for implant primary stability under realistic conditions. One reason for this could be the high computational cost of accounting for the real boundary condition between the implant and the surrounding bone, as this condition makes the analysis highly nonlinear (43). Since the simulation of OI involves analyzing dozens of loading cycles, simplifying real contact conditions can significantly reduce computational cost, and thus make the analysis feasible. Moreover, converting the complex 3D geometry into a 2D geometry with axial symmetry, while preserving the main features of the model is one of the methods that many researchers have employed in order to reduce computational costs to date (21). The development and use of efficient modeling methods for simulating implant OI, while considering correct boundary condition can, of course, offer results that are most likely trustable.

Although there is a difference between bone healing and OI process, some researchers have adapted existing algorithms, which were originally designed for bone fracture healing simulation, and employed them to investigate the OI (25-27), which may need critical reconsiderations. Developing new algorithms to accurately capture the biological and mechanical aspects of the OI process requires meticulously designed and costly experiments, which can yield novel results and expand our understanding of the unique process of OI.

It is important to note that OI models are mostly based on experimental studies conducted on animals. Even though human bones share biological similarities with certain animals bones (44), interspecies differences must also be taken into account when researcher try to interpret their results. For instance, the rate of bone formation in rabbits is reported to be three times that of humans (45).

Various parameters are considered in different OI models, particularly in bioregulatory models, each of which can influence the results of the simulations (32, 46). To ensure the reliability of simulations' outcomes, sensitivity analysis should be conducted on parameters of each model (47). It should be noted that simulations' results are reliable if they show low sensitivity to parameters with less precisely known values (48).

Conclusion

Computer simulations of OI can help explore different aspects of this phenomenon from both biological and mechanical perspectives. Further advancements in existing OI mechanobiology algorithms and modeling techniques are necessary to develop more practical and applicable simulations in the future, with the ultimate goal of designing more efficient bone implants.

Conflict of Interest

The authors declare no conflict of interest in this study.

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