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Literature Review on The Application of Osseointegration Technology in Prosthetics

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Abstract

The field of Osseo-integrated prostheses has garnered significant interest from both specialists and individuals who have undergone amputations. This innovative technology has numerous significant benefits that enhance the amputee's quality of life, promote their autonomy, increase their range of motion, and alleviate their discomfort. Furthermore, osseointegration offers a crucial function called Osseo-perception, which allows the individual to experience a comprehensive sensation of their new prosthetic limb. Furthermore, osseointegration possesses restrictions that necessitate ongoing research and advancements in order to attain the best equilibrium and utmost advantage from this crucial procedure. The present study offers a thorough examination of the existing literature on Osseo-integrated prostheses, focusing on their benefits and limitations, the various systems that utilize this concept, the surgical methods employed, the use of surface enhancements, and the choice of suitable materials for different implant systems. Since the objective is to trace the factual development of this revolutionary field over time, an extensive search was conducted for several studies and theses about this subject, spanning from its inception to the most recent advancements and updates, without any temporal limitations imposed on the date of the study.

Introduction:

The advancement of prosthetic limb implantation and osseointegration through continuous research and development has a direct impact on the well-being of amputees, whose population is increasing in parallel with the rise in violent rates. Work-related and traffic accidents, as well as unhealthy lifestyle choices, can lead to diseases that require amputations, particularly in the lower extremities.

Prosthetic sockets are currently employed as a treatment for amputees due to the debilitating effects of limb amputation, including incapacitation, expensive medical expenses, and impaired everyday activities [1]. The comparison between socket and bone-anchored prostheses reveals notable disparities in terms of time and expense [2]. The distinction between a conventional socket and an Osseo-integrated prosthesis is illustrated in 'Fig. 1'. Prosthetic sockets remain the preferred method of therapy for individuals who have had amputation. However, it is important to note that they might potentially lead to localized discomfort, skin ulceration, and anguish at the point of contact with the socket. Therefore, a

minimum of one-third of individuals who have undergone amputation see a decrease in their reliance on prosthetics, resulting in a decline in their overall quality of life [1].

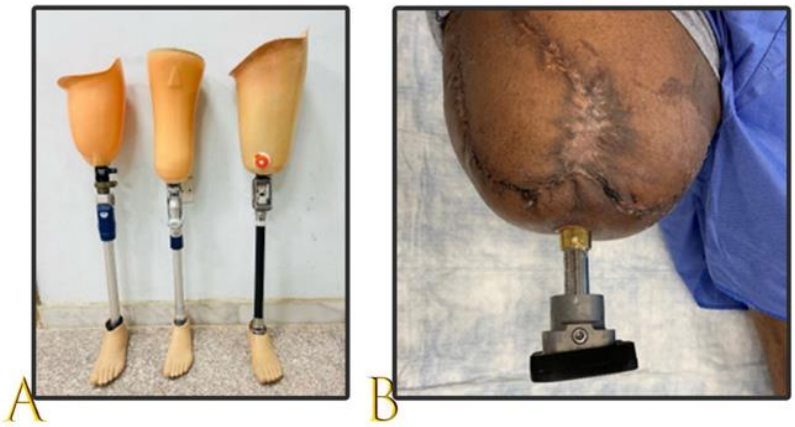

Fig. 1 *(A) A traditional above-knee prosthesis, (B) A transfemoral osseointegration prosthesis.*

In the last five decades, bone-anchored prostheses have transitioned from an experimental treatment notion to a fast-advancing field in orthopedics and traumatology [3]. One of the primary advantages of osseointegration is its ability to directly connect bone, muscles, tendons, receptors, and prostheses, eliminating the requirement for a socket and enhancing the range of motion. Amputees are able to "feel" their prostheses without seeing them, which enhances their ability to maintain balance and control [4]. Complications can arise from every surgical procedure. The most prevalent ailment in bone-anchored prostheses is a soft tissue infection in the stoma, which does not involve any harm to implants or bones. Osteomyelitis, periprosthetic hip fractures, implant fractures, and implant loosening are less frequent but carry greater significance [5].

Biomaterials are substances that interact with biological systems to assess, treat, enhance, or substitute organs, tissues, and body functions [6]. Orthopedic clinical studies indicate that several implant materials, particularly bone-anchored prostheses, are required to exhibit long-term performance [7]. Several bone-anchored prosthetic applications necessitate biocompatibility, mechanical strength, long-lasting performance, resistance to corrosion, and load-bearing properties [8-10]. These conditions can be partially met using alloy. Surface modifications are important because they control the interaction between implanted devices and living tissues. Biocompatibility is mostly determined by the characteristics of the surface [11]. Surface modifications encompass many techniques, such as coatings, treatments, and hybridization [7].

Advantages and Limitations:

In a study conducted by ***Brånemark et al. (2019)*** **[12]**, the researchers incorporated a cohort of 51 individuals, ranging in age from 20 to 70 years, who experienced complications with traditional socket-suspended prostheses, were unable to utilize a prosthesis or chose not to use one. Specifically, the data revealed that superficial infections were the most common adverse event, reported in 70 instances among 34 patients. A cumulative count of 85 significant adverse events was documented within a cohort of 26 patients. A cumulative count of 14 instances of deep infections was identified within a cohort of 11 individuals throughout a 5-year duration. One of these infections resulted in premature loosening or failure of the implant fixture. A total of 43 mechanical problems were observed among a cohort of 15

patients. The occurrence of 16 bent abutments in 9 patients can be attributed to instances of falling and stumbling. The researchers proposed that it would be beneficial to do long-term patient follow-ups. The findings of the study indicate that a significant majority of the participants, specifically 70%, consistently utilized their prostheses on a daily basis, with an average duration of 13 hours each day, so the use of bone-anchored prostheses, in comparison to conventional socket-suspended prostheses, might be considered significantly higher. Ultimately, notwithstanding the favorable elements of the investigation, the researchers expressed apprehension over the escalation rate of deep infections and mechanical difficulties. Flashing backward in time, in a study conducted by ***Pezzin et al. (2004)*** **[13]**, the researchers aimed to investigate the utilization and contentment associated with conventional prosthesis use. The study specifically focused on a sample of 935 individuals with significant amputations. Approximately 75% of cancer patients who underwent amputations experienced amputations at the highest level, specifically above the knee. Most people who have had amputations expressed satisfaction with the fit, appearance, and weight of their prosthetic device as a whole. The majority of participants expressed high satisfaction with the ease of donning or doffing their gadgets. A significant proportion of individuals with lower-limb amputations, almost one-third, have reported unhappiness with the comfort of their prostheses when in standing or sitting positions. Conversely, there was a dark side via the use of data obtained from other individuals; it has been determined that several factors, including perspiration, discomfort caused by pressure, breakdown of skin, and inadequate fit, contribute to the limited adoption of prosthetics and therefore result in a worse quality of life.

According to ***Hoellwarth et al. (2020)*** **[14]**, most individuals with amputations experience substantial improvements, subjectively and objectively, while transitioning from a conventional socket prosthesis to an Osseo-integrated prosthesis. In addition, the researchers made an intriguing observation regarding a supplementary phenomenon that enhances the overall patient experience while utilizing an Osseo-integrated prosthesis, known as Osseo-perception. Osseo-perception refers to the mechanical stimulation of a bone-anchored prosthesis, which is converted into neural signals by mechanoreceptors in the muscles, joints, skin, and other tissues adjacent to the bone. These signals are then transmitted to the central nervous system, resulting in the passive perception of a patient's sensorimotor position and function. It has also been shown that osseointegration creates a direct connection between the prosthetic limb and the bone, incorporating afferent and efferent neural integration. This integration enables patients to intuitively control the applied force with greater precision.

Frossard et al. (2017) **[15]** conducted an economic analysis within a specific region, comparing the costs of conventional prosthetics with Osseo-integrated limbs. The study focused solely on the direct costs of these devices, excluding additional expenses such as surgical procedures, rehabilitation, and medical care. It was noted that bone-anchored prostheses have the potential to alleviate various burdens associated with prosthetics, medical care, and financial costs by mitigating skin-socket interface issues throughout an individual's lifetime. The observed disparity suggested that the bone-anchored prosthesis alternative exhibited cost savings, cost neutrality, and uneconomical outcomes compared to socket fitting.

In summary, investigations comparing Osseo integrated prosthetic limbs to traditional prosthetic limbs have identified both advantages and limitations. Osseo integrated prosthetic limbs offer superior advantages in terms of both range of motion and long-term usability, as

well as in terms of economic affordability. However, the implant may have limits over time, such as being susceptible to mechanical irritation or superficial infections.

Osseointegration Implant Systems:

In a study by ***Hall (1974)*** **[16]**, experiments were conducted on large animals to evaluate the efficacy of three different types of intramedullary implant materials. Initially, a sandblasted Vitallium rod was employed to achieve a snug fit. However, the device's pull strength was significantly compromised over time due to bone resorption. Another approach involved the utilization of metallic rods, specifically Vitallium or stainless-steel implants, in goats. The maximum duration of successful maintenance was seven months, after which subsequent failure was attributed to chronic osteomyelitis. Most of the failures of this technique were attributed to mechanical causes. On the other hand, ***Carlsson et al. (1986)*** **[17]** fabricated implants using pure titanium. A total of six adult dogs were utilized for the trials. One set of screws remained in the bone site for three months, another set for 14 months, and the remaining implants remained in place for seven months. The animals were permitted to be fully weight-bearing for the entire duration. It was observed that all implants exhibited clinical stability. Upon microscopic examination, it was observed that the titanium screws exhibited a high level of integration with the surrounding bone tissue.

Li and Brånemark (2017) **[18]** reviewed a comprehensive analysis of the first osseointegration operation administered to a female amputee. The patient had previously had a bilateral transfemoral amputation. On May 15, 1990, a titanium implant was surgically inserted into the patient's remnant femur on the right side. After six months, a titanium abutment was attached to the implant that had successfully fused with the surrounding osseous tissue. In 1991, a comparable two-stage surgical intervention was performed on the patient's left femoral stump. The researchers believed these pioneering initiatives were largely responsible for the useful experience that led to the OPRA program's subsequent standardization. They went on to say that the patient had the implants for 23 years before finally having to get them removed because of issues with the soft tissues.

Brånemark et al. (2014) **[19]** described OPRA as the initial contemporary direct skeletal attachment system evolved by Dr. Brånemark in the 1990s, capitalizing on his proficiency with titanium for dental implants. The OPRA implant comprised the abutment, the fixture, and the abutment screw as its three primary components, as shown in 'Fig. 2A'. The titanium alloy (Ti-6Al-4V) was utilized in the system's construction. With Osseo-integrated implants, the OPRA system improved health-related quality of life, mobility, and prosthetic utilization. However, the study's investigators were still concerned about the skin infections and bone fractures. Specifically, the OPRA implant features a central canal within its fixture and abutment, enabling the passage of electrodes. A recent study by ***Tropf and Potter (2023)*** **[20]** examined the most recent phases of the OPRA implant's development. Titanium alloys remain the material of choice for implants due to their biocompatibility, corrosion resistance, and ability to generate a surface oxide layer that promotes bone ingrowth. In light of this, the OPRA implant continues to utilize Ti-6Al-4V alloy as a threaded titanium intramedullary implant with a nano-porous (Bio-Helix) surface coating technology, which has demonstrated enhanced biomechanical anchorage and accelerated osseointegration. Up to the date of the study, the case has been reviewed by the USA 'Food and Drug Administration (FDA)', as OPRA implants for transfemoral amputees have acquired this permission. At the same time, other implant systems failed to get this green light. ***Hobuch et al. (2020)*** **[21]** observed that the

utilization of OPRA implants resulted in a notable enhancement in implant survival rates, ranging from 40% to 80%. This positive outcome was observed after a minimum follow-up period of nine years after implementing the OPRA implant protocol. It is worth noting that, out of the total of 18 patients, three individuals required implant removal due to infection. The OPRA implant demonstrates a 92% survival rate after five years following the surgical procedure. Additionally, there is a 25% risk of deep infection and a 66% occurrence of superficial soft-tissue infections in patients.

In a separate study, ***Aschoff et al. (2010)*** **[22]** followed a German-developed implant for a decade. By the end of 2009, the implant had undergone design revisions and had been implanted in 37 patients. An 'Endo-Exo-Femur prosthesis (EEF)' is a non-cemented, modular device with a hard-point attachment that goes through the skin and into the femur's medullary canal. In most cases, the results were satisfactory. The implant was removed from four patients. Most patients who have used this implant with a prosthetic leg have said it greatly improves their quality of life. They also noticed that it improves gait and relatively reduces energy usage. Recent adjustments to the procedure have reduced the occurrence of soft-tissue disorders at the stoma, which were previously a concern. In the same context, ***Juhnke et al. (2015)*** **[23]** examined the system first dubbed the EEF. 'Integral-Leg-Prosthesis (ILP)' is the name it presently goes by after several design revisions and surgical procedures. The design development stages were discussed in this study. Typically, this implant features a stem made of a cast cobalt-chrome-molybdenum alloy. An enhanced implant design compared to the ILP implant was introduced in a study by ***Al Muderis et al. (2017)*** **[24]**, in 2013 regarding the 'Osseo-integrated Prosthetic Limb (OPL)', as shown in 'Fig. 2B'. This improved design aims to achieve optimal outcomes for osseointegration. The material has been changed to Ti-6Al-4V, more closely aligned with the bone's elastic modulus. For amputees of the lower limbs, this study's findings show that osseointegration surgery with the OPL implant is a safe and successful method of repair and rehabilitation.

Acceptance of bone-anchored prostheses had been considerably delayed in the USA; ***McGough et al. (2017)*** **[25]** attributed this to justifiable concerns about infection in their study, with a significant portion of these delays in the USA attributable to the FDA's regulatory environment. The development of the COMPRESS system, which originated in the 1990s as an endo-prosthetic system intended for oncologic limb salvage reconstruction, facilitated the subsequent generation of gradual expansion as bone-anchored prostheses. The alloy utilized in this implant system is Ti-6Al-4V alloy in general. Upon completing data compilation, the researchers ascertained sufficient evidence to proceed with the custom utilization of this device.

The United Kingdom contributed to the development of one of the implant systems. In their study, ***Fitzpatrick et al. (2011)*** **[26]** undertook a noteworthy investigation into the 'Intraosseous Transcutaneous Amputation Prosthesis (ITAP)' implant. Designed to address difficulties encountered with stump socket prostheses or skin-implant interfaces, ITAP was intended for application in the human digit. The ITAP implant had three parts: an intraosseous stem made of Ti-6Al-4V alloy, as shown in 'Fig. 2C'; an umbrella-shaped flange placed under the skin with holes in it so that skin could grow on it; and an extracutaneous peg at the very end that connected the stem and flange to the Exo-prosthesis. The researchers documented favorable clinical results in four dogs after implementing ITAP for limb salvage. The initial implementation of ITAP on a weight-bearing limb segment was in these dogs. The findings from this case series have significantly influenced the design and implementation of

analogous devices for dogs and humans alike. ***Drygas et al. (2008)*** **[27]** stated in a study conducted a few years ago that, to their knowledge, the dogs' transcutaneous tibial implants have yet to be described for use. The experiment was somewhat similar. The implant system was tailor-made to be developed specifically for single-surgery implantation of a single-component system in a dog. After 14 months, the first implant was removed due to osseointegration failure. Until the research date, the dog exhibited typical ambulation on both pelvic limbs and had resumed routine activities, such as running.

The research team led by ***Agarwal et al. (2018)*** **[28]**, conducted preclinical trials for a decade to develop the 'Percutaneous Osseo-integrated Prosthesis (POP)', a novel osseointegration device intended to restrict infection and facilitate a swift return to ambulation while maintaining mechanical stability. Compared to other existing Osseo-integrated techniques, clinical outcomes revealed low preliminary infection rates, preservation of distal cortical bone, enhanced functional outcomes, increased periprosthetic bone density, and accelerated weight-bearing. This prompted ***Zaid et al. (2019)*** **[29]**, to monitor the progress of the POP system, which was under review for an FDA Early Feasibility Study. The researchers detail the prosthesis's architecture, including an implant site for intramedullary bone. Reports of increased deep infections and mechanical problems with implant systems in the intermediate term have continued to worry researchers.

In the field of theoretical simulation, ***Prochor et al. (2016)*** **[30]** created a new implant for direct skeletal connection of prosthetic limbs that keeps the anchoring elements and makes sure that the bone is under less stress. They designed the 'Limb Prosthesis Osseo-integrated Fixation System (LPOFS)'. Two components comprised LPOFS: the bone-screwed glass-particle-reinforced 'Polyether Ether Ketone (PEEK)' fixture and the Ti-6Al-4V abutment. Although the authors found that the OPRA system provided better anchoring, the LPOFS system distributed stress more appropriately in the bone.

Marwa et al. (2022) **[31]** conducted a practical experiment and a theoretical simulation. They devised a three-component implant. The 'Lim Osseointegration Implantable Adapter (LOIA)' is constructed with PEEK, Ti-6Al-4V, and stainless steel. A histological analysis showed that the group with coated implants had better bone growth. Concurrently, this outcome generated greater fixation than its predecessors. In the context of the simulation research, the deformation of stainless steel was less than Ti6Al4V. In addition, the results demonstrated that the implant design and type of materials employed considerably influenced the strain and stress distributions along the bone and implants.

The groundbreaking implant reviewed by ***Guirao et al. (2018)*** **[32]**, originated in Spain. The idea behind it was that people with knee disarticulation amputation benefit from having distal support inside the socket and having their weight directly transferred to their remaining limbs when the femoral condyles are kept, which is not the case with trans-femoral amputation. There were three parts to the distal weight-bearing implant utilized in this research, as shown in 'Fig. 2D'. Patients can choose between sockets or prostheses attached to their bones with this implant type. Regarding the study's practical implications, 23 patients who underwent trans-femoral amputations were given this implant, which enabled the residuum to bear distal weight within the socket. After 14 months, patients demonstrated improvements in their physical functional score, walking distance, and gait speed. Going back in time, in Hospital de Mataró, in Spain, the first experiment with this type of implant was conducted by ***Guirao et al. (2017)*** **[33]**, who carried out the first study to assess the functional ability of individuals with transfemoral amputations after the implant was placed.

This implant enabled the distal weight-bearing of the residuum. Ten patients undergoing transfemoral amputation got a titanium implant during a single procedure. The study findings demonstrated enhancements in the functional capacity and gait speed of individuals who underwent amputations, received implants, and then used sockets, as observed 14 months post-surgery.

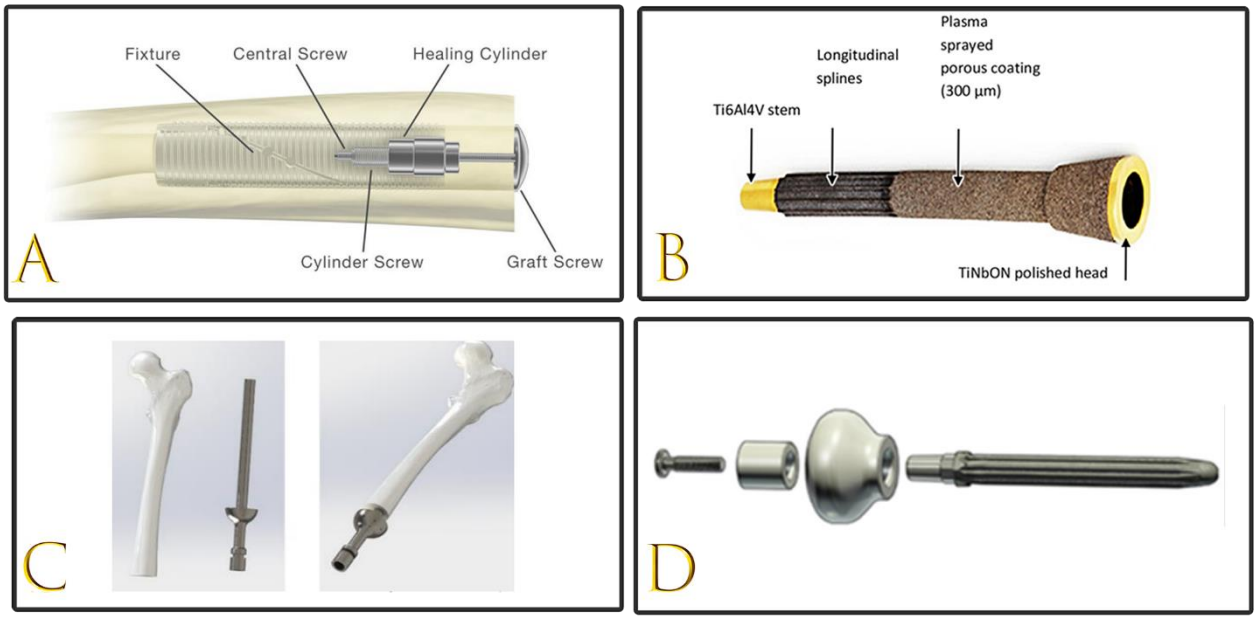

Fig. 2 *a cluster of implant systems including (A) OPRA, (B) OPL, (C) ITAP, and (D) The distal weight-bearing implant.*

The 'Keep Walking Implant (KWI)', also known as the distal weight-bearing implant, was recently the subject of an economic analysis by ***Guirao et al. (2021)*** **[34]**. The researchers also think that KWI would be an excellent intervention to lower the number of socket fits. Before and after Osseo-integrated percutaneous device implantation, the results showed that KWI provided a greater degree of benefit than socket-suspended and bone-anchored prostheses.

In a concise manner, the majority of medical implant systems were examined sequentially to ascertain the advancements and distinctions of each system. This organization of data enables researchers and individuals with an interest in the subject to determine the most suitable implant for each particular scenario. Furthermore, it is regarded as a scientific source that evaluates the advancements made in implants up to the current period. The Ti-6Al-4V alloy is widely recognized as the predominant alloy used in medical implants across many systems.

Surgical Approach:

In their study, ***Li and Fellander-Tsai (2021)*** **[3]** examined the progress made in prosthetic limbs, focusing on bone-anchored prostheses. The surgical techniques employed for various implant systems were categorized in this research, and they fall into two primary classifications: screw-type and press-fit. According to the authors of this study, OPRA implants are attached surgically via a screw-type system. While for other percutaneous implant systems, the press-fit system is utilized in the surgical procedure.

Reif et al. (2022) **[5]** conducted a study that included, in one aspect, a discussion of a screw-type system inspired by the original technology employed in dental implants. The screw-type approach involved two surgical procedures, with a six-month interval between them. The

initial step involved the insertion of the threaded intramedullary bone anchor, followed by the complete closure of the distal soft tissue. The second process involved the formation of a stoma at the point where the skin and implant meet and the connection of the transcutaneous abutment to the implanted fixture. The study indicated that after six months of second surgery, if feasible, the amputees should aim to walk independently without the need for crutches.

In a separate study conducted by ***Rizzo (2020)*** **[35]**, he referenced the press-fit method as the second system within the context of his research. He mentioned that this technology's development took place in Germany, and its implementation necessitated two surgical procedures, with a time interval of around 4–8 weeks between them. Subsequently, in 2014, a group of Australian physicians proposed streamlining this method into a single surgical procedure. The ultimate Osseo-integrated reconstruction and rehabilitation only took 3–6 weeks, resulting in a shortened overall duration.

Atallah et al. (2018) **[36]** compared amputations treated with a screw-type system and a press-fit system of the bone-anchored implant. The study also investigated interventions associated with these complications. The findings revealed a low incidence of implant infections in specific transfemoral implants, with screw-type implants ranging from 2% to 11% and press-fit implants ranging from 0% to 3%. Similar findings were noted regarding the occurrence of implant loosening in transfemoral cases, with screw-type fixation showing a rate of 6% and press-fit fixation ranging from 0 to 3%. In transfemoral implants, the occurrence of intramedullary device breakage was infrequent, with a rate of 0% for screws and 1% for press-fit devices. The researchers determined that individuals who had a transfemoral implant saw a lower occurrence of significant problems, such as implant infection and implant loosening when using a press-fit implant rather than a screw-type implant.

In brief, two distinct surgical procedures are employed to implant medical implants. After investigating these two varieties (the screw-type and press-fit type), research suggests that the press-fit type is the preferred surgical approach for medical implant operations.

The Complication Rates and Outcome Measures:

Through their research, ***Kunutsor et al. (2018) [37]*** discovered that the rates of complications vary from 1% to 77%. These complications mostly consist of mild infections in the soft tissues or superficial layers of the skin around the implant. It is important to note that the process of osseointegration causes no further amputations or fatalities. ***Karaismailoglu et al. (2021) [38]*** noted that over 22% of patients have mechanical complications in Osseo integrated prostheses. The complications observed in this study included loosening, which occurred in 19% of instances, and implant failures, with seven documented incidences of implant failure.

Hillock et al. (2024) [39] conducted a study on outcome measures, which involved participants (Mean age 52 years) who underwent osseointegration surgery. The main discoveries included enhanced functionality, with participants experiencing notable improvements in their ability to walk, move, and use prosthetics after undergoing osseointegration. Additionally, there was a significant reduction in pain associated with traditional socket-based prostheses. Moreover, participants reported an overall enhancement in their quality of life and satisfaction with Osseo integrated prostheses.

Although osseointegration enhances functional outcomes and quality of life, it is crucial to closely evaluate and address these mechanical complications. Close surveillance and prompt action for skin-related problems are essential.

Surface Enhancements:

In their study, ***Haïdopoulos et al. (2006)*** **[40]** examined the matter of surface enhancements and modifications. They defined these terms as overarching concepts that may be further subdivided into surface coatings, surface treatments, or hybridization. On the other hand, surface coatings may be applied via dry or wet processes. Furthermore, it was established that the adhesion properties between a coating and a metallic substrate, in addition to the chemical structure of the thin film, are significantly influenced by the surface composition and morphology of the metallic substrate.

According to ***Van den Borre et al. (2022)*** **[41]**, the successful integration and long-term survival of percutaneous titanium implants rely on osseointegration and the high-quality integration of soft tissues in the area where the implant penetrates the skin. Through their examination of the topic, they determined that ceramic coatings could diminish inflammation. Additionally, they demonstrated that Growth factors trapped in apatite stimulate the formation of a highly effective interface between the implant and the surrounding soft tissue.

Arcos and Vallet-Regí (2020) **[42]** concluded in their comprehensive study that surface modifications of dental and orthopedic implants are a successful approach to promoting bone regeneration during the initial stages of implantation. They indicated that, due to its exceptional biocompatibility and osteoconductive properties, coating implants with a layer of HAp is one of the most frequently utilized alternatives. As an aside, they stated that outstanding bone regeneration capabilities have been observed with silica-HAp coatings deposited on porous metallic implants due to the synergistic effect of osteoconductive HAp and the osteo-inductive behavior of the soluble silica species released from the coatings. ***Mustafa et al. (2014)*** **[7]** obtained natural HAp from fishbone sourced from Iraq. They achieved this by subjecting the fishbone to mechanical and thermal treatments. Subsequently, they applied a coating of this extracted HAp onto medical screws made from Ti-6Al-4V alloy using electrophoretic deposition. Untreated and treated screws were surgically inserted into the tibia of 15 rabbits. After 18 weeks following surgical intervention, it was observed that new osseous tissue had formed around all of the treated implants. These results pertain to the efficacy of all utilized coating materials. The removal torque test was used to estimate that after 12 weeks, all coating materials had similar mechanical strengths (torque values) at the bone-implant interface.

According to ***Hamdi et al. (2019)*** **[43]**, the HAp layers were found to have a significant impact on biocompatibility. The results demonstrated an increased level of crystallinity in the HAp following the SBF immersion experiment. The corrosion was assessed, revealing a notable enhancement in the corrosion resistance of this coating, along with better bio-medical characteristics of Ti-6Al-4V alloys. The HAp layers significantly contributed to the biocompatibility of the surface. Then, ***Hamdi (2022)*** **[44]** conducted an experiment where it was used the dip coating process to coat a Ti-6Al-4V alloy with coating contained HAp. In vitro investigations were then conducted using SBF. Biomimetic experiments observed the efficacy and biocompatibility of the coated surface.

Mohaned and Thekra (2023) **[45]** created nano-composite zirconia implants. They measured the healing durations at 2 and 6 weeks by inserting screws into the femurs of

rabbits and conducting in vivo tests. The implants were well-tolerated, had no postoperative infection, and showed good osseointegration capacity; they also exhibited notable mechanical qualities and outstanding biocompatibility.

Catauro and Bollino (2017) **[46]** noted that, in their study, there had yet to be a successful integration of the mechanical, chemical, and tribological properties of biomaterials with their biocompatibility, despite advancements in the field. This is the underlying factor contributing to premature implant failure. The authors commended the innovative concept of fabricating organic-inorganic hybrid materials. Later, ***Catauro et al. (2019)*** **[47]** found that the utilization of metallic materials as implants has significant disadvantages, primarily due to their detrimental impact on living organisms, particularly the effects caused by corrosion. The researchers suggested using 'silica (SiO_2)' and ZrO_2 composites as bioactive and biocompatible materials to coat titanium discs. Following the completion of the required testing, all the coatings enhanced the corrosion resistance of the titanium alloys. Regarding mechanical capabilities, the coatings containing SiO_2 exhibited superior performance due to their improved adherence to titanium alloys.

Ravarian et al. (2010) **[48]** conducted a study on bioactive glasses, which form reactive layers on their surfaces when exposed to body fluids or tissues. They noted that while the biocompatibility of HAp is high, its bioactivity can be enhanced. Ultimately, via the implementation of trials and tests carried out by academics, it has been unequivocally established that the glass exerts a significant influence on the structure of the HAp. By combining glass with HAp, ***Garibay-Alvarado et al. (2017)*** **[49]** created a novel nanocomposite. Because HAp is so brittle, this study suggests adding glass to make it more suitable for bone replacement. Both HAp and SiO_2 were produced. To fully exploit HAp's potential in osseointegration, the researchers stressed the significance of glass addition to the HAp. The objective of another study conducted by ***Razali et al. (2018)*** **[50]** was to assess the impact of various combinations of HAp and silica as fillers in dental resin. Various weight percentages of silica (0, 5, 15, 20) were incorporated into HAp and blended with an organic resin. The weight ratio of fillers to organic resins was 70:30. The findings demonstrated that the mechanical characteristics are contingent upon the relative proportion of HAp and silica. The composition that yielded the highest flexural and compressive strength consisted of 85% by weight of HAp and 15% by weight of silica.

Concisely, surface modifications and enhancements represent a significant advancement in the field of medical implants, as they contribute to the necessary acceleration of the osseointegration process and provide additional resistance to potential inflammation or infection. A review was conducted of the most prominent surface modifications that researchers employed in the development of medical implants.

The Current State and The Recommendations for The Future

The current state of femoral Osseo integrated prosthesis, as revealed by the studies examined in the current study, signifies notable progress in amputation reconstruction achieved by two distinct surgical procedures. Osseointegration involves surgically anchoring a custom-made, porous titanium (most common currently) implant directly to the bone. It is recommended that this implant be coated with a bio-based coating that improves the process of osseointegration. Extensive research and ongoing studies are being undertaken to get an optimal and improved coating. Individuals utilizing Osseo integrated prosthetic limbs benefit from enhanced movement, proprioception, and less neuropathic discomfort. Additional

evidence is needed to demonstrate if the distal weight-bearing implant is a superior implant system for individuals with transfemoral amputations due to the limited number of study participants and short follow-up period. Because they make up a big portion of the amputee population, they have the greatest potential to gain from the technology.

There are numerous recommendations for future research that have yet to be actively investigated or prioritized in previous studies. Optimizing implant design and material selection is still necessary to improve the overall performance and lifespan of the implants. It is imperative to establish effective surveillance and detection methods in order to guarantee the long-term success of Osseo integrated prostheses. X-rays and other imaging instruments can also be employed to assess the osseointegration process and detect any complications, such as bone fractures or infections. Furthermore, advancements in manufacturing methods, such as additive manufacturing and biomaterials science, can enable the development of implant geometries that are tailored to the specific needs of each patient. By analyzing vast quantities of data from numerous sources, including electronic health records and implant registries, algorithms may be developed to identify trends and risk factors associated with implant failure. This has the potential to improve the overall success rate of orthopedic operations and assist patients and surgeons in making decisions. By incorporating a variety of sensing techniques, it is feasible to enhance the dependability and precision of osseointegration diagnosis. For example, the utilization of ultrasonic detection may lead to a more comprehensive understanding of the osseointegration process. These developments may lead to more precise and expedited diagnosis, monitoring, and therapy for medical implants.

Conclusion

After a comprehensive review of the existing literature and theses about osseointegration, the initial focus was on studies examining clinical trials of bone-anchored prosthetics. These trials examined the advantages and disadvantages of Osseo-integrated prosthetic limbs compared to conventional sockets. This led to an innovative concept that merges the advantages of conventional and Osseo-integrated prosthetic limbs. Additionally, the literature review was conducted historically to serve as an index and historical context for those interested in the subject. This approach aimed to extract comprehensive and adequate information, which laid the foundation for developing the present implant systems. An examination was conducted of studies about the various types of implants and the substances employed in them. It is essential to remember that subsequent research by the same author on the same subject matter may be of interest if it determines the author's conclusions from a more recent study. Following a review of studies about the majority of Osseo-integrated implants, the surgical approach and the benefits and drawbacks of these approaches were reviewed. Then, the materials and processes utilized to enhance the surfaces of implants for osseointegration applications and their ongoing development, in addition to the future guidelines cited in these studies, were discussed. To provide a concise overview, this research was structured around the following components: advantages, limitations, implant system types and materials, surgical contexts, and surface enhancement methods with biomaterials utilized for coating implant surfaces. This enables the investigator to rapidly review the research and its findings, thereby facilitating the acceleration of protracted research procedures.

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