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Review Article

Orthopaedics Section

Design, Materials and Biomechanics of Orthopaedic Implants: A Narrative Review

MELROSE BARRETO[1], SAUMYA SRIVASTAVA[2], HARRAMB MITTAL[3]

ABSTRACT

Millions of patients' lives have been improved by orthopaedic implants. Joint replacement surgery has helped to relieve pain and improve function, while fracture fixation implants promote faster bone healing, resulting in a quicker return to daily activities. The use of more wear-resistant bearing surfaces has increased the longevity of artificial joints. As with any implant, special attention must be paid to the material and design used to create the implants; otherwise, bone fractures or defects may occur, and bone healing may not occur at all. This review highlights the parameters of implant design, the different biomaterials used in implants, and the types of implants, along with their biomechanics. The review provides a brief explanation of the factors involved in designing an implant, the materials used to manufacture it, and the biomechanical principles behind the most common types of implants.

Keywords: Biomaterials, Biomechanical principles, Implant design

INTRODUCTION

Orthopaedic implants, which include artificial prostheses and internal fracture fixation devices, are used to replace joints and fill in bone defects. They aid in preserving, supporting, and repairing the structure and functionality of the musculoskeletal system [1]. Today, a variety of devices and implants are utilised to restore the function of wounded tissues, consequently increasing the quality of life for patients. Metal plating was first used for orthopaedic surgery in 1895, leading to the use of internal fixation implants as aids in fracture healing. Subsequently, a variety of plates held together with screws emerged. In 1909, German surgeon Martin Kirschner invented smooth pins, using them as support wires for implants and traction for bones [1]. Stainless steel first appeared as a bone screw material in 1920 and was considered to possess sufficient strength and biocompatibility [2]. While implants have evolved alongside modern technology and medical science, research to enhance their performance is still being carried out. The parameters of implant design, the biomaterials commonly used, and the biomechanical forces associated with some common implants will be discussed in this article.

IMPLANT DESIGN

The design of an implant is of utmost importance in improving performance and facilitating the restoration of joint mobility, enabling individuals to engage in daily activities. The impact of interacting with the physiological environment and selecting biomaterials with appropriate physiochemical properties are important factors to be considered. In order to achieve comparable mechanical performance, the implant must exhibit properties closely resembling those of the host bone. Therefore, it must be both stiff enough to withstand physical loading and permeable enough to allow blood to flow through it [3].

Implants are primarily in accordance with three major parameters:

1. Defined mechanical properties of implantable biomaterials.
2. Specifications for bone fractures.
3. Biocompatibility of the biomaterial to be used [4].

Mechanical Properties

Biomaterials are materials that are accepted and can be used for tissue replacement when introduced into living tissues. There are two types of mechanical properties that a biomaterial should possess in order to be considered for use in an implant: bulk properties and surface properties [5].

Bulk properties:

- Tensile strength: It refers to the maximum level of stress that a material can withstand before experiencing fracture or failure. It is imperative to possess high tensile strength to ensure the prevention of implant fracture and the optimisation of functional stability [6].
- Yield and fatigue strength: Yield strength is the critical threshold at which the transition from elastic deformation to plastic deformation occurs. Biomaterials must also have a high fracture value to withstand compressive forces during loading [7].
- Modulus of elasticity: It is indicative of stretch and deformity and is calculated as the ratio of tensile stress divided by tensile strain. It is important for ensuring even stress distribution at the implant-bone interface [8].
- Ductility: It is the material's ability to withstand significant plastic deformation before failure. This property is used to contour implants [5].
- Hardness and toughness: These properties are used to decrease the fracture and degeneration of implant materials [5].

Surface properties:

- Surface tension: Protein absorption and maintaining surface contact by the extracellular matrix are governed by this property [9]. It assesses the biomaterial-host interface between blood and the implant surface. Surface tension, intimately related to wettability, is known to correlate with biological interactions. Material wettability is a determining factor for protein adsorption and thus also for cell adhesion. It is usually reported that biomaterial surfaces with moderate hydrophilicity improve cell growth and have higher biocompatibility. Osteoblasts adhere better to the implant surface [9].
- Surface roughness: The augmentation of the implant's surface area facilitates enhanced cellular adhesion to the bone. The classification of implant surfaces is based on their roughness, texture, and irregular orientation [10]. Surface roughness of implant surfaces has been classified as minimally rough (0.5-1 μm), intermediately rough (1-2 μm), and rough (2-3 μm). The texture of the implant surface can also be characterised as concave texture or convex texture, and the orientation of

surface imperfections can also be classified: Surfaces that are isotropic have identical topology. The roughness of anisotropic surfaces varies greatly [5].

Specification for Bone Fracture

The configuration of a bone fracture influences the design of the bone implant. Fracture healing is governed by a complex interplay of biology and mechanics, with the goal of providing optimal stability while causing the least amount of damage to the local biology as possible. To accomplish a primary union without callus formation, simple fracture patterns are preferably treated with compression and absolute stability. Lag screws and plating techniques work best for interfragmentary compression. To achieve secondary union with callus formation, multifragmentary fracture patterns are ideally treated with relative stability. It is vital to keep the strain within a range that promotes callus formation but does not exceed a critical tolerance threshold beyond which callus formation fails. Bridge plating, intramedullary nails, and external fixators are frequently used to achieve relative stability. Newer implant designs with a small bony footprint and locking screw fixation help to protect the local blood supply even more [11]. The implant must provide adequate support to the damaged bone based on the quality of the bone or soft tissue status, anatomy, location, and pattern of the fracture, and it must conform to the initial skeletal configuration prior to the fracture [12].

Biocompatibility of Biomaterial Used

Biocompatibility is a critical requirement for any orthopaedic implant. Cytocompatibility and haemocompatibility tests should be performed to ensure overall compatibility in the physiological environment before implantation [13].

ORTHOPAEDIC IMPLANT BIOMATERIAL

A biomaterial can be described as a substance or a combination of substances that has been engineered to interact with the physiological environment in order to provide treatment, enhancement, or substitution for any bodily tissue or function [14].

Biomaterials must possess certain properties in order to be used for a prolonged duration without rejection.

- **Biocompatibility and Toxicology:** It denotes the biomaterial's compatibility or harmony with living systems and the ability to exist in proximity to the physiological environment without causing undue harm. It must not have a negative impact on the host environment and should not be carcinogenic, pyrogenic, toxic, allergenic, blood compatible, or inflammatory [15,16]. Toxicology is concerned with substances that migrate out of implant material. Unless specifically designed, a biomaterial should not emit anything from its mass.
- **Biofunctionality:** In mechanical terms, biofunctionality entails performing a specific function. When used for bone replacement, it should optimise stress distribution and allow necessary articulation allowance for movement.
- **Mechanical properties:** Some of the most important properties of biomaterials include tensile and yield strength and surface finish.
- **High corrosion and high wear resistance:** The issue of corrosion resistance plays a significant role in the choice of metallic biomaterials, as the corrosion of metallic implants is an inevitable consequence of exposure to corrosive bodily fluids. Accumulation of corrosion products leads to the shortening of implant life, necessitating revision surgery [17]. Implant loosening occurs as a result of low resistance to wear or a higher friction coefficient or due to the generation of wear debris that leads to a severe inflammatory response resulting in the degeneration of the healthy bone that provides support to the implant [18].
- **Adequate strength and long fatigue life:** Insufficient strength may lead to the occurrence of implant fracture. The occurrence of bone-implant interface failure results in the development of soft fibrous cells at the interface. This tissue formation induces heightened relative movement between the implant and the bone during loading, resulting in patient discomfort. Consequently, the replacement of the implant becomes necessary through a revision procedure [19]. Repeated cyclic load is proportional to the fatigue strength of an implant. Fatigue fracture is a major cause of implant loosening and eventual implant failure [20].

Types of Biomaterial

Biomaterial science is the study of the properties and composition of materials, along with their interaction with the environment in which they are placed. Metals, polymers, and ceramics are the most commonly used classes of biomaterials. Most implantable devices available today are made up of these classes, either individually or in combination [21].

Metals

The prevailing categories of metals employed in the fabrication of implants include stainless steel, cobalt-chromium alloys, and titanium and its corresponding alloys. Stainless steel is widely utilised for internal fixation devices for fractures, despite its poor corrosion resistance [22]. Subsequently, cobalt-chromium alloys emerged as a replacement for stainless steel due to their notable corrosion resistance; nevertheless, subsequent research has demonstrated their carcinogenic properties. Titanium and its alloys are commonly employed, which can be attributed to the formation of a titanium oxide layer on the surface. Nevertheless, it also releases vanadium, resulting in toxic effects [23].

Ceramics

Ceramics are a diverse class with three basic types currently available: bioinert, bioactive, and bioresorbable. They exhibit superior mechanical features such as hardness, tremendous strength, and resistance to corrosion and wear. They function well under compressive forces but perform poorly under tensile forces [24].

Polymers

Polymers are widely used in biomedical applications due to their flexibility, good biocompatibility, and are easily available. Several prominent categories of polymers currently utilised include Ultra-High Molecular Weight Polyethylene (UHMWPE), Polyethylene (PE), and Polymethylmethacrylate (PMMA) [25]. [Table/Fig-1] lists the different biomaterials along with their associated advantages and disadvantages [26-41].

TYPES OF IMPLANTS

Orthopaedic implants are specifically engineered to aid in the treatment or substitution of injured bones and joints, with the primary objective of reducing strain on articulating surfaces. They are categorised into two types:

1 **Permanent orthopaedic implants:** Joint replacement implants.

2 **Temporary orthopaedic implants:** Bone screws, bone plates, intramedullary nailing, wires, pins, and cables.

1. Permanent Orthopaedic Implants

Permanent orthopaedic implants, also known as endoprostheses, are clinically used as replacements for diseased joints such as the hip, knee, ankle, shoulder, elbow, wrist, and finger joints [42]. Unlike trauma implants, which can be removed once a bone has healed, the purpose of joint reconstruction implants is to remain in the body permanently in order to restore normal, pain-free joint function [43]. Hip and knee joint prostheses have experienced rapid development and are the most performed replacement surgeries in recent years.

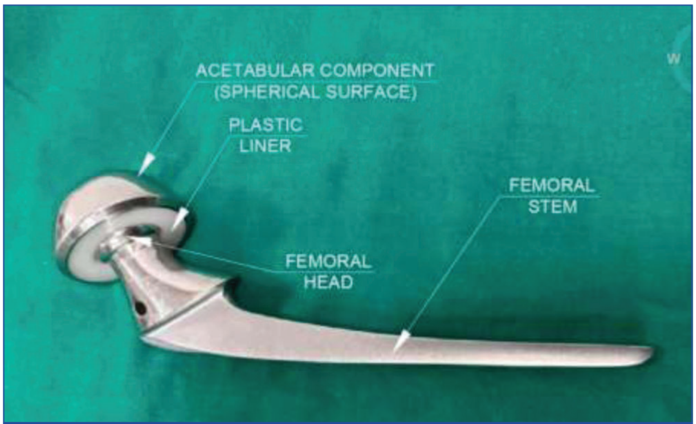
Material-Metals	Advantages	Disadvantages
Stainless steel [26,27]	High elastic modulus	Susceptibility to crevice corrosion
	High wear resistance	Reactivity to nickel present in stainless steel alloys can (but infrequently) cause an allergic reaction
	Good fatigue resistance	Metal ions are released with corrosion
	Low cost and inexpensive to fabricate	
	Plates, screws, sliding hip screws, and rigid intramedullary nails are all commonly made from stainless steel	
Cobalt-Chrome [26,28,29]	Highly resistant to corrosion	Young's modulus is extremely high, indicating the possibility of stress shielding
	Used as a bearing surface in metal-on-metal hip arthroplasty.	Cobalt chrome particles from metal-on-metal wear cause a slew of surgical problems and have been widely documented as immunogenic.
		Nickel reactivity can (but rarely does) result in an allergic reaction.
Titanium and its alloys [15,16,30]	High tensile strength with a moderate elastic modulus of around 110 Gigapascals	Systemic toxicity-release of aluminum and vanadium
	Good resistance to corrosion and fatigue	Relatively expensive
	Biologically inert	
	Used in total hip femoral stem components, total shoulder arthroplasty stems, intramedullary rods and pedicle screws	

Material-Ceramics		Advantages	Disadvantages
Bioinert	Alumina (Al_2O_3) [31-33]	Excellent resistance to corrosion	Expensive
		Excellent biocompatibility	Low fracture toughness
		High strength and wear resistance	Cannot deform under stress
		High mechanical characteristics	Audible squeaking
		Used in loadbearing hip prostheses	
	Zirconia (ZrO_2) [31-33]	High mechanical strength	Expensive
		High fracture toughness	Slow crack growth
		Used in Total Hip Replacement (THR) for ball heads	
Bioresorbable ceramics	Calcium phosphates [34]	Good stiffness	High temperatures make it unstable
		Mechanical properties resemble trabecular bone	Low tensile strength
	Hydroxyapatite [35,36]	Non toxic, highly biocompatible and promotes bone growth with high osseointegration	When used as a coating over metallic implants, there is a risk of delamination and abrasion wear.
Bioactive	Bioactive glass [37]	Bone formation occurs at a rapid rate	Fabrication is difficult.
		Improved fixation	Brittle in nature
		Used for filling bone defects	Bending and fatigue strength are both low

Material-Polymers	Advantages	Disadvantages
Ultra-High Molecular Weight Polyethylene (UHMWPE) [16,38]	Outstanding mechanical properties	Releases debris
	Enhanced modulus	Adverse tissue biological reactions
	In total hip arthroplasty, it is used in the liners of the acetabular cups, in the tibial insert and patellar component	Osteolysis, or bone loss, which causes implant loosening
Polyethylene (PE) [39,40]	Low coefficient of friction	Wear debris is released over prolonged period
	Fracture toughness	Ionising radiation
	High impact strength	
Polymethylmethacrylate (PMMA) (Bone cement) [41]	Superior osseointegration	Faces microfractures
	Provides primary fixation of the prosthesis	Cement particles are released
		Leads to foreign-body response locally

[Table/Fig-1]: Advantages and disadvantages of types of biomaterials [26-41].

Hip arthroplasty: Surgeon John Charnley from England was a pioneer of Total Hip Replacement (THR), often known as total hip arthroplasty. He invented the low-friction complete hip arthroplasty, which uses a stainless steel femoral component and a plastic (polyethylene) acetabular socket. In the late 1950s, Charnley performed numerous successful hip replacement surgeries, and his method is still regarded as the gold standard of total hip arthroplasty with long-term clinical follow-up results [44]. Total hip arthroplasty involves removing the diseased femoral head and acetabular cup and replacing them with prosthetic components. The artificial components of total hip arthroplasty include a metallic stem that fits into the proximal metaphysis and diaphysis of the femur, a metallic or ceramic ball that replaces the femoral head, and an acetabular cup that replaces the hip socket [Table/Fig-2]. The acetabular cup can be non modular, i.e., a single piece made of metal or PE, or a modular two-piece system with a metallic shell in combination with a bearing surface liner made of PE, metal, or ceramic. Hemiarthroplasty involves replacing the femoral head with a prosthesis while retaining the natural acetabulum and acetabular cartilage [45]. Metals, polymers, and ceramics are the three most commonly used biomaterials for the bearing surfaces. [Table/Fig-3] below shows the commonly used surface bearings and their associated advantages and disadvantages [46].



[Table/Fig-2]: Parts of total hip arthroplasty.
Images provided by Dr Harramb Mittal[3]-Kanachur Medical College

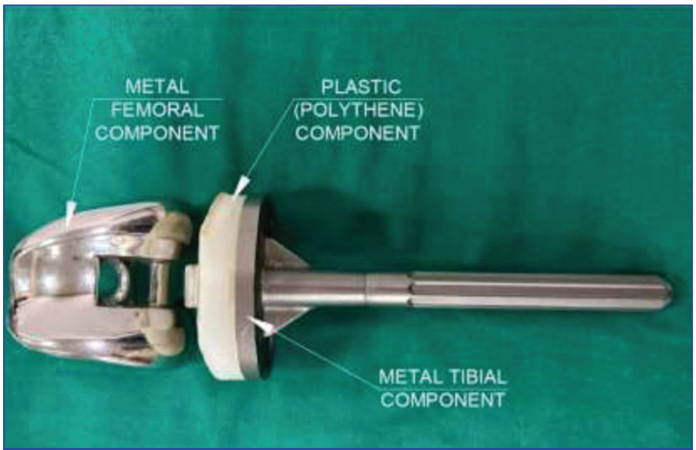
Types	Advantages	Risks
Metal-to-polyethylene [46]	Inexpensive	The cement ages and then disintegrates-"cement disease"
	Easier to implant	Greater wear and tear at metal-plastic interface
	Allows immediate load-bearing	Particles produced may, in addition to "polyethylene disease" also cause osteolysis
		Prosthesis longevity is poor
Metal-to-metal [46]	Reduction in wear	Patient hypersensitivity to metal
	Fewer failures due to producing less wear particles	Release of metal ions (cobalt, chromium and titanium)
		Flexing or scratching the implant could break its protective surface covering and corrosion could accelerates the process of failure due to fatigue.
Ceramic [46]	High wear resistance with modern medical grade ceramic being very hard and scratch resistant	Sensitive to proper positioning of components
	Relatively no toxicity of wear particles	Chipping of the ceramic cup liner
	High corrosion resistance	Squeaking sound
	Good biocompatibility of ceramic	

[Table/Fig-3]: Hip arthroplasty surface biomaterials.

Knee arthroplasty: The knee implant system is made up of four components [Table/Fig-4] [47]:

- Femoral component: It is composed of a metal cap that is placed on the femoral condyles after the damaged joint surfaces have been removed.
- Tibial component: This platform usually consists of a metal alloy with a short stem anchored in the tibia.
- Plastic spacer: Made of PE, it is inserted between the top and lower components. This substitutes the joint space and meniscus, allowing the implant to move more freely. Some implants employ a fixed bearing, while others use a movable bearing that can easily rotate around its own axis or glide forward and back.
- Patellar component.

During a total knee replacement, all three compartments of the knee are replaced, while during partial knee replacements only one compartment is replaced [48]. Metals, ceramics, and plastics are once again the most commonly used materials for bearing surfaces. [Table/Fig-5] lists the commonly used surface bearings and their associated advantages and disadvantages [49].



[Table/Fig-4]: Parts of total knee arthroplasty.
Images provided by Dr Harramb Mittal[3]-Kanachur Medical College

Types	Advantages	Disadvantages
Metal on polymer [49]	Least expensive type of implant	Can cause an immune reaction triggered by tiny particles that wear away from the spacer. This can cause bone to break down, leading to loosening and failure of the implant
	Longest track record for safety and implant life span	
	Metals commonly used include cobalt-chromium, titanium, zirconium, and nickel	
Ceramic on polymer [49]	Used for people who are sensitive to the nickel used in metal implants	Plastic particles from this type of implant also can lead to an immune reaction
	Uses a ceramic femoral component instead of metal (or a metal component with a ceramic coating)	
Ceramic on ceramic [49]	Ceramic parts are least likely to react with the body	Ceramic joint prostheses can make a squeaking noise while walking.
		In rare cases, they can shatter under heavy pressure into pieces that must be removed by surgery
Metal on metal [49]	Metal implants originally were developed to provide longer-lasting joint replacements for younger people.	Traces of metal leaking into the bloodstream has been detected due to the chemical breakdown of the implant hardware
	Metal-on-metal implants may be considered only for young, active men, because they may last longer than other materials.	

[Table/Fig-5]: Knee arthroplasty surface biomaterials.

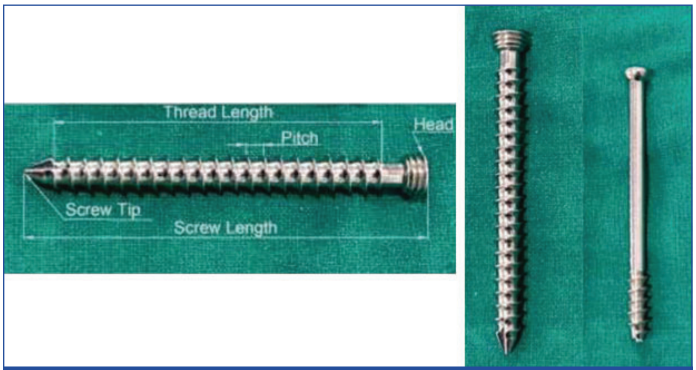
2. Temporary Orthopaedic Implants

In order to stabilise damaged or broken bones while they recover, temporary orthopaedic implants are also necessary. The purpose of temporary orthopaedics is to support the mending of bones for a brief period of time [43].

Bone screws: A bone screw is a geometrically tapered cylindrical structure featuring helical threads encircling its exterior surface. It consists of four distinct functional components: the head, shaft, thread, and tip [Table/Fig-6] [50]. The threads on cortical bone screws are smaller (in diameter) and more closely spaced (lower pitch). The core diameter is relatively large, providing the required strength. The screw's holding power improves as the pitch decreases. Cancellous bonec screws have bigger threads and a greater pitch than cortical screws. The smaller core diameter than the shaft diameter gives a larger surface area for screw thread purchase on bone. A cancellous screw's pull-out strength increases as its thread diameter increases [50]. Screws are used to attach implants to bone, to fix bone to bone, or to fix or anchor soft tissue. They are often used in conjunction with plates to secure the bones, as well as independent components to secure fractured fragments [51].

Orthopaedic screws are classified into three types:

1. Cortical screws-used in diaphyseal bones.



[Table/Fig-6]: Parts of a screw, types of screw (Cortical, Cancellous).
Images provided by Dr. Harramb Mittal[3]-Kanachur Medical College. (Images from left to right)

2. Cancellous screws-made specifically for cancellous bone. The threads are deeper and have a larger pitch and outer diameter.
3. Locking head screws-exhibit an increased core diameter, a superficial thread, and rounded edges [52].

Biomechanical Principles-screws

- Screws are utilised to transform rotational forces into compressive stresses along a fracture site. For successful fixation, it is imperative that the screw is applied in a manner where the proximal portion of the screw smoothly moves within the nearby bone while the threads securely engage with the opposite cortex. This ensures that the screw head effectively increases the load and brings the bone ends closer together. The screw angle in relation to the fracture must be meticulously chosen to prevent displacement of fracture fragments during compression [53].
- The utilisation of tensile stresses in the screw forms the basis of bone-plate fixation [54]. The application of torque during screw insertion and the subsequent tension generated exhibit a nearly linear correlation. To attain the desired increased screw tension, it is recommended to insert the screw at the maximum attainable torque, while ensuring that bone shearing does not occur. A higher screw tension is preferable as it necessitates increased frictional pull to be overcome for loosening to transpire. Additionally, this is likely to decrease stress shielding [53].
- The concept of "biomechanical compatibility" refers to the stress, strain, or other mechanical stimuli distribution that occurs in the bone surrounding a screw when it is tightened during the implantation process [55]. The problem of screw loosening frequently occurs in the context of bone fracture fixation. One of the contributing factors to the occurrence of excessive bone resorption is stress shielding that occurs specifically around the threads of screws. The phenomenon of bone loss in the proximity of screw threads has been a subject that has been relatively understudied. This phenomenon is particularly evident in instances of brittle fractures occurring in low density osteoporotic bone, wherein the rate of bone resorption near implants is expected to surpass that of a comparable fracture in healthy bone, owing to the pre-existing compromised condition of the bone [56].

Bone plates: Plates of diverse dimensions and configurations, featuring both screw and pin apertures, are employed to achieve stabilisation and compression of bone fragments in load-bearing bones, facilitating the healing process.

Classification

Neutralisation plate: These plates are placed transversely across an aligned fracture and compressed by screws. A neutralisation plate acts as a 'bridge,' transmitting various forces from one end of the bone to the other, bypassing the area of the fracture. Its main function is to act as a mechanical link between the healthy segments of bone above and below the fracture. Such a plate does not produce any compression at the fracture site [50].

Compression plate: A compression plate produces a locking force across a fracture site to which it is applied. The plate is attached to a bone fragment and then pulled across the fracture site by a device, producing tension in the plate. As a reaction to this tension, compression is produced at the fracture site across which the plate is fixed with screws. The direction of the compression force is parallel to the plate [Table/Fig-7] [50].

Buttress plate: The mechanical function of this plate, as the name suggests, is to strengthen (buttress) a weakened area of cortex. The plate prevents the bone from collapsing during the healing process. It is usually designed with a large surface area to facilitate wider distribution of the load. They are positioned at the apex of the fracture, and the plate-screw construction serves as a load-bearing device [Table/Fig-7] [51].

[Table/Fig-7]: Bone plates (Compression, Buttress), Intramedullary nail.
Images provided by Dr Harramb Mittal[3]-Kanachur Medical College. (Images from left to right)

A bone plate serves two mechanical purposes:

1. To facilitate force transmission from one extremity of a bone to the other by bypassing and thereby inhibiting movement in areas affected by fractures.
2. It holds the fracture ends together while keeping the fragments in proper alignment throughout the healing process [57].

Biomechanical Principles-Internal Fixation with Plates

- Plates serve as a load-bearing mechanism and are responsible for load transmission. However, the plate may bend if there is a discrepancy at the site of the fracture. This mostly occurs due to improper reassembly of the fractured bone, likely causing early fatigue failure of the plate as a result of cyclical backward and forward movement resulting from incomplete bone-plate construct, leading to forward and backward bending on limb loading [53].
- Lengthening the plate enhances the lever arm of the construct, thereby reducing the pullout force exerted on the screws. The effective measurement of a plate's working length refers to the distance spanning the fracture site, encompassing the two closest points of bone fixation to the plate. Including an additional screw in proximity to the fracture site significantly enhances the axial stiffness [58].

Intramedullary nail: An intramedullary nail is a metal rod that is inserted through the medullary canal to achieve stabilisation of the fractured bone segments. For rotational stability, an intramedullary nail depends on the length of contact with cortical bone and friction between the nail and bone [Table/Fig-7]. A nail's ability to govern angulation and translation is due to its interaction with cortical bone. Weight bearing can be resumed significantly sooner after intramedullary nailing than after other methods of fixation, since it is a load-sharing device that is much stronger than a plate [59,60]. The intramedullary nail is commonly used for most diaphyseal and certain metaphyseal fractures and is also employed in the fixation of fractures of long bones [39,47].

Screws are utilised as independent fixators as well as in conjunction with other orthopaedic hardware devices, most notably plates. They are principally responsible for the stability of most screw-plate fixation systems and are frequently associated with failure due to pull-out, due to poor screw purchase or bone loss. Screw-hold in bone is critical for maintaining the integrity of plated-bone structures and providing essential interfragmentary compression [61,62].

Biomechanical Principles-Intramedullary Nail Fixation

- Intramedullary nails serve as intrinsic splints that distribute load. The load distribution of a nail is influenced by various factors, including the size of the nail, the number of interlocking screws used, and the distance between the interlocking screws and the fracture site [63].
- Torsion, compression, and tension are the biomechanical forces exerted on an intramedullary nail. The torsional rigidity of the nail is determined by its cross-sectional configuration and its interaction with the endosteal bone located within the medullary canal [64]. A larger diameter creates a construct of tight fit within the intramedullary canal, which reduces the movement between the nail and bone, providing optimum compression [63].
- Minor movements of the nails and screws facilitate regulated motion and relative stability, whereas interlocking screws restrict translation and rotation at the site of the fracture. Contemporary nail designs incorporate interlocking screws in multiple planes, thereby providing enhanced stability. The utilisation of multiple proximal and distal interlocking screws, in conjunction with the implementation of a larger diameter intramedullary nail, can effectively achieve stable intramedullary fixation for an unstable fracture pattern [51].
- Intramedullary nails at both the proximal and distal fracture sites effectively restrict any potential rotational or sliding movements between the two ends of the fractured bone. This approach also has the potential to preserve physiological alignment and bone reduction position, thereby offering substantial support for the healing of soft tissue and bone.

The working length of the intramedullary nail is established by measuring the distance between the closest locking screw at the proximal and the distal position where the nail makes contact with the bone. This measurement represents the length of the nail responsible for bearing the majority of the load at the fracture site. The relationship between the resistance to bending and torsion and the working length of the nail is directly proportional. In this scenario, it can be observed that the bending stiffness of a nail exhibits an inverse relationship with the square of its working length, while its torsional stiffness demonstrates an inverse correlation with its working length. Consequently, a reduced working length leads to enhanced fixation strength, while an increased working length is associated with greater mobility at the fracture site under the influence of limb weight [38].

Wires: Wires are used to reconnect bone fragments and to reattach long oblique and spiral fractures of long bones. Malleable wire with a high tensile strength is also used to suture tissues such as tendon, subcutaneous tissue, and skin.

Uses of Wire

1. Wire is especially useful when firm fixation is required through a small, relatively inaccessible space.
2. Tension band wiring is a technique for achieving maximum fracture stability while using the least amount of fixation material.
3. Percutaneous cerclage is a successful treatment method for a long oblique or spiral tibial fracture [39].

Cables: Cables are made of braided wires. They are commonly used in internal fixation in conjunction with pins and plates and this combination is called the cable pin system or the cable plate system. Compared to stainless steel wires, cables have more strength and superior pliability. They are also highly strain resistant and may be optimally tightened and secured to ensure that the fixation is robust and resistant to load [64].

Pin: A surgical pin is a thin, straight wire with exceptional bending resistance. Pins are used as an adjunctive implant to withstand a large loading force in complex bone fractures, or used on their own to fix bone fragments under significantly weaker forces. Pins are extremely versatile and are frequently used for internal fixation [65].

CONCLUSION(S)

The design of an implant improves its functionality and ability to restore movements, providing stability for a person's daily activities. To match mechanical performance, an ideal implant should have properties resembling those of the host bone. The more closely an implant's design resembles the original bone or joint structure, the higher its probability of becoming integrated.

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PARTICULARS OF CONTRIBUTORS:

1. Postgraduate Student, Nitte Institute of Physiotherapy, NITTE (Deemed to be University), Deralakatte, Mangaluru, Karnataka, India.
2. Associate Professor, Nitte Institute of Physiotherapy, NITTE (Deemed to be University), Deralakatte, Mangaluru, Karnataka, India.
3. Assistant Professor, Department of Orthopaedics, Kanachur Institute of Medical Sciences, Mangaluru, Karnataka, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Saumya Srivastava,
Nitte Institute of Physiotherapy, NITTE (Deemed to be University),
Mangaluru-575018, Karnataka, India.
E-mail: saumyasri2000@nitte.edu.in

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