# MODELING, ANALYSIS, AND MANUFACTURING OF A PROSTHETIC KNEE JOINT (REVIEW STUDY)

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**ABSTRACT**

The prosthetic knee joint is a vital component of prosthetic limbs for individuals who have undergone above-knee amputations. This review study assesses the modeling, analysis, and manufacturing of knee prostheses. Addressing the urgent requirement for efficient prosthetic solutions in response to the rising number of amputations. The study reviewed various types of mechanical passive prosthetic knee joints, including single-axis, polycentric, pneumatic, and hydraulic designs. The inspection and comparison of a microprocessor-controlled and powered knee joint were also carried out. To determine how much patient comfort improves while walking and performing other activities, and how the body stabilizes during activities or duties such as stair ascent and walking on an uneven surface.; the study found that many studies have focused on the progress of prosthetic knees, particularly those utilizing MP controls, in enhancing mobility, stability, and comfort. Enhancements in materials and design, facilitated by Finite Element Analysis (FEA), have proved transformative. The cost remains a practical constraint; therefore, research should focus on simplified and more affordable systems. The research indicates a need for further development in adjustable or custom-fit prosthetic knees, encompassing 3D-printed devices and lightweight materials. This review study recommends that further studies continue to develop various types of knee prostheses, aiming to design one that is less complex and more affordable for many clients, while also addressing the challenges that affect the development of prostheses

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## 1. INTRODUCTION

Transfemoral amputation (also known as above-knee or AKA) is a critical surgical procedure for those with non-recoverable limb damage. More than one million lower limb amputations occur every year worldwide, and transfemoral amputations represent >25% of these cases [1]. Recent United States data have demonstrated a reversal of AKA (from the long-term decline) in 2012, with an annual increase of 4% through 2021. This is possibly due to the changes in the profile of risk factors and an aging population [2]. Peripheral vascular disease (PAD) is believed to account for greater than 50% of these above-knee amputations [1]. This treatment is necessary for many severe diseases and is performed below the hip, beneath the femur. Non-healing chronic diabetic foot ulcers, large traumatic wounds that preclude limb salvage, and oncological conditions are all associated with the need for AKA along with peripheral artery disease [3]. The prosthetic field—prosthesis and prosthesis art—is more relevant now, given the ongoing wars and conflicts. As a result, the number of amputees has increased significantly. Consequently, it is acknowledged that companies have produced several types of knee joints for transfemoral amputation [4]. A prosthesis is an artificial replacement for the human lower extremity following amputation. [5] A lower limb prosthesis consists of a socket, a knee component, a pylon, and a prosthetic foot.[6] as illustrated in Fig. 1


Fig. 1 Fundamental elements of a transfemoral prosthesis [7]

## 2. METHOD

This literature review examines and evaluates recent developments in the modelling, analysis, and fabrication of prosthetic knee joints of various types.
A total of 60 peer-reviewed publications were examined, chosen from esteemed journals, conferences, and academic databases, including IEEE Xplore, ScienceDirect, Springer, and Google Scholar. Guaranteeing the incorporation of modern methodologies and advancements.
To systematically review and organize the findings, the collected papers were categorized into two main themes, as illustrated in Fig. 2

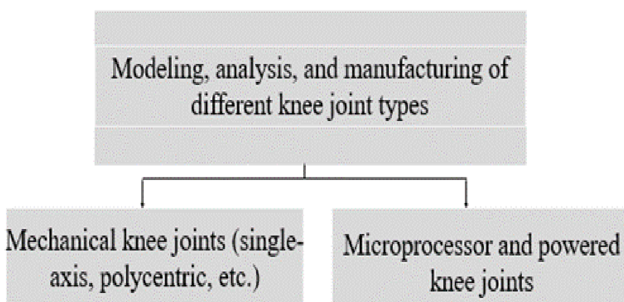


Figure 2 illustrates the distribution of analysed studies across two theme domains

### 2.1. Mechanical knee joints (single-axis, polycentric, etc.):

The artificial knee joint can substitute the natural, unfunctional or absent knee in a person whose own knee is not functional, though which may have been lost as a result of trauma or disease. Various types of prosthetic knees are available with different components that might be more appropriate for one patient than another. Knee joints function in different modes depending on classification and geometry. The kinematics and potential of the natural human knee have been designed to be as accurate as possible [8] [9] for all implant knees. Passive knees for basic locomotion on the ground Passive (basic) knees available 30. [10]. They frequently include hydraulic or pneumatic elements, which maintain a constant impedance that does not permit for movement under changing conditions. They do not include sensors to control interaction between the user and its surroundings. Other kinds do not have an external power supply of a control system [11, 12]. Current commercially available passive prototypes are only capable of providing walking stability on flat ground, but have yet to be tested on uneven terrain, especially in

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developing countries.[13] There are different types of knee joints described in the following sections, with all knee joints ' functions, which have been constructed for lower flexibility leg prosthesis

### 2.1.1. Single axis:

This artificial knee joint, featuring a simple hinged mechanism that allows the knee to flex and extend in only one direction, provides a straightforward, easily used motion, similar to a door hinge, especially for patients with difficulty moving. [8], [9]
Benefits: This artificial knee prosthesis is durable and requires minimal care and maintenance. Also, the cost is relatively inexpensive compared to pneumatic and hydraulic knee joints.
Cons: Requires reasonable muscular control for knee support and is not adaptable to different walking rates.

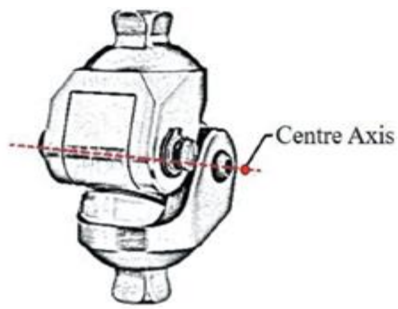


Figure 3. (Mechanical passive knee joints) Single-axis [14]

### 2.1.2. Polycentric (Four or Six-Bar):

A polycentric knee simulates human knee motion by introducing multiple pivot points via a four-bar linkage. They are more stabilizing and often used in people with extended periods of walking or standing [15], [16]
This mechanism provides flexion, extension, and adaptation of the knee to different walking speeds and terrain.
Benefits: Prosthetic designs adjusted for longer residual limbs allow for a broad range of functional levels. Additionally, costs are unusually low compared to pneumatic and hydraulic knee joints.
Cons: Polycentric knees are more challenging to hide cosmetically due to joints or links, and are bulkier and heavier overall. Figure 4 illustrates various mechanical passive knee joints


Figure 3. Mechanical passive knee joints: (Polycentric Knee with 4-bar linkage mechanism) [14]

#### 2.1.2.1. Polycentric knee joint design and modeling:

An artificial knee joint according to the four-bar mechanism could be utilized as a hinge in a low-cost prosthesis for trans-femoral amputees. The kinematical scales are set by means of a multi-criteria optimization based on scans of all possible points uniformly sampled in a nD cube [17]. Poliakov et al. [18] have studied different methods of synthesis. New designs for the polycentric prosthetic knees have been studied in detail [19, 20]. Several designs are offered by well-known manufacturers like Ossur, Otto Bock, Hosmer, Endolite, Teh Lin and others [18]. However, the vast majority have significant geometric and functional differences from their native counterparts.

Using measurements derived from CT or MRI images, along with existing literature on the knee, computer-based software can estimate the dimensions of the prosthetic knee joint for various sagittal radii and flexion angles [21]. The measurement of pertinent knee characteristics, including mean and variance, is crucial for the design of knee prostheses. In a trans-femoral prosthetic system, the anatomical knee is substituted with a polycentric mechanism that endures significant structural stress. Consequently, mathematical models of knee mechanics are frequently employed for kinetic study, simulation, and the identification of potential faults. [22]

### 2.1.3. Pneumatic knee joint:

Pneumatic knee joints are controlled by air pressure to adjust the knee movement and stability. In most cases, being lightweight enough for people on the go. [9], [10]
Benefits: Flexibility, shock absorption, lightweight, silent operation, and full customization.
Cons: Maintenance, complexity, inapplicability to specific operations, and the need to change air pressure. In addition, a Pneumatic knee joint is significantly more expensive than a plain knee joint system. Design and assessment of the “Energy Restoring Intelligent Knee” (ERiK), which captures energy during sitting in a pneumatic cylinder and releases it during standing. The method would reduce the duration of transitions and facilitate greater load distribution by the prosthetic limb.[23].

### 2.1.4. Hydraulic Knee:

Hydraulic knee joints use fluid-filled chambers and valves to control kinematics and stability. They enable a normal gait and are commonly used by active individuals who participate in various sports [13].
Benefits: the hydraulic Knee joints provide smooth, continuous movement, stability, shock absorption, security, and adaptability.
Cons: It requires maintenance, is heavy, has a steep learning curve, and may not be the best option for all pursuits. The items are also expensive to purchase and maintain, making them challenging for some people to use.

Figure 6. Hydraulic Knee [23]

The hydraulic knee is highly appropriate for active transfemoral amputees. These knees function using incompressible fluid, enabling modulation of friction force with walking speed [24]. This capability is achieved by controlling the opening and closing of valves within the hydraulic system to ensure stability during the stance phase, a process known as stance-phase control. The Mauch SNS, a prevalent commercial hydraulic prosthetic knee, uses a hyperextension moment to facilitate stance-phase control. Under typical circumstances, this knee provides substantial resistance, helping maintain stability throughout the initial stance phase. During the terminal stance phase, a hyperextension moment diminishes resistance, facilitating unrestricted flexion [25]. Nonetheless, this does not afford adequate stance-phase knee flexion to replicate natural walking [26, 27]. A different approach to stance phase regulation for hydraulic knees is Ground Reaction Force (GRF) control. The knee is normally mobile and becomes locked when the ground reaction force attains the threshold value [28].

Table 2: Summary of previous studies on mechanical passive prosthetic knee joints

| Reference | Title | Year | Authors | Method | Conclusion |
|---|---|---|---|---|---|
| [29] | Application of Assembly and Manufacturing | 2014 | Muhammad Ahmed Khan, Tahira Mumtaz et | Inspired by reverse engineering to | A simple single-axis knee prosthesis with |

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| | Technology In the field of Biomedical Engineering: Three-Dimensional Solid Modeling of Prosthetic Knee Joint | | al. | develop a single-axis prosthetic knee joint. | two DOFs (flexion and extension It has been successfully modelled and is stronger, cheaper, lighter, and simpler than a complex electronic prosthesis. |
| [30] | Design and optimization of the exoskeleton structure of the lower limb knee joint based on a cross four-bar linkage | 2021 | Moyao Gao et al. | Developed a bionic knee exoskeleton based on a cross four-bar linkage mechanism | The system has a human reciprocal rotation center for realistic knee motion, and test results indicate that it can reasonably simulate the human knee motions during standing and walking. |
| [31] | Design and Evaluation of a Smooth-Locking-Based Customizable Prosthetic Knee Joint | 2024 | Kunyang Wang et al. | Developed a well-locking passive prosthesis knee using a compliant four-bar linkage and evaluated spring configurations for knee flexion. | Achieved the same knee flexion angles as normal gait, and may become an economic custom prosthetic for above-knee amputees |
| [32] | Design and Evaluation of a Prosthetic Knee Joint Using the Geared Five-Bar Mechanism | 2015 | Yuanxi Sun et al. | designed a prosthetic knee with a geared five-bar mechanism and optimization of the Instantaneous Center of Rotation (ICR) and ankle trajectory | The gear drive of the five-bar linkage leads to a significant gain in bionic performance and trajectory accuracy compared with four-bar mechanisms |
| [33] | Evaluation of 3D printed | 2021 | Tyagi Ramakrishnan et | 3D Printed Customised | Differences in gait pattern were |

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| | anatomically scalable transfemoral prosthetic knee | | al. | Transfemoral Prosthesis) Ossur Total Knee 2000 and an anatomically deployable prosthetic knee were tested on a walking transfemoral amputee. | highlighted by motion capture and force recordings: The Ossur Total Knee showed increased total gait asymmetry, peaking at knee flexion, with the worst-case high-step-time asymmetry. |
| [34] | Design and preliminary field validation of a fully passive prosthetic knee mechanism for users with transfemoral amputation in India | 2018 | Murthy Arelekatti et al. | Developed a prototype for an inexpensive, passive prosthetic knee with integrated automatic Early Stance Lock (ESL) stability and load adaptive Different Friction Damping System (DFDS). | The prototype performed reasonably well, especially for stance-to-swing transitions. The first position lock provided stability. |
| [35] | A method for performance comparison of polycentric knees and its application to the design of a knee for developing countries | 2017 | Anand TS, Sujatha S. et al. | Objective standards with which to evaluate commercially available prosthetic knee systems, concentrating, among other things, on stability, toe clearance, maximum flexion, as well as several other essential features. | Worked these features to develop a new knee design with the trendiest shape that provides stability and toe clearance. This design excels on rough terrain, which is common in developing countries. |
| [36] | Design for manufacture and assembly of a polycentric | 2019 | Taahirah Mangera et al. | Used design for manufacture and assembly to develop a | Improved assembly yield to 10.1% by optimizing die- |

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| | paediatric prosthetic knee | | | polycentric pediatric prosthetic knee, improving alignment and removing excess parts | casting technology to speed up and simplify the process. Finite Element Analysis confirmed the design changes and provided a further 13.6% efficiency gain. |
| [37] | Design and Comparison of Different Available Models of Prosthetic Knee Joint | 2021 | Himakshi Pareta, M. Chaturvedi et al. | Compared prosthetic designs —single-axis and polycentric — based on maximum stress, handling criterion, mass, and production cost. Finite element analysis simulated with ANSYS. | specify an optimal design for a prosthetic knee. The stress, mobility, and weight analyses conducted on the prototypes helped design a system for prosthetic restoration of the knee joint. |
| [38] | Finite element analysis and topology optimization of a high-performance lower prosthetic limb | 2023 | Bountourelis, Theologos et al. | Developed a prosthetic knee joint using Nickel alloy 718 and Additive Manufacturing. Mechanical properties were evaluated by finite element simulation. | Lost a considerable amount of weight whilst not slipping at all. |
| [39] | Structural analysis of a Four-bar linkage mechanism of the Prosthetic knee joint using the Finite Element Method | 2020 | Shailendra Singh Chauhan, S C Bhaduri et al | Confirmed the design of an above-knee prosthesis with a four-bar linkage mechanism. A CAD model was developed, and an FEA was performed under both static and | FEA results confirmed the prosthesis's strength; at 90° of compression, the maximum stress in the baseline design was well below the yield point. |

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| | | | | cyclic loading conditions. | |
| [40] | Design and experimental validation of a high-performance polycentric prosthetic knee joint for transfemoral amputees in developing countries | 2023 | P. Marisami and R. Venkatachalam et al. | Optimized the size for the polycentric knee linkage with the aid of SAM software and materials chosen, which are aluminium, CFRP, and GFRP. Fatigue assessment, tests, and validation were conducted in ANSYS. | Increased mid-swing toe clearance for no scuff coverage on any terrain. It was established that CFRP had better fatigue strength than aluminium and GFRP, making it suitable for machining knee joints for prosthetics. |
| [41] | Design, analysis and verification of a knee joint oncological prosthesis finite element model | 2014 | Lukáš Zach et al. | A finite element model for the hinged PROSPON oncological knee prosthesis. A 3D model CAD was created. Stress was analyzed using finite element analysis (FEA). | The study confirmed that the maximum Von Mises stress was lower than the yield strength, indicating plastic stability. |
| [42] | Design and analysis of polycentric prosthetic knee with enhanced kinematics and stability | 2022 | Rajesh Kumar Mohanty et al. | FEA of polycentric knee mechanisms to evaluate and optimize design. A modified design is proposed following failure analysis, and simulations are conducted to examine stress distributions, deformations, safety factors, and fatigue life. | The new polycentric knee endoprosthesis has improved static and fatigue strength; the maximum deformation is below 1 mm, whereas the minimum safety margin is within this range of 1.7 to 2. |
| [28] | Design and | 2019 | Keeratihattayakorn | Designed and | The prototype |

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| | evaluation of a hydraulic mechanism with available components for passive knee prostheses | et al. | built a prototype hydraulic knee with a simple component | hydraulic knee can be assembled from available hydraulic components for low cost and ease of maintenance, and provide stance and swing control |

## 2.2. Microprocessor-controlled and powered knee joint:

According to the mode of actuation, transfemoral prostheses are classified as follows: passive, microprocessor controlled and powered knee joint. Sensors that control actuators and detects the user's intention, and environmental situations are embedded in the knee microprocessor. But they require external power, and are much more costly, while the powered knee joint has actuators to modify damping according to circumstances of movement, walking speed or environment. Not to be confused with the mechanical passive knee that has several springs, hydraulic dampeners, and a mechanical lock. They are rigid, cheap and do not fit the stump [43].

Passive prostheses Mostly assigned in stabilizing of the stance phase. The difference between powered and microprocessor-controlled actuation systems is whether or not the weight of the amputee is redistributed by active prostheses. produces the necessary torque analogous to calf muscle and internal power enables mobility and performance improvement in regulated prosthetics. The damping of the knee joint of a microprocessor-controlled TF prosthesis, as well as the necessary brake torque can be varied. [44]. A powered prosthesis has inclusive of both power generation capabilities similar in some form to a natural limb and a control system for providing. the necessary joint torques for mobility, while ensuring stable and coordinated interaction with the user and the environment. Powered transfemoral prostheses also energize the ankle joint alongside the knee joint, yielding a net positive work during the stance phase of ambulation. The fundamental configuration of an ankle joint comprises parallel and series spring mechanisms activated by an actuator to generate the torque required to simulate typical human ankle function.[45]. Figure 7 illustrates the classification of the TF prosthesis


Figure 7. Classification of TF prosthesis: (a) microprocessor-controlled TF prosthesis, (b) Powered TF prosthesis [14].

Table 2: Summary of previous studies on microprocessor cntrolled and powered prosthetic knee joints

| Reference | Title | Year | Authors | Method | Conclusion |
|---|---|---|---|---|---|
| [46] | Design And Manufacturing Knee Joint for Smart Transfemoral Prosthetic | 2018 | Fahad M Kadhim et al. | Enhanced Transfemoral Prosthesis through designing a microcontroller-based knee actuated using a DC motor, and modelled the knee in SOLIDWORKS, followed by FEA analysis (ANSYS) to evaluate the strength. | The novel knee prosthesis met the bending and strength demands. The FEA results showed that the model can withstand the required loads, thereby promoting mobility for amputees. |
| [47] | The comparison of transfemoral amputees using mechanical and microprocessor-controlled prosthetic knee under different Walking speeds: A randomized crossover trial | 2018 | Wujing Cao et al. | I-KNEE: A microprocessor-controlled prosthetic knee with fluidic damper and servo valves for dynamic resistance control of flexion and extension | The swing flexion angle of 60–70° maintained by the i-KNEE at various walking speeds was similar to that seen in human gait. The NMPK, however, demonstrated a marked increase in flexion angle with increasing velocity. All in all, the i-KNEE was superior at adjusting for different speeds. |
| [48] | A Lightweight, Efficient, Fully-Powered Knee Prosthesis with Actively Variable Transmission | 2019 | Minh Tran et al. | Designing and validation of the Utah Knee, a powered knee orthoter that uses an Actively Variable Transmission (AVT) | Utah Knee is a full-function pyramid knee weighing the same as top-end passive knees but delivers the required torque and speed for optimum ambulation on |

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| | | | | | both level ground and stairs. |
| [49] | Optimization and Dynamics of the Six-Bar Mechanism Bionic Knee | 2019 | Yonghong Zhang et al. | Genetic algorithm for optimization | The ICR trajectory of the six-bar prosthetic knee joint is well optimized, and the percentage of successful gait falls within a reasonable range. |
| [50] | Artificial Knee Joints Actuators with Energy Recovery Capabilities: A Comparison of Performance | 2016 | Roberta Alò et al. | Evaluates three actuators to artificial knee joints: Flywheel-IVT (FIVT), Series Elastic Actuator (SEA), and Clutchable Series Elastic Actuator (C-SEA) for energy expenditure and power during level ground walking and stair ascent under different speeds . | The energy consumption of the C-SEA is lower than that of the F-IVT and SEA for wearable devices. The F-IVT reduces peak power requirements, potentially enabling a lower-rated electric motor and greater mobility. |
| [51] | Comparative biomechanical evaluation of two technologically different microprocessor-controlled prosthetic knee joints in safety-relevant daily-life situations | 2019 | Malte Bellmann et al. | Evaluated safety while six transfemoral amputees ascended stairs, slopes, walked backwards, and took small steps with two microprocessor-controlled knee units: the Rheo Knee XC and the C-Leg. | The C-Leg continued to provide stability when lifting heavy objects and facilitating heavy-duty tasks, thereby unloading the remaining limb. But the Rheo Knee XC needed performance adjustments to compensate for its lower burden-carrying capacity. |
| [52] | Enhancement of | 2018 | Sara Agueda et | Evaluated use of | 3E80 offers |

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| | a prosthetic knee with a microprocessor-controlled gait phase Switch reduces falls and improves balance confidence and gait speed in the community ambulators with unilateral transfemoral amputation | | al. | the 3E80 microprocessor-enhanced knee relative to conventional non-microprocessor prosthetic knees in walking, balance, and protection | improvements in walking confidence, bumper clearance, and comfort vs. non-microprocessor alternatives. |
| [53] | Modeling and analysis of a novel smart knee joint prosthesis for transfemoral amputation | 2021 | SH H Kamel et al. | Using the Finite Element Method (FEM) for biomechanical simulation of daily activities, a high-efficiency, smart prosthetic knee joint with natural mobility was developed. | The joint represents residual limb motion. From the analysis, there is an increase in von Mises stresses during flexion, with relatively higher displacement and decreased safety factors. Allegations about the safety of its usage have been proven wrong. |
| [54] | Modeling and Evaluation of Smart Economic Transfemoral Prosthetic | 2020 | Fahad M Kadhim et al. | We evaluated a new smart prosthetic knee joint using gait-cycle and EMG assessments in an above-knee amputee to compare traditional and innovative prostheses—validated load-bearing capability via ANSYS. | Enhanced the walking cycle. It reduced physical effort and, thus, energy consumption, and improved comfort compared with standard prostheses. |

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| [55] | A Biomimetic Design of an Artificial Knee for Lower Limb Prosthesis | 2019 | Gokul Gopinath et al. | Create a prosthetic knee joint with a "kine spring" type feature to mimic the action of healthy knees. The design was simulated in Autodesk Inventor for joint torque and reaction force analysis, and in ANSYS for FEA. | The final design candidates simulated natural knee motions very well. FEA simulation results showed the design can support the required loads with a safety factor of more than 2 |
| [56] | A novel prosthetic knee joint with a parallel spring and damping mechanism | 2016 | Huiqun Fu et al. | Invented the 4-bar parallel spring knee joint (PSKJ) based on theoretical analysis, modeling, and experimental testing. | The PKJ shows enhanced stability and accurately reproduces normal gait during walking in transfemoral amputees, with high reliability and user-friendly operation. |
| [57] | MyKnee: Mechatronic Design of a Novel Powered Variable Stiffness Prosthetic Knee | 2024 | Gregorio Tagliabue et al. | Design and implementation of VSA-powered prosthetic knee joint based on a compact VSA: finite element analysis and experiment validation. | The powered knee joint presented is capable of effectively addressing humans up to the weight range under consideration (100 kg) for ADLs. |
| [58] | A Novel Design of Smart Knee Joint Prosthesis for Above-Knee Amputees | 2023 | Shaimaa H. Kamel et al. | Designed a microcontroller knee joint prosthesis for above-knee amputees, which included sensors, actuators, and control electronics to mimic natural | The new knee mimics normal knee biomechanics, allowing for improved walking. It reduces metabolic cost and increases comfort, stability, and mobility, |

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| | | | | knee biomechanics. | making it an efficient and cost-effective solution. |
| [59] | Optimization and Testing of a New Prototype Hybrid MR Brake with Arc Form Surface as a Prosthetic Knee | 2018 | Seiyed Hamid Mousavi, and Hassan Sayyaadi et al | Designed a hybrid MR brake with a T-shaped drum for prosthetic knee application, which focuses on increasing braking torque through slab technique modeling. The developed design was manufactured, tested experimentally, and FEM-simulated. | The new MR brake offers excellent controllability and economy. It guarantees consistent gait performance. The prototype closely mimics natural knee kinematics, providing a lightweight, efficient, and reliable alternative to a prosthetic knee. |

These studies demonstrate a broad range of techniques and principles in knee prosthetic design and analysis. Each approach targets a distinct biomechanical challenge—ranging from augmenting gait naturalness and optimizing energy efficiency to facilitating intelligent user adaptation. Together, they provide a solid foundation for the future advancement of intelligent, modular, and user-intent-driven prosthetic devices.

### 2.3. Prosthetic knee joint analysis:

At the broadest level, the joint use of computational methods (analysis) and experimentation is commonly utilised to investigate stress distribution in prosthetic knee joints and their biomechanical response properties.

Finite element analysis (FEA) is an essential tool for studies of knee joint mechanics. Stress distribution analysis has been carried out across a range of sagittal planes, radii, flexion angles, and external loadings. [60] The purpose of the FEA method in such cases is to turn a complex mechanical problem into a system of algebraic equations and to evaluate the integrity of the LLP structure. A prosthetic part is broken down into small elemental forms of simple shape for computing deformations, stresses, or potential failure. The technical features of every single item should be identified. If all the parts are in equilibrium with respect to forces and couples, it is possible to anticipate the mechanical response of a whole system subjected to external influences. Theoretical Finite Element Analysis (FEA) allows you to test a component or assembly under load. Recent developments in computing power have increased the precision and efficiency of Finite Element Analysis (FEA), which is now readily available as part of several commercial simulation software packages. [14]

Degradation behaviours are determined by the nature of the material itself, as well as the conditions of loading.

Prediction of stress distribution using simulation models is possible with an error of approximately 20%. [61] The diversity of knee joint designs has implications for knee FES [and] some, however, pneumatically powered devices seem to provide better load transfer. [9]. The trends reported here further demonstrate the necessity of investigating dynamic and kinetic links in the design of artificial knees that move more like native knees, thereby approaching normal motion and loading.

The compromise between cost and performance in the choice of material. The plastic part is stronger than those made of HDPE, PA6, and PA66, whereas the HDPE part is lighter but also has acceptable strength. [62]

Design changes can result in considerable differences in cost-effectiveness. Good value for what you get, using high-quality aluminum that is both light and strong. 7075-T6 alloy, enhancing access to prostheses in populations with low purchasing power. [63]. These results suggest that a detailed examination of material properties, loading conditions, and design variables is needed to study prosthetic knee joints. Such validation is computationally and experimentally necessary to move towards safe, functional, cost-effective alternatives for amputees.

## 3. RESULTS AND DISCUSSION

The literature shows that studies on mechanical passive prostheses are abundant. KAFOs have been tested with single-axis, four-bar, and hydraulic knees. These were found to have varying degrees of stability: the hydraulic knee provided the best response, stabilising the impact load during walking and absorbing shock over rough ground.
The investigators also aim to design a microprocessor-controlled, low-mass knee prosthesis. Some of those studies demonstrated that, by using high-technology devices and materials, individuals become less unstable during ADLs and ambulation. Moreover, FEA is shown to assist in design without sacrificing the new product's strength and quality. The cornerstone of 40 years of success has been modular and adjustable knee joints, which have significantly contributed to end users' aspirations and independence.
The question of cost-effectiveness in making knee prostheses affordable was discussed. However, due to cost constraints, MP-based (microprocessor-based) and powered knee joints are still not prevalent in developing countries. Growing innovation in the design of simpler, affordable knee prostheses for all.

### 3.1. Challenges and Deficiencies:

The literature review has identified several substantial issues and research gaps, including the complexity of prosthetic knee joint design. With the incorporation of high-tech materials and advanced technologies, prosthetic knee performance has improved, but at the expense of simpler design and fabrication. However, such a complex structure can increase maintenance requirements and make repairs expensive for users.
Among the important problems is the cost of sophisticated prosthetic knees, including microprocessor-controlled, powered models. This makes them too expensive for most amputees, especially in low-income countries where they are not widely available. To do this, low-cost options need to be developed.
Each prosthetic knee has advantages and disadvantages that depend on the patient's needs, capabilities, and functional level. Some prosthetic knee challenged to move fluidly from one terrain to another. While other, better-suited hydraulic and polycentric designs perform well on uneven terrain, the performance of simpler (single-axis) joints remains insufficient, particularly on difficult terrain. This is a place where more work needs to be done in terms of adaptability and flexibility
The interaction between the prosthesis knee and the residual limb remains important for comfort and use. Improvements in user feedback devices (e.g., sensors) to modulate knee behaviour during movement and in the environment are also required to enhance natural gait and the user experience.

### 3.2. Essential Characteristics of the Proposed Solution and Its Viability:

Emphasize cost-effectiveness to make it broadly accessible even in low-resource countries by deploying lightweight, efficient materials and well-suited designs that reduce production and maintenance costs.
Reduction to a simpler design can be achieved by emphasizing mechanical elements (such as single-axis or polycentric designs), with no need for complex control systems. To be cost-effective, reliable, and easier to service
The artificial knee must be sufficiently versatile to accommodate various situations, including uneven surfaces, stairs, and ramps. Furthermore, microprocessor-controlled systems, such as feedback (sensor-aided) systems, could enable the prosthesis to adjust to different walking conditions.
The latter capability is increasingly achievable through microprocessor-controlled prostheses and advanced fluid-based damping devices (e.g., hydraulic and pneumatic knee systems).
The prosthetic knee is also required to have a long service life, such that it can be used for extended periods without substantial loss of performance. It also needs to be durable, resisting wear and stress for long-term reliability under varying levels of physical demand.
Use of FEA in the design process highlights potential failure areas, material selection, and design modifications.

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## 4. CONCLUSION

The major challenges highlighted were the cost of modern knee systems (microprocessor-controlled and powered-controlled prostheses), which preclude many amputees in low-income or developing countries. The complexity of prosthetic knees and the requirement that they be maintained and repaired by trained specialists are also barriers to greater use.
Reduce the cost and complexity of traditional high-end knee joints while preserving or enhancing their performance.
Recent advances in 3D printing, modular design, and low-cost materials offer promise for developing lower-limb prosthetic knees that are more affordable and durable. In addition, FEA and state-of-the-art manufacturing technologies will enable the optimization of prosthesis design by enhancing strength and reliability. While the

emphasis of our solution is on customization and user feedback, this would lead to a better fit, greater comfort, and ultimately improved performance for a broader segment of amputees.

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