STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 1, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Review JoPC

Polymer Chemistry in Shoulder Orthotics

Kashinath D. Sahoo[1,*], Devyani Mukund Moghe[2]

Abstract

The design of effective shoulder orthotic devices has increasingly made use of polymeric materials because of their versatility, durability, and biocompatibility. This review illustrates polymer chemistry role in constructing an orthotic device for shoulder subluxation, which is a commonly occurring post stroke or injury condition. Proprietary design elements such as polypropylene are rigid yet moldable which help in anatomical formulating for joint stabilization. On the other hand, rubber elastomers, medicinal rubber and ethaflex help improve comfort provided to the patient with regard to pressure and shock absorption around the shoulder and upper arm. These viscoelastic materials also reduce friction between skin surfaces which improves adherence to the device. Modern designs of orthoses include the new feature of electrodes being embedded within the cushioning layer made of polymers. These parts assist in pain alleviation by means of Transcutaneous Electrical Nerve Stimulation (TENS), which is a type of non-invasive electrotherapy. Functional polymers are used to coat the electrodes so that they will have insulation, protection, and flexibility. The combination of rigid and soft polymers facilitates transfer of forces by a three-point pressure system of dominant forces to the frame, resulting in reduction of discomfort when moving the arms during subluxation treatment. Sutureless self-tightening devices that are flexible achieve better movement adaptability compared to conventional orthoses. Anticipation of smart polymers, biodegradable matrices, and antimicrobial surfaces will result in orthoses that have responsive, eco-friendly, and therapeutically useful properties. Polymer chemistry aids in the progression of orthotic, or prosthetic, devices because it simplifies the industrial fabrication of shoulder orthoses through the integration of design, function, structure, and patient.

Keywords: Biomechanics, medicinal rubber, orthotic devices, polymer chemistry, polymeric materials, polypropylene, shoulder subluxation, TENS therapy

INTRODUCTION

In rehabilitative medicine, orthotic devices are critically important for patients suffering from musculoskeletal conditions, like shoulder subluxation that occurs due to a stroke or a traumatic injury. Orthotics aid in providing structural scaffolding and realignment that helps rest the body part and reduce discomfort. Historically, orthotic devices have been made from metal bones and simple cloth, which sufficiently limited basic movement but were too heavy and uncomfortable for long-term wear[1]. In addition, most patients would stand to benefit from these devices, but their design made them unreasonably expensive for patients with limited means.

The development of sophisticated polymeric materials has dramatically changed orthotic technology. Sophisticated modern orthotics uses polymers like polypropylene, ethaflex, and medicinal rubber, which are easily manipulable as their chemical and physical properties can be finely adjusted. These materials are biocompatible and allow the construction of devices that are light in

***Author for Correspondence**
Kashinath D. Sahoo

[1]Associate Professor and Head, Department of Prosthetics and Orthotics, Krishna College of Physiotherapy, Krishna Vishwa Vidyapeeth (Deemed to be University), Karad, Maharashtra, India
[2]Researcher and student, Department of Prosthetics and Orthotics, Krishna College of Physiotherapy, Krishna Vishwa Vidyapeeth (Deemed to be University), Karad, Maharashtra, India.

Received Date: May 03, 2025
Accepted Date: May 16, 2025
Published Date: November 11, 2025

Citation: Kashinath D. Sahoo, Devyani Mukund Moghe. Polymer Chemistry in Shoulder Orthotics. Journal of Polymer & Composites. 2026; 14(Special Issue 1): S21–S28p.

weight, strong, and easily modified to suit the patient's anatomy. Biocompatible polypropylene provides the structural rigidity and moldability essential for forming stable, crush-formed shoulder supports. On the other hand, ethaflex elastomers and medicinal rubbers add critical function by increasing comfort because of their viscoelastic behavior which allows them to absorb shocks and distribute mechanical stress uniformly[2].

Newer orthotic devices are integrated with supportive mechanisms using more complex techniques like Transcutaneous Electrical Nerve Stimulation (TENS). This is done by placing electrodes into the cushioning layers of the polymer and using conductive polymers capable of applying a medically useful voltage to the electrodes[3]. Such multifunctional devices are not only capable of supporting and stabilizing the joint but also helps in providing pain relief, improving overall treatment outcome.

Bridging polymer chemistry and innovation in orthotic devices with respect to materials and design that facilitate effective shoulder immobilization will be the focus of this review. Marking the advancement of technology in orthopedics, this study analyzes the integral and structural aspects of the device. It demonstrates the extent to which polymer science advances orthotic devices, moving beyond mere clinical efficacy to economic efficiency and ergonomic design for broader application.

While previous studies have focused on individual materials or clinical applications, this review uniquely synthesizes recent material innovations – including smart polymers and bio-integrated electronics – within the context of next-generation shoulder orthoses. It aims to guide future orthotic design by highlighting emerging material trends and unresolved challenges.

ROLE OF POLYMERS IN ORTHOTIC DEVICES

Polymeric materials are crucial in the modification and manufacture of modern orthopedic devices, especially shoulder supports. Their application is so broad because their physical and chemical properties can be customized to fit mechanical and patient specific requirements. Such materials allow the design of orthotic devices that not only meet the structural requirements, but also patient comfort, durability, and low cost[4].

Some requirements of the materials used in making orthoses for shoulders are quite complex. First, bearing the high dynamic loads created by arm movement, particularly during abduction and flexion, demand impact and tensile strength. These materials must endure these loads repeatedly throughout motion cycles, without relaxing or experiencing failure. For this reason, polymeric composites and reinforced thermoplastics are often chosen[5].

Second, construction weight affects wearability. This is especially true in post-stroke patients who may be suffering from some degree of muscular weakness. Orthoses made from polymers with a favorable strength-to-weight ratio tend to be less bulky and, more importantly, lessen the fatigue associated with the prolonged use of the device. This makes the device more useful and encourages better patient compliance[6].

Third, compatibility with skin is an unyielding necessity. The associated polymers have to be hypoallergenic, non-toxic, and mechanically robust enough to retain interface stability with human skin during perspiration, heat, and extended wear time[7].

Additionally, polymers provide a tunable elastic modulus, assisting in the distribution and modulation of forces across the orthotic structure. This is vital for designs that use biomechanical concepts such as the three-point pressure system. The capacity to design particular areas of stiffness and flexion with polymer blends or multilayer composites particularly increases the comfort of the device[8].

Polypropylene in Orthotic Applications

The use of polypropylene (PP) in orthotic applications has become widespread due to its distinctive mechanical and chemical properties. PP has a tensile strength of approximately 30–40 MPa and a

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

flexural modulus ranging from 1000 to 1500 MPa, which provides the structural rigidity needed for shoulder orthoses. Its low density (~0.90 g/cm³) further enhances patient comfort during prolonged wear. It is a semi-crystalline polyolefin thermoplastic polymer widely used in healthcare. Its use is even more diverse in structural application. In the area of orthotics, PP is favored because it is rigid and extremely durable, with a tensile strength ranging from 30 to 40 MPa and a flexural modulus of approximately 1000 to 1500 MPa, making it suitable for resisting deformation under the repetitive loading conditions encountered in shoulder orthoses [5]. Despite its strength, PP remains lightweight (density ~0.90 g/cm³), helping to avoid anatomical distortion over time or under stress[9].

PP Possesses the Following Characteristics That Make It Ideal for Orthoses:
- High stiffness and zero/marginal loss of shape over time
- Resistance to chemicals and bodily fluid
- Moldable to anatomical contour
- Cos
- Low density aiding in fatigue resistant material
- Thermoformable and recyclabl

The shoulder is one of the highly mobile and mechanically complicated joints. Therefore, any support circumferentially has to orthoses have high stiffness. Construction of the shoulder orthoses must allow free movement of the shoulder; hence the device must not deform. Prolonged immobility attributed to post stroke makes rehabilitation difficult. PP considers resistance to fatigue a prerequisite. Thus, the functional properties remain stable even during prolonged use[10].

PP's chemical inertness further ensures that its mechanical properties do not undergo any degradation due to sweat, skin oils or cleansing agents which could affect hygiene and device lifespan. Its low density also adds to patient comfort and enables use in wearable devices that need to be worn for several hours each day.

More importantly, Polypropylene can be thermoformed into custom anatomical shapes. Using heat and pressure, orthotists are able to apply sculpting techniques to PP sheets to accurately match the contours of the patient's shoulder and enhance therapeutic efficacy. The entire process is not only streamlined but also reproducible, making it simpler to achieve the desired outcomes in rehabilitation.

In the examined orthopedic device, the orthotic support is made of rigid polypropylene. Its selection offers strong mechanical support, but also allows for customization at the case-by-case level. Custom polypropylene structures are constructed to suit individual patients by transferring loads and posture while integrating into an entire device elastic straps and electrode systems[11].

Medicinal Rubber and Ethaflex

The inner cushioning layer of the orthotic device is made of elastomeric materials like medicinal rubber and ethaflex due to their high biocompatibility and viscoelastic attributes. These materials aid in comfort, but most importantly, enhance the functional performance of the orthotic device by moderating managing pressure, lowering localized stress, and accommodating minor movements without allowing the system to become unstable.

- *Medicinal rubber:* This skin-safe and hypoallergenic rubber features great elasticity which allows it to closely conform to the skin. It also provides the interface between the orthosis and the user's body, helping absorb shocks, and consolidating pressures during shoulder and arm movements. This material is particularly useful in minimizing soft tissue damage due to the reduction of blood flow through the skin, avoiding skin irritation, and reduced pressure sore, especially when used for extended periods of time[12]. Its resilience ensures that the cushioning effect is maintained over time, making it suitable for long term therapeutic use

- *Ethaflex*: Ethaflex falls under a particular group of foams referred to as polyethylene-based closed-cell foams. These types of materials have a unique balance of softness, lightness, and supportive structure. Because of its closed cell structure, Ethaflex does not absorb moisture, which improves hygiene and prevents the growth of germs. It is highly formable and can be thermo-molded to contour to patient specific anatomies. Ethaflex exhibits a Shore A hardness of around 20–30 and compressive stress values typically below 0.3 MPa at 25% compression, making it suitable for reducing localized skin pressure. It also has a thermal conductivity of approximately 0.04 W/m·K, enhancing its insulation capability. Additionally, Ethaflex offers improved comfort and therapeutic value through thermal insulation and damping properties[13]

These materials facilitate both enhanced biomechanics and patient adherence. In shoulder orthotic devices, this system is important in aligning the joint as well as providing stabilization while still permitting partial movement. For patients suffering from flaccid muscle tone in neurological conditions post-stroke, this method is vital to lessen the mechanical load on the affected joint[14]. These materials assist in reducing the subluxation condition by minimizing the exacerbation of the shoulder and upper arm's rotational forces.

In addition, the combination of elastomeric materials enables the incorporation of other specialized features like embedded electrodes for TENS therapy. Its flexibility and toughness guarantee that the electrodes remain in place while actually touching the skin. This type of interaction between structural and functional features reveals the ways materials can be chosen to optimize treatment results. In this case, the chosen materials of medicinal rubber and ethaflex show tradeoffs of mechanical strength, comfort to the patient, and effectiveness clinically.

In summary, medicinal rubber and ethaflex demonstrate how advanced engineering with orthoses and polymers relies on the design of the device to provide skeleton-like support while meeting the needs of patients for easy use and satisfaction with the treatment.

Integration of Functional Polymers in Pain Management

The application of electrotherapeutic modalities for the pain management, rehabilitation, and even comfort of users is modernizing orthotic designs. One of the most promising modifications is integrating TENS therapy directly into electric orthotic devices. This method utilizes the help of electrical impulses to ease pain from nerve endings, be it chronic pain or acute pain. The orthotic device under review is an example of this integration where pairs of electrodes are positioned in the cushioning part of the device which enables the transmission of required therapeutic signals precisely and adequately[15].

The functionality and effectiveness of such device systems is primarily determined by the construction materials which are chosen for the covering electrodes and the devices themselves. In most cases, the electrodes are encapsulated in conductive polymers with some degree of flexibility or are encapsulated in a polymeric like matrix. These materials are designed not only for proper conduction but also for a set of mechanical, biological, and even electroductive criteria which entail patient safety and comfort during use.

To begin with, biocompatibility represents an essential factor. In order to fulfill safety requirements regarding contact with skin, the polymer systems utilized must be biocompatible and non-toxic, non-sensitizing, and hypoallergenic. Silicones, hydrogels, and elastomers based on polyurethanes are frequently used because of their medical-grade quality and proven history of use in biomedical applications[16]. These polymers form an interface with the electronics that is sufficiently inert and stable to poise little danger to human skin or tissues.

For the second point, maintaining adhesion of the electrodes to the inner surfaces of the orthotic device is fundamental to avoiding movement of the electrodes relative to the structure and therefore, achieving continuous therapeutic action. For this bound and interracially bonded functional electronic component, polymers with specific surfaces and functional groups are designed. During dynamic motion with bending and compressing, interfacial adhesion of the components to the substrate along with the integrated parts maintains the position of the electrodes with respect to the orthotic structure[17].

At the same time, there is a critical need for mechanical protection of the electrodes. The polymers of the device must protect sensitive electronic elements from distortion, shear, and impacts while maintaining the overall device flexibility. Ordinary orthoses are particularly susceptible to daily physiological stresses. In the case of soft but rigid polymer matrices, they capture and distribute mechanical stress, thereby prolonging the operational durability of the embedded electronics.

The primary integration of TENS therapy powered via incorporated electrodes demonstrates the multifunctional capacity of polymer materials in orthotic device design. Designers have to achieve an equilibrium between insulation, conductivity, and mechanical flexibility. Conductive polymers have to transmit electrical signals without risk of short-circuiting or stifled signal flow, and maintain the degree of formability needed for patient movement. Thermoplastic elastomers or crosslinked silicone rubbers serve as the insulator's active shunt, which caps and prevents excessive current flow, protecting the signal from being corrupted. Having explored the commonly employed materials in orthotic construction, the subsequent section delves into how these materials are practically implemented in design frameworks and commercial products.

BIOMECHANICAL PERFORMANCE AND FORCE DISTRIBUTION

Managing the biomechanical forces during arm movement is one of the most difficult issues in the design and use of shoulder orthoses. Ineffective distribution of force can result in discomfort, limited recovery function, or worse, further aggravate the pre-existing injury. This particular orthotic device mitigates this problem by adding a secondary strap made from advanced flexible polymers, known as the secondary polymeric strap, which improves force control. The strap functions in a three-point pressure system, which is generally known as Jordan's principle' and is frequently applied in orthopedic bracing to achieve stabilization without complete movement restriction. Using this principle, the device transfers the mechanical loads at critical anatomical landmarks[18]. Thus, the device inhibits high pressure and stresses at particular regions, enhancing optimal comfort for the user.

Additionally, the polymer strap has adjustable elasticity which allows it to flexibly accommodate different ranges of patient movement and muscle activity. This adaptability aids in maintaining proper positioning of the shoulder joint during various aspects of arm repositioning. The strap acts in real time as the patient performs movements, countering the changes in force vectors while providing continuous support to the joint. This enables supported movement of the joint, which helps in recovery by lessening forces inflicted on sensitive structures. Using flexible polymers in this case provides mechanical strength together with biomechanical softness which helps the material protect and move with the body[19].

FUTURE DIRECTIONS IN POLYMERIC ORTHOTIC DESIGN

Innovations in smart polymers, self-repair materials, and stimuli-responsive elastomers are expected to redefine the design and functionality of modern orthotic devices. These novel materials can provide dynamic reactions to alterations in temperature, pH, stress, or electrical fields and enable orthoses capable of real-time adaptation to the user's physiological and biomechanical requirements[20]. As polymer science advances, a combination of functionality, biocompatibility, and responsivity is facilitating new horizons in custom orthotic care.

Important expected developments in this area are the adding of piezoelectric polymers able to transform mechanical stress into electricity, providing constant monitoring of motion, pressure distribution, and device activities. This feature could improve rehabilitation responses and help customize orthotic treatments with greater precision.

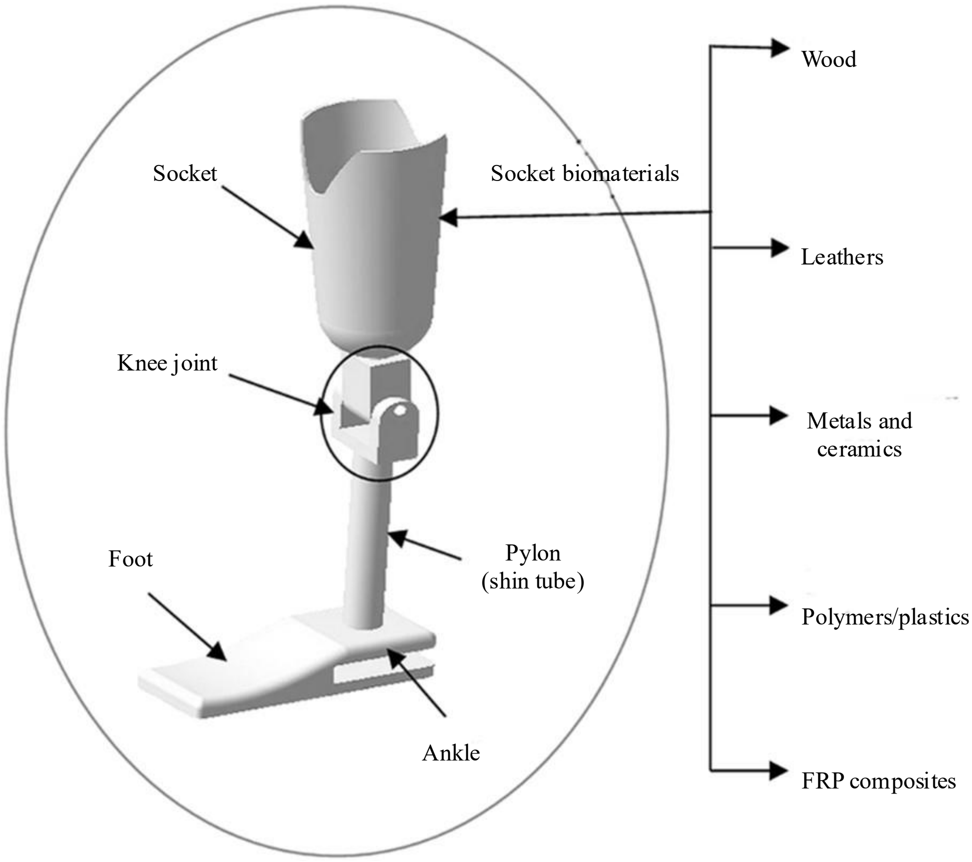

Figure 1. Potential uses of natural fiber-reinforced polymer bio composites in knee prostheses

Biodegradable polymers for temporary orthotic support, especially following surgery, represents another promising direction. These materials offer support during healing and decomposition without harming the body, environment, or the need for removal. Figure 1 shows the Potential use of natural fiber-reinforced polymer bio composites in knee prostheses[21].

Also, the development of antimicrobial polymeric coatings provides a solution to a specific problem associated with the prolonged use of orthotics: the danger of infections and microbial growth. Such coatings have the ability to eliminate biofilms and enhance cleanliness, thus fortifying the safety and durability of orthotic devices[22].

While embedded electrodes and TENS therapy offer functional restoration, issues like optimal electrode placement, signal interference due to sweat or movement, and risks of skin irritation must be addressed. Furthermore, signal fidelity is affected by motion artifacts, requiring robust filtering and placement strategies.

CONCLUSION

The integration of polymer chemistry into the design and construction of orthotic devices has made them stronger, more comfortable, and much more functional. Different engineers and healthcare professionals are able to create orthoses at different levels of performance by considering the individual needs of each patient using different polymers. The orthotic device discussed in this document demonstrates the complex yet synergistic use of polymeric materials by employing polypropylene to provide structural support silicone elastomers for patient comfort. Polypropylene is well-suited for use in load bearing components due to its lightweight, fatigue resistant, and durable qualities. On the other hand, elastomers used in polymers impart greater flexibility and cushioning thus lowering pressure contact points therefore increasing comfort for the user with prolonged use of the orthotic device. All these factors emphasize the meticulous approach taken towards material selection and certainly expand the boundaries of device functions. The advancements in polymers that are expected to come are functional and smart polymers such as shape memory polymers, self-healing materials, and stimuli-responsive systems, which is likely to alter the domain of orthopedic aids forever. The potential of these next generation materials includes the ability to enable dynamic adaptability to monitor biomechanical performance and even respond to environmental changes or movement of the body in real time. With the ongoing advancements in polymer science, incorporating highly tailored and sophisticated orthotic devices for patients will enhance patient satisfaction and outcomes, and improve their overall quality of life even further.

REFERENCES

1. Molla S, Abedin MM, Siddique IM. Exploring the versatility of medical textiles: applications in implantable and non-implantable medical textiles. World J Adv Res Rev. 2024;21(1):603–15.
2. Alarifi IM. A comprehensive review on advancements of elastomers for engineering applications. Adv Ind Eng Polym Res. 2023;6(4):451–64.
3. Raj GK, Singh E, Hani U, Ramesh KV, Talath S, Garg A, et al. Conductive polymers and composites-based systems: an incipient stride in drug delivery and therapeutics realm. J Control Release. 2023;355:709–29.
4. Alemayehu DG, Zhang Z, Tahir E, Gateau D, Zhang DF, Ma X. Preoperative planning using 3D printing technology in orthopedic surgery. Biomed Res Int. 2021;2021:7940242.
5. Biron M. Thermoplastics and thermoplastic composites. Oxford: William Andrew; 2018.
6. Hoque ME, Shafoyat MU, Tabassun F. Polymers, their composites, blends, and nanocomposites for the fabrication of prosthetics. In: Applications of biopolymers in science, biotechnology, and engineering. 2024. p. 361–89.
7. Vhanbatte SB, Thakur B, Gotipamul RL. Review on breathable fabrics part I: fabric construction. J Text Assoc. 2022;83(2):82–7.
8. Fan Q, Duan H, Xing X. A review of composite materials for enhancing support, flexibility and strength in exercise. Alexandria Eng J. 2024;94:90–103.
9. Nouri A, Wang L, Li Y, Wen C. Materials and manufacturing for ankle–foot orthoses: a review. Adv Eng Mater. 2023;25(20):2300238.
10. Itoi E, Arce G, Bain GI, Diercks RL, Guttmann D, Imhoff AB, et al. Shoulder stiffness: current concepts and concerns. Arthroscopy. 2016;32(7):1402–14.
11. Gupta P, Toksha B, Patel B, Rushiya Y, Das P, Rahaman M. Recent developments and research avenues for polymers in electric vehicles. Chem Rec. 2022;22(11):e202200186.
12. Gefen A, Alves P, Ciprandi G, Coyer F, Milne CT, Ousey K, et al. Device-related pressure ulcers: SECURE prevention. J Wound Care. 2022;31(Suppl 3a):S1–72.
13. Querol-Martínez E, Crespo-Martínez A, Gómez-Carrión Á, Morán-Cortés JF, Martínez-Nova A, Sánchez-Rodríguez R. Analyzing the thermal characteristics of three lining materials for plantar orthotics. Sensors (Basel). 2024;24(9):2928.
14. Suputtitada A, Chatromyen S, Chen CP, Simpson DM. Best practice guidelines for the management of patients with post-stroke spasticity: a modified scoping review. Toxins (Basel). 2024;16(2):98.
15. Huang Y, Yao K, Zhang Q, Huang X, Chen Z, Zhou Y, et al. Bioelectronics for electrical stimulation: materials, devices and biomedical applications. Chem Soc Rev. 2024.
16. Ghosh A, Orasugh JT, Ray SS, Chattopadhayay D. Recent development in polyurethanes for biomedical applications. In: Polyurethanes: preparation, properties, and applications. Vol 3. Washington (DC): American Chemical Society; 2023. p. 163–89.
17. Xiao Y, Wang M, Li Y, Sun Z, Liu Z, He L, et al. High-adhesive flexible electrodes and their manufacture: a review. Micromachines (Basel). 2021;12(12):1505.
18. Dvorznak M, Fitzpatrick K, Karmarkar A, Kelleher A, McCann T. Orthotic devices. In: An introduction to rehabilitation engineering. Boca Raton: CRC Press; 2006. p. 287–312.
19. Bonardd S, Nandi M, Hernandez Garcia JI, Maiti B, Abramov A, Diaz Diaz D. Self-healing polymeric soft actuators. Chem Rev. 2023;123(2):736–810.

20. Karim MR, Siddiqui MI, Assaifan AK, Aijaz MO, Alnaser IA. Nanotechnology and prosthetic devices: integrating biomedicine and materials science for enhanced performance and adaptability. J Disabil Res. 2024;3(3):20240019.
21. Kumar S, Bhowmik S. Potential use of natural fiber-reinforced polymer biocomposites in knee prostheses: a review on fair inclusion in amputees. Iran Polym J. 2022;31(10):1297–319.
22. Tran PL, Hamood AN, Reid TW. Antimicrobial coatings to prevent biofilm formation on medical devices. In: Antibiofilm agents: from diagnosis to treatment and prevention. Berlin: Springer; 2014. p. 175–204.

