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Bamboo Medical Application: A State-of-the-Art Review

Haymanot Beza Lamesgin[1] | Koosje van der Stoel[1] | Vera Popovich[2] | Paul Breedveld[1]

[1]Department of Biomechanical Engineering, Faculty of Mechanical Engineering, Delft University of Technology, Delft, The Netherlands | [2]Department of Materials Science & Engineering, Faculty of Mechanical Engineering, Delft University of Technology, Delft, The Netherlands

Correspondence: Haymanot Beza Lamesgin (h.b.lamesgin@tudelft.nl)

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ABSTRACT

Bamboo, known for its unique mechanical and antibacterial properties, has attracted growing interest as a sustainable material for medical applications. Despite its potential, its adoption in modern clinical settings remains limited. This review aims to provide a comprehensive overview of current medical uses of bamboo-based materials, focusing on application areas and material composition. A systematic literature search across the PubMed and Scopus databases yielded 45 relevant articles. These were categorized according to medical application and material utilization. Bamboo medical devices exhibited greater variability; those used inside the body often incorporated bamboo as a significant structural element, whereas external devices typically used bamboo as reinforcement. Textiles for treatment primarily used bamboo as a minor component, often combined with antimicrobial or mechanical strengthening agents. In contrast, protective textiles used bamboo primarily as a significant component, leveraging its inherent comfort and breathability. Across all applications, bamboo was selected for its mechanical, antimicrobial, and breathable characteristics. The integration of bamboo in medical technologies is growing, driven by its sustainability and functional performance. However, challenges remain in processing complexity and in demonstrating clear advantages over conventional materials.

1 | Introduction

1.1 | Background

Bamboo, a fast-growing and renewable resource with unique mechanical properties, has gained increasing interest for its potential use in sustainable structural and engineering applications [1–3]. Known for its high specific tensile strength, light weight, and hardness, bamboo is considered a functionally graded material, with properties that vary throughout its structure. Species, chemical composition, age, and location within the culm influence these properties. The internal structure of bamboo plays a key role in its mechanical performance. The culm, or stem, is typically hollow and segmented into nodes and internodes (Figure 1). The concentration of vascular bundles, which are part of the plant's transport system, increases from the interior to the exterior of the culm wall, creating a gradient of stiffness and strength that enhances bamboo's ability to resist bending and axial loads. Additionally, bamboo fiber (BF) has numerous pores, contributing to its lightweight, breathable nature [1, 2, 4, 5].

Due to these properties, bamboo has historically been used in regions of Africa and Asia for orthopedic devices such as splints [6]. With basic techniques such as heating and bending, bamboo can be shaped into various medical devices, including crutches, canes, and prosthetics [7, 8]. In addition, BFs have been used in textiles that offer antibacterial and breathable properties [2, 4, 9]. These characteristics have recently attracted interest in

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Haymanot Beza Lamesgin and Koosje van der Stoel contributed equally to this work and share first authorship.

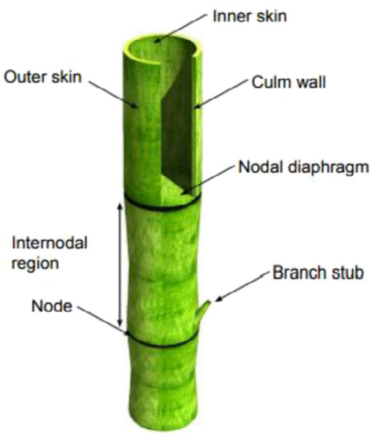

FIGURE 1 | Structure of a bamboo culm segment [5].

the biomedical field, particularly in applications that leverage bamboo's biodegradability and antibacterial properties [2, 4]. A significant characteristic supporting bamboo's potential is its similarity to bone, making it suitable for implantable bone devices. Bamboo's hierarchical porous structure, which contributes to its mechanical strength, shows a structural similarity to human bone, with an elastic modulus very close to bone, especially compared to other biomaterials such as calcium phosphate or titanium [10].

Interest in bamboo for healthcare is partly driven by the environmental burden of conventional medical materials. Healthcare delivery relies heavily on single-use plastics and polymer-intensive consumables, particularly in operating rooms, for example major orthopaedic procedures can generate substantial plastic waste of 7.3 kg per case [11]. In parallel, medical nonwovens used in surgical gowns, masks, and packaging represent a growing demand segment for disposable healthcare products [12]. These challenges have intensified interest in renewable and potentially biodegradable materials that reduce reliance on fossil-derived plastics while maintaining performance [13]. Bamboo is a promising candidate due to its renewability and favorable mechanical properties arising from its hierarchical, functionally graded structure [1, 3, 7]. However, sustainability benefits remain strongly dependent on processing methods and end-of-life considerations [8, 13].

Despite this potential, the literature on bamboo in healthcare remains fragmented. Material properties vary significantly with species, age, moisture content, and culm position [1, 3, 7], while different processing approaches, ranging from chemical modification to textile fabrication and fiber blending, limit cross-study comparison [9, 10, 12]. Moreover, lack of standardization, particularly in orthopedic applications, continues to hinder broader adoption and highlights the need for regulatory frameworks and consistent testing protocols [7]. Some studies report biocompatibility and cytotoxicity assessments, but the evidence base remains largely preclinical, making clinical translation and relevance difficult to evaluate without further validation [7, 8, 10, 12]. Although bamboo has long been used in traditional and non-medical contexts, its role in modern healthcare has not yet been systematically synthesized. This review aims to provide a comprehensive overview of current medical applications of bamboo-based materials, with a focus on their material composition. It examines bamboo's potential in healthcare, identifies emerging trends, and outlines opportunities for future innovation and development.

2 | Method

2.1 | Literature Search

To obtain a comprehensive overview of current and potential applications of bamboo in the medical and biomedical fields, a systematic literature search was conducted. The databases PubMed and Scopus were accessed with the last update made on November 28, 2025. The search query was divided into two categories: 'Material' and 'Application Area'. Within each category, keywords were generated and combined using Boolean operators. A broad search strategy was intentionally adopted to minimize the risk of missing relevant publications. The search was limited to English-language publications. In Scopus, additional filters were applied to include only documents within the following subject areas: Medicine, Materials Science, Engineering, Health Professions, Multidisciplinary, Dentistry, and Neuroscience. This approach was used to exclude articles related to pharmaceuticals, therapeutics, or non-medical applications. The following search query was used for Scopus and adjusted accordingly for PubMed: TITLE-ABS-KEY (("bamboo" OR "bambusa") AND ("medical" OR "healthcare" OR "clinical" OR "biomedical" OR "biomechanical")) AND (LIMIT-TO (SUBJAREA, "MEDI") OR LIMIT-TO (SUBJAREA, "MATE") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUB-JAREA, "HEAL") OR LIMIT-TO (SUBJAREA, "MULT") OR LIMIT-TO (SUBJAREA, "DENT") OR LIMIT-TO (SUBJAREA, "NEUR")) AND (LIMIT-TO (LANGUAGE, "English")).

2.2 | Eligibility Criteria

The following criteria were used to determine the eligibility of articles for inclusion in this review. Articles were included if they described or evaluated devices, materials, or manufacturing methods based on bamboo or bamboo composites, with demonstrated or potential applications in medical, biomedical, or biomechanical contexts. Medical devices were defined following the definition of the Medical Device Regulations (MDR); in short, a medical device was any instrument, apparatus, appliance, software, implant, reagent, material, or other article, intended by the manufacturer for one or more specific medical purposes, such as diagnosing, preventing, monitoring, or treating, and whose principal intended action was not achieved via pharmacological, immunological, or metabolic means [14]. Articles were excluded if they referred to non-botanical definitions of bamboo, such as "bamboo spine" or bamboo-named animal species. Studies that only mentioned bamboo without specifying a relevant medical application, or studies focusing on general personal health products, such as sanitary napkins or diapers, were excluded. Additionally, articles discussing pharmaceuticals, drugs, or therapeutic agents were excluded from this review.

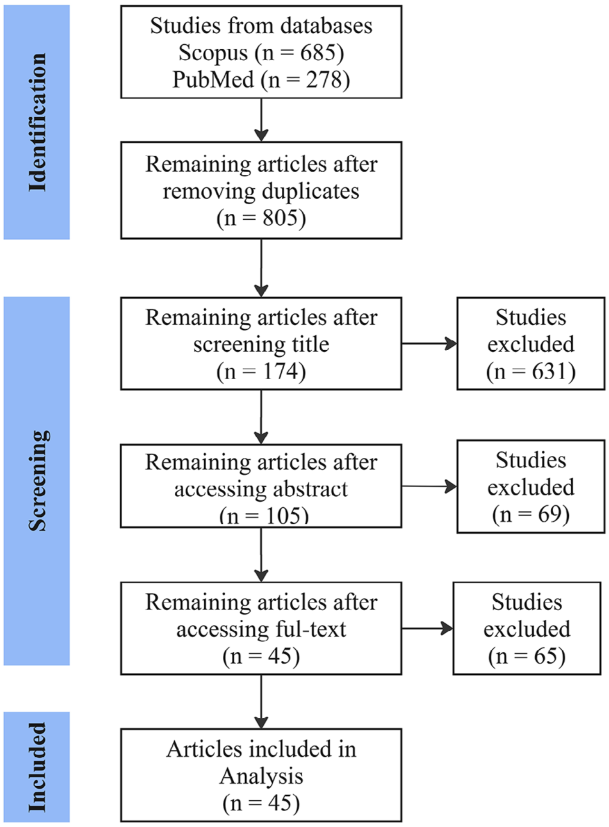

FIGURE 2 | PRISMA diagram of the used literature search and article selection method.

2.3 | Literature Search Results

The search yielded 685 papers from Scopus and 278 from PubMed. After removing duplicates, there were 805 unique records. Title screening based on the eligibility criteria resulted in 174 articles. After reviewing the abstracts and figures, 105 articles remained. After a full-text evaluation, 65 of these were excluded due to unclear or unspecified use of bamboo-based materials, lack of a defined medical application, or inaccessible full text, leaving 45 articles included. The figure below displays the PRISMA diagram of the selection process (Figure 2).

3 | Results

3.1 | Classification

All articles included in this review are discussed within two overarching classifications: ‘medical applications’ and ‘material utilization’ (Figure 3). These categories enable a systematic analysis of current healthcare applications of bamboo, focusing on its structural incorporation into medical materials. This approach aims to map both the functional and structural performance of bamboo and identify potential relationships between them. Medical applications refer to the various domains in which bamboo-based materials have been applied within the medical, biomedical, or biomechanical fields. The “medical applications” group was subdivided into two categories: ‘medical textiles’ and ‘medical devices’. Medical textiles include two subcategories: ‘textiles for protection’ and ‘textiles for treatment’. Medical devices include three subcategories based on the device’s invasiveness: ’devices outside the body’, ’devices on the body’, and ’devices inside the body’.

Material utilization focuses on the specific material compositions in which bamboo is employed in medical contexts. The “material utilization” group is further subdivided according to the structural role of bamboo into three categories: ’Bamboo as the only component’, ’Bamboo as a major component’, and ’Bamboo as a minor component’. The last two categories refer to bamboo-based composite materials. In the major component category, bamboo constitutes the majority of the material. In the minor component category, bamboo is present in a small proportion of the overall composition.

3.2 | Bamboo—Medical Applications

3.2.1 | Textiles

Out of the 20 articles identified in the medical textiles category, 12 address applications in textiles for protection [9, 12, 15–24] and the remaining 8 articles focused on textiles for treatment [25–32]. Here, bamboo-based fabrics are used for surgical wear, such as gowns and face masks, due to their antibacterial activity and fluid repellency [12, 16, 22]. For example, Gao et al. [12] developed a bamboo-based fabric tailored for medical use, incorporating bamboo cellulose fibres (BCFs) into a non-woven structure suitable for applications such as surgical gowns, face masks, and instrument packaging. BCFs served as the major structural component, while functional modification was achieved through the in situ growth of ZIF-67 and subsequent polydimethylsiloxane (PDMS) coating. The fabric showed high antibacterial properties with an antibacterial rate of >99% for a range of microbial pathogens. This rate refers to the extent to which the textile inhibits or kills bacterial growth. Additionally, it demonstrated excellent biocompatibility and breathability, with no irritation observed on rabbit skin. Unlike surgical wear, hospital garments are worn by healthcare personnel during daily activities.

Various studies highlight the antibacterial activity, breathability, moisture management, and comfort of bamboo-based fabrics, making them suitable for this type of garment [17–19, 21, 22, 24]. Bamboo fabrics are also used in medical lifestyle products, such as bedding and bed mats, where the focus is on integrating BF into products that are biocompatible, hygienic, and comfortable [9, 22]. For example, Kandhavadivu et al. [22] describe a multifunctional fabric made from charcoal and bamboo, suitable for bedding, hospital clothing, and surgical gowns. Fabrics were developed using polyester-based bamboo charcoal (PBBC) as a major component, with varying PBBC/lyocell compositions (100:0, 75:25, 50:50, and 25:75), enabling the correlation of material composition with specific healthcare applications. Bamboo charcoal (BC) is produced through high-temperature pyrolysis and can be included in various forms, such as powder, embedded within fibers, or as whole segments. The study emphasizes that the combination of BC’s antibacterial (bacterial reduction rate of up to 90%) and

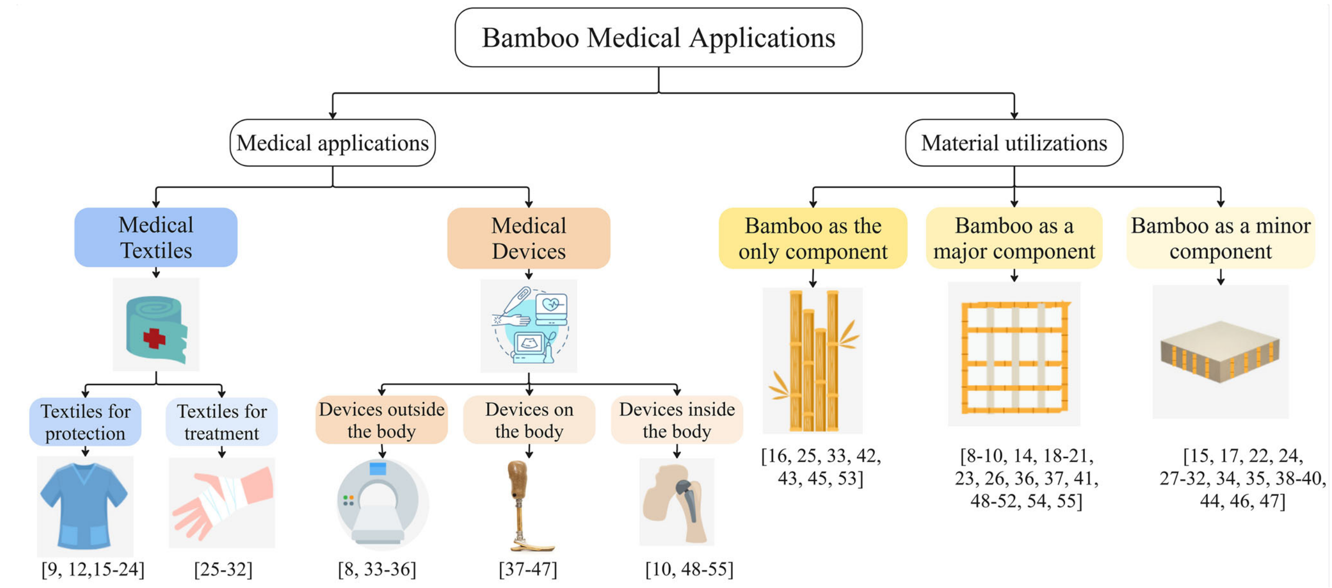

FIGURE 3 | A two-tier classification framework for bamboo-based medical applications identified from the reviewed literature. The left branch classifies studies by application type, distinguishing medical textiles and medical devices, with further subdivision into specific functional categories. The right branch classifies studies by material utilization, indicating whether bamboo is used as the only, major, or minor constituent of the final material. Numbers in brackets correspond to the references of the included articles.

antifungal properties results in a fabric that meets the functional requirements of hospital textiles.

In a more advanced application, Huang et al. [23] developed a bamboo-based elastic composite fabric with far-infrared (FIR) emissivity, contributed by BC fibers, and electromagnetic shielding effectiveness (EMSE), enabled by stainless steel fibers. The composite yarns were designed with BC-containing fibres as the main sheath material and SS fibres as the conductive core. FIR has been proven to promote blood circulation and enhance metabolic activity. Therefore, combining FIR and EMSE properties makes the fabric suitable for thermal healthcare garments, such as neck supports, knee pads, and abdominal wraps, as well as for protective clothing used in electromagnetically sensitive environments.

Textiles for treatment proposed different types of bamboo-based wound dressings, emphasizing their antimicrobial activity, absorbency, breathability, and moisture management [9, 27–29, 31, 32]. A recent study by Zeng et al. [32] introduces a novel cooling fabric designed for thermal and moisture regulation, providing a moist yet non-sticky microenvironment to support wound healing. Bamboo viscose fibres were incorporated as a minor hygroscopic component, whereas cool synthetic filaments such as polyethylene (PE), cool polyester (CPET), and cool polyamide (CPA) formed a major structural and cooling elements, thereby linking material composition to moisture management and thermal-regulation performance. In addition, Bamboo viscose fibers were regenerated from bamboo pulp using the viscose process, exhibiting inherent antimicrobial properties, which further contribute to improved wound care outcomes. Bamboo has also been investigated for use in bandage applications, primarily for its antimicrobial properties [25, 26, 30]. N Oğlakcioğlu et al. [30] evaluated bamboo-based compression bandages with a focus on pressure and comfort. Bamboo fibres were incorporated as a minor sheath component in elastane core-spun yarns, while elastane provided the main compressive function. Their findings suggest that these bandages can deliver adequate pressure for compression therapy and offer greater thermal resistance than conventional compression garments.

3.2.2 | Medical Devices

Among the 25 articles classified under medical devices, five addressed devices intended for outside the body [8, 33–36], eleven focused on devices designed for on-body applications [37–47], and nine investigated devices intended for inside the body use [10, 48–55]. Devices used on the body are defined as external-use devices, meaning they come into contact only with the skin. In the field of orthopedic devices, four papers present components of prostheses made from bamboo. These studies note that bamboo-based materials are well-suited for prosthetic applications due to their mechanical properties, including high strength, elasticity, low density, and environmental benefits such as recyclability and biodegradability [8, 41, 45–47]. For example, Sosiati et al. and Irawan et al. both explored bamboo composites as potential materials for prosthetic sockets, as illustrated in (Figure 4a) [41, 47]. Bamboo fibres or laminates served as the primary reinforcement phase, typically combined with polymeric matrices to provide the structural performance required for prosthetic use. Beyond socket applications, recent work by Minuto et al. [8] extended the use of bamboo laminates to load-bearing prosthetic feet, demonstrating mechanical performance comparable to that of commercial carbon-fiber feet while reducing weight, cost, and environmental impact. Other bamboo-based orthopedic devices focus on providing support or correction, typically in the form of orthotic devices [39, 40, 42].

(a) (b) (c)

FIGURE 4 | Examples of bamboo-based orthopedic applications: (a) prosthetic socket [41]; (b) ankle guard [42]; (c) orthosis for ankle fractures [40].

Lu et al. [42] describe a nano-BC powder-based ankle guard, designed to reduce pain, improve ankle joint balance, and enhance movement and range of motion in combination with rehabilitation therapy (Figure 4b). Similarly, Hou et al. [40] present a bamboo-composite material with potential orthopedic applications, particularly in orthoses for ankle fractures, due to its mechanical strength and lightweight properties (Figure 4c). In a more traditional context, two papers describe the use of bamboo in orthopedic applications. [43, 44]. For example, Meng et al. [43] describe a traditional bamboo splint used for Colles fractures and compared it with a redesigned version based on the same concept. Bamboo was the only structural material, providing rigid external support for fracture fixation. The bamboo curtain splint consists of four curtain splints, each fixed with cotton tape. Advantages of the bamboo splint include adjustability, good air permeability, and X-ray transparency, while its main disadvantage is its complexity of use.

Three papers present the use of bamboo in medical monitoring devices [36–38]. In the work of Zhu et al. [38], bamboo is processed into a carbonized bamboo aerogel (CBA), which serves as a conductive scaffold for strain sensing. This bamboo aerogel shows potential for monitoring human motion, such as breathing, airflow, or abdominal motion related to breathing. Eight articles discuss medical devices inside the body, all being orthopaedic applications. Bamboo is used for internal bone fixation devices, based on its mechanical similarity to bone [48, 56]. In this context, Liu et al. [56] describe a bamboo-based antibacterial hydrogel that can be used as a lightweight bone filling material to prevent infection at the implant site. In this material, bamboo charcoal acted as the main structural substrate, whereas antibacterial performance was achieved through the incorporation of silver nanoparticle (AgNP)-containing thermo-sensitive hydrogel. Bamboo-based materials are also used for dental restoration, bone scaffolds, or bone materials in tissue engineering, highlighting their favorable mechanical properties and hierarchical porous structure [49, 51–55].

Ma et al. [51] assess the feasibility of a bamboo-based bone material designed to replicate the structure and composition of natural bone, identifying its potential for bone regeneration. In this biomimetic system, bamboo fibre acted as the organic matrix, while nano-hydroxyapatite (n-HA) served as the inorganic bioactive phase. Expanding on this research, Jiang et al. (2022) [49] investigated BF composite membranes for guided bone tissue regeneration (GBR), highlighting their high strength, biodegradability, and low cost as key advantages for biomedical applications. Three articles describe bamboo-based applications used outside the body. Both articles focus on medical devices intended for diagnosis, treatment, monitoring, or support within healthcare settings [33–35]. For example, Gawande et al. [33] investigated bio-composite skew-laminated composite sandwich (SLCS) plates for use in biomedical imaging systems, specifically for MRI and CT scan beds or machines. Material properties, such as biodegradability, radiolucency, lightweight, high strength, and vibration resistance, are key considerations for the suitability of the SLCS plate for biomedical imaging machines.

While Section 3.2 described the medical applications in which bamboo has been explored, the next section shifts focus to the material strategies underlying those applications. Specifically, it examines the physical forms and structural roles of bamboo as the only component, and of composites (bamboo as a major or minor component) to achieve the functional properties required for the medical uses described above.

3.3 | Bamboo—Material Utilization

3.3.1 | Bamboo as the only Component

Bamboo can be used in various physical forms, including whole segments, fibres, and particles, as shown below (Figure 5), and the following sections will discuss the found articles on these material forms. Bamboo is used as the only component in seven papers, with five papers using whole bamboo and two using BF [24, 26, 34, 43, 44, 46]. Shashmin et al. [46] describe the flexural, compressive, and tensile properties of dried and reformed bamboo. Reformed bamboo is created from dried bamboo by cutting the raw culms to size, softening them through hot steam treatment, and carbonising the strips, allowing for reshaping. This process aims to address issues such as low modulus of elasticity and lower durability

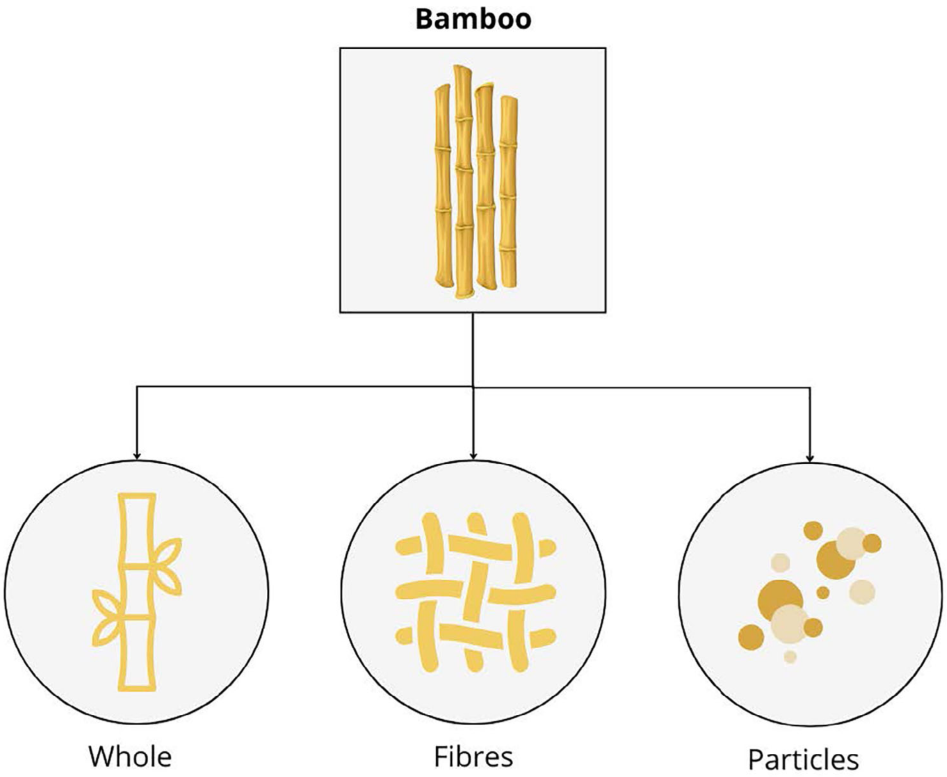

FIGURE 5 | Overview of material, physical forms of bamboo.

found in natural bamboo. The mechanical properties, including Tensile Yield (230.0 ± 6.2 MPa), Compression Yield (87.6 ± 4.3 MPa), and Flexural Yield (270.6 ± 3.5 MPa) of the reformed bamboo, were found to be 0.3%–4% improved as compared to the dried bamboo. The study also notes that bamboo is twice as strong as aluminum and three times stronger than fiber-reinforced plastic. Kalkanci et al. [24] investigated textiles made entirely from BF, comparing them with other materials in terms of filtration performance and antibacterial properties.

3.3.2 | Composites—Bamboo as a Major Component

Out of the 35 articles discussing bamboo as a composite material, 18 describe bamboo as a major component. Among these, 14 report bamboo in fibre form and three report the use of whole bamboo. Different BF composites were enhanced with synthetic or natural fibres [9, 16, 17]. Chonsakorn et al. [9] describe a non-woven fabric from BF derived from bamboo waste blended with polyester fibre. BFs were mainly added due to their antimicrobial properties. In contrast, polyester fibre was needed for the mechanical processing, such as carding or needle-punching, a nonwoven fabrication technique in which barbed needles mechanically entangle fibres to form a cohesive fabric with defined structure and sufficient mechanical strength for moulding. An optimal bamboo-to-polyester fibre ratio of 70:30 enabled stable processing into a needle-punched nonwoven fabric.

Manjula et al. [27] describe a bamboo non-woven fabric as a major structural component with relatively high strength. The bamboo fabric underwent oxygen plasma treatment to enhance its hydrophilic properties, which are favorable for wound dressings. Subsequently, solid silver nanoparticles were deposited as a surface coating onto the bamboo fabric. These silver nanoparticles exhibit strong antimicrobial activity, helping prevent microbial penetration. Six articles describe BFs enhanced with inorganic or mineral additives to enhance structural performance [12, 20, 42, 49, 51, 53]. The combination of nano-hydroxyapatite (n-HA) with BF (n-HA/BF) was explored to overcome the mechanical limitations of n-HA, such as brittleness and low wear resistance.

Ma et al. [51] focused on developing bulk composites, resulting in a solid composite sample, while Jiang et al. [49] focused on a thin composite membrane. Ma et al. [51] showed that incorporating BF into pure n-HA improved compressive strength, with the 30% BF composite exhibiting the highest compressive strength of 31.0 MPa. Jiang et al. [49] showed that increasing n-HA content initially enhanced the membrane's tensile strength, peaking at 20% n-HA (36.32 MPa), but decreased at higher n-HA due to particle agglomeration, in which nanoparticles cluster together instead of remaining uniformly dispersed, leading to stress concentrations and weakened load transfer. Here, bamboo was also found to be sensitive to the processing temperature, exhibiting increased thickness and a reduced projected surface area with increasing temperature, due to changes in hydrogen bonds between BF molecules.

Bamboo can be a source of cellulose fibres, which are extracted from the cellulose content of bamboo through mechanical and chemical processes [15]. The study of Zhang et al. [53] reported the fabrication of aerogels from bamboo-derived cellulose nanofibrils (CNFs) extracted from bamboo parenchyma cells. These CNFs were assembled into a porous aerogel structure to address the

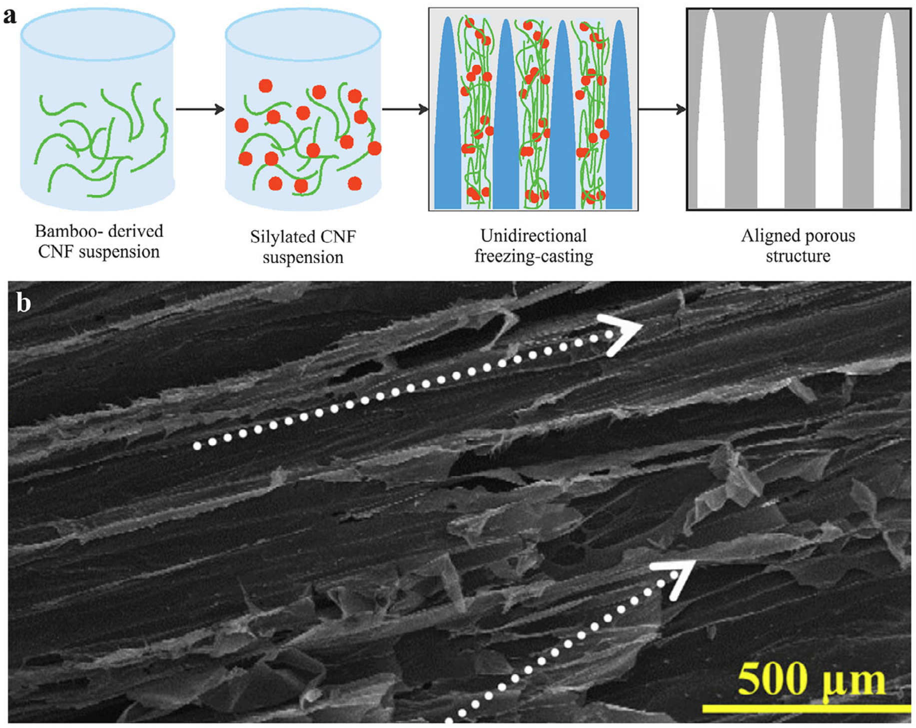

FIGURE 6 | Fabrication and anisotropic lamellar structure of silylated bamboo-derived cellulose nanofibril aerogels. (a) Schematic illustration of the fabrication of silylated bamboo-derived cellulose nanofibril (CNF) aerogels via unidirectional freeze-casting, producing an aligned porous architecture. (b) Vertical-section Scanning electron microscopy image of the silylated CNF aerogel, showing its aligned lamellar pore structure along the freezing direction. Adapted from [53].

inherent hydrophilicity and fragility of conventional cellulose aerogels (Figure 6a). The resulting aerogel exhibited anisotropic mechanical properties due to its aligned lamellar architecture, which was achieved by freeze-casting a mixture of CNF suspension and methyltrimethoxysilane (MTMS) sol. This aligned structure contributed to improved strength and stiffness in the axial direction, i.e., along the freezing direction (Figure 6b).

Additionally, Gao et al. [12] describe the fabrication of bamboo cellulose fibres (BCFs) into a non-woven fabric structure. These fibres retain inherent properties like high strength and flexibility. ZIF-67, a metal–organic framework, is grown in situ on the BFs, and polydimethylsiloxane (PDMS) is coated on these ZIF-67 modified fibres. The final material showed a maximum fracture force of 51.09 N and an average tensile strength of 12.51 MPa.

Zhu et al. [38] describe a bamboo-based composite primarily composed of two components: carbonised bamboo aerogel (CBA) and silicone resin. The CBA features a 3D network essential for the material's electrical conductivity and elasticity, making it the functional core for strain sensing. The CBA exhibits a recoverable compressive strain of up to 60%, meaning it can be compressed up to 60% of its original thickness and fully return to its initial shape once the load is removed, without any permanent deformation. Within this range, the material demonstrates a quasi-linear stress–strain response. However, beyond 60% strain, a sharp rise in stress occurs, resulting in permanent structural failure. The silicone resin is incorporated by encapsulating the CBA, improving flexibility and stretchability. Under 60% compressive strain, the composite achieves a stress of 331 kPa, approximately 43 times higher than CBA alone and about twice that of neat silicone. Furthermore, the combination with silicone improves the tensile strength of the composite from 104.1 kPa (neat silicone) to 244.4 kPa.

Among the 19 articles that describe bamboo as a major component, three describe the use of whole bamboo [52, 56]. In this context, bamboo was used as a scaffold or template, ensuring the mechanical stability and space for other materials to adhere to. For example, Liu et al. [56] describe a composite composed of BC substrate and an AgNP hydrogel. BC, characterized by its porous structure, light weight, and low density, was used as the main structural material, serving as the base onto which surface modifications and coatings were applied. The hydrogel is primarily composed of poly(N-isopropyl acrylamide) (NIPAAm), known for its thermosensitive properties. Xue et al. [52] describe calcium phosphate mineralised bamboo-based composite scaffolds (CaP-bamboo). CaP was introduced into delignified bamboo templates, primarily to induce bone ingrowth into a bone scaffold; however, as a side effect, the mineralized layer on the cells also enhanced the material's strength. The mineralized CaP-bamboo scaffolds achieved a flexural strength of 246.2 ± 18.7 MPa, a compressive strength of 104.3 ± 10.2 MPa, a flexural modulus of 8.7 ± 0.5 GPa and a compressive modulus of 3.1 ± 0.3 GPa. The CaP-bamboo scaffolds exhibited high mechanical strength and a low flexural modulus, comparable to human cortical bone.

3.3.3 | Composites—Bamboo as a Minor Component

Out of the 33 articles discussing composite materials, 16 used bamboo as a minor component. Among these, 14 composites used bamboo fibres, one used bamboo particles, and one used whole bamboo. Bamboo was used as reinforcement in polymer matrix composites to enhance strength, toughness, and stiffness. The polymer matrix binds fibres and transfers stress, with different polymers selected based on application requirements [21, 33, 39–41, 48]. In particular, Hou et al. [40] describe a lightweight polymer composite made of aligned bamboo macrofibres embedded in a polycaprolactone polyol (PCL) matrix. The bamboo macrofibres are used for their intrinsically aligned microstructure, which enables high strength, and the PLC acts as a binder that holds the bamboo macrofibres together. The bamboo macrofibre–filled lightweight polymer composite (BMC) shows ultrahigh strength (31.5 MPa, 3.3× PLA) and high toughness (21.7 MJ m^{-3}, 4× PCL). Strength and modulus increase with fibre content, though the modulus drops beyond 20% fibre loading.

Jiang et al. (2017) [48] describe a biodegradable ternary composite composed of BF, n-HA, and a poly(lactic-co-glycolic) (PLGA) matrix. BF was introduced to reinforce the PLGA and increase the mechanical properties of the n-HA/PLGA composite. Contrary to previous articles, increasing the BF content led to low mechanical strength and stiffness due to aggregation and poor interfacial adhesion. A percentage of 5% BF showed the highest bending strength, approximately 147.5 MPa.

Four articles describe the combination of BFs as a minor component in combination with synthetic fibres [22, 25, 31, 32]. For example, Zeng et al. [32] developed a Janus hygroscopic-cooling fabric (J-HCF) based on filament/bamboo core yarns, combining cool synthetic filaments (CPET, PE, or CPA) with a bamboo viscose fibre sheath. The bamboo component provided high moisture absorption and capillary transport, while the synthetic core enhanced thermal conductivity and contact cooling. This hybrid core–sheath design improved yarn strength by 11.6–14.3% compared with the corresponding neat cool filaments (CPET, PE, or CPA) used as monofilaments, demonstrating that bamboo-based regenerated cellulose fibres can effectively enhance both functional performance and mechanical robustness. Importantly, the use of bamboo viscose highlights the potential of renewable, plant-derived fibres to partially replace fully synthetic systems in high-performance textiles [28–30, 57].

Among the reviewed articles, Oğlakcıoğlu et al. [30] stands out for its focus on compressive performance. Tubular medical bandages were manufactured by using core-spun yarns, with elastane, a synthetic fiber, as the core and bamboo as the sheath. Bamboo was used for its inherent advantages like breathability, softness, and moisture management, while elastane was used as a core material to provide compression. The bamboo-based fabric sample showed a pressure value of 25.98 mmHg, air permeability of 50.01 $L\cdot m^{-2}\cdot s^{-1}$, water vapour permeability of 36.76%, and thermal resistance of 0.0310 W/m^2K. The results indicated that the bandages have good comfort abilities, besides adequate pressure values for the compression effect. Huang et al. [23] introduced a composite yarn where BC roving (70% rayon, 30% BC fibre) forms the sheath and stainless steel (SS) fibre the core. BC fibre enhanced tensile strength, while SS provided electromagnetic shielding but did not significantly improve mechanical strength. Rubber thread was included to enhance elasticity.

Sallal et al. [45] investigated bamboo particles as a reinforcement in a lamination resin composite. In this study, the resin served as the matrix, while the bamboo particles, sized at 5 µm, were added to enhance mechanical performance. However, compared to other organic and inorganic fillers, the bamboo particles yielded relatively lower tensile strength values, ranging between 40 and 50 MPa. This reduction in strength was attributed to the needle-like morphology of the particles, which increased stress concentrations and facilitated crack propagation, particularly at high loading ratios. A similar needle-like morphology can be observed in (Figure 7) of the present study, which may contribute to comparable mechanical behavior [58].

Sosiati et al. [47] describe the incorporation of whole bamboo segments with bamboo slats for a laminated composite. The composites were fabricated using a polyester matrix reinforced by woven E-glass and woven bamboo, and filled with eggshell microparticles (EMPs).

The laminated composites were fabricated in different stacking sequences of woven E-glass (G) and woven bamboo. Bamboo was selected for its high tensile strength (up to 335.8 MPa) and elastic modulus (15.8 GPa). The GBGBG stacking sequence demonstrated the best performance, with the highest flexural strength (177.19 MPa), impact toughness (88.13 kJ/m^2), and lowest water absorption (0.64%), attributed to the increased glass fibre content and strong interlaminar bonding.

4 | Discussion

4.1 | Comparative Analysis

This review provides an overview of the current medical use of bamboo-based materials. Medical applications are classified into medical textiles and medical devices, while bamboo material compositions are categorised as bamboo as the only component, a major component, or a minor component. Clear application patterns emerge, with bamboo utilisation closely linked to structural role and performance requirements. This section, therefore, explores the relationship between bamboo material composition and medical applications. The distribution of bamboo-based applications in medical textiles and medical devices, together with their corresponding material compositions, is shown below in (Figure 8a).

In medical textiles, protective applications such as hospital garments prioritise comfort and breathability properties, which BFs naturally provide [9, 16, 19]. In contrast, treatment-oriented textiles, such as compression bandages, require greater elasticity. In these cases, bamboo is typically used as a reinforcing component alongside elastic materials such as elastane, which primarily determine the textile's mechanical performance [25, 26, 30]. Similarly, wound dressings demand enhanced wound-healing efficacy and antimicrobial functionality, which bamboo alone cannot always provide. As a result, additives such as silver nanoparticle coatings or antimicrobial oils are frequently incorporated to improve antimicrobial performance [27, 29, 59].

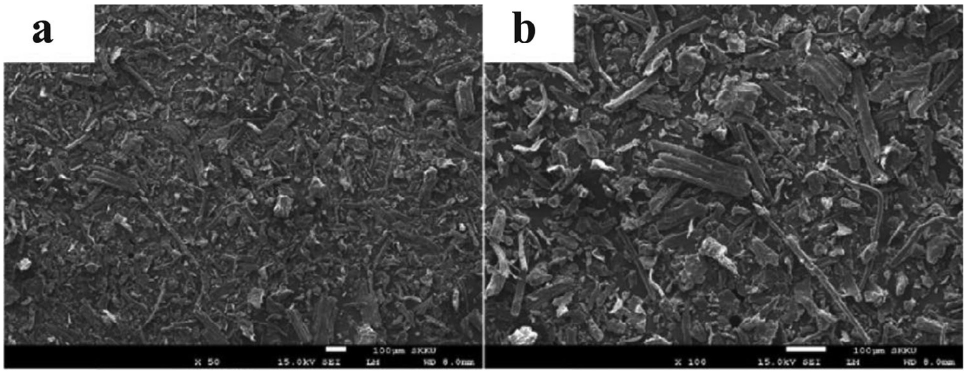

FIGURE 7 | SEM micrographs of bamboo particles at different magnifications: (A) 50× and (B) 100×, showing elongated, needle-like morphology [58].

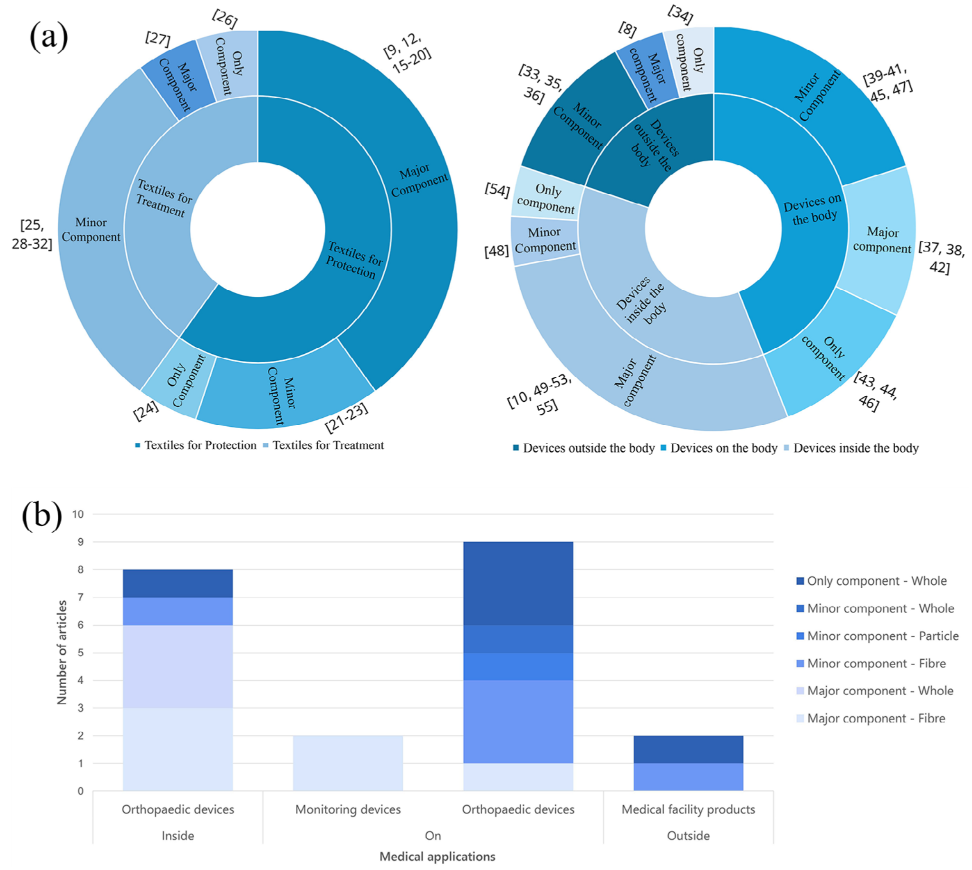

FIGURE 8 | Comparative analysis of bamboo-based medical applications: (a) Distribution of applications and material utilization in medical textiles (left) and medical devices (right), with reference numbers in brackets indicating the corresponding articles; (b) Distribution of material composition and bamboo form used in various bamboo-based medical devices.

A range of processing methods is used in medical textiles to enhance fibre performance, hygiene, and biocompatibility. Table 1 provides an overview of these processing approaches and their functions. Textiles for protection mainly rely on additive or surface modification techniques, which enhance external performance such as antimicrobial, fluid-repellent, or stain-resistant properties without fundamentally altering the internal fibre structure. In contrast, treatment textiles undergo more extensive processing at the fibre, yarn, and fabric levels. These intrinsic modifications directly influence softness, absorbency, moisture management, and biocompatibility. This distinction reflects the functional requirements of the two categories: protective textiles must act as barriers against external contamination, whereas treatment textiles must interact closely with skin or wounds and therefore rely on built-in material properties.

Medical devices show a broader variation in bamboo material composition depending on application, as illustrated in

TABLE 1 | Overview of processing methods for medical textiles and devices, with examples of specific techniques and their intended purposes in relation to device invasiveness and textile application type.

Processing Method	Specific Techniques	Purpose	Device Invasiveness /Textile application	Refs.
Medical Textiles				
Antimicrobial Enhancement	Metal nanoparticle coating, copper sulfate treatments, and natural antimicrobial oils	Infection control and bacterial reduction	Protection	[20, 27, 29]
Functional Surface Treatments	Nano-soybean treatments, O2 plasma modification	Water repellent, stain resistant, durability	Protection	[17, 27]
Advanced Coating Systems	PDMS encapsulation, alginate/copper coatings, ZIF 67 frameworks	Barrier properties while maintaining breathability	Protection	[12, 20]
Fibre Purification	FX-100 processing, bio-fermented water treatment, delignification	Create soft, skin-compatible fibres	Protection /Treatment	[9, 12]
Fabric Construction	Single jersey knitting, plain weaving, spunlace non-woven, needle-punching	Appropriate architecture for specific medical uses	Protection /Treatment	[9, 16, 21, 22, 27, 28, 31, 32]
Thermal Curing	Controlled curing, heat bonding, and controlled drying	Set finishes permanently, sterilizes	Protection /Treatment	[12, 21]
Yarn Production	Ring spinning, core-spun bamboo yarn, wet spinning	Create uniform yarns with controlled properties	Treatment	[9, 16, 21–23, 30, 32]
Medical Devices				
Solvent Purification	Ethanol extraction, toluene treatment, DMAc/LiCl systems, ultrasonic cleaning	Remove compounds causing inflammatory reactions	Inside	[10, 48–50]
Biomineralization	n-HA precipitation, simulated body fluid treatment, Cap coating	Enhance cellular attachment (bone)	Inside	[10, 38, 51, 52]
Chemical Delignification	NaOH treatment, acidified NaClO2, peroxyformic acid	Improve biocompatibility and reduce immune response	Inside/On	[38, 40, 43, 47, 52, 53]
High-Temperature Processing	Carbonization, pyrolysis, steam treatment	Create bioactive surfaces and sterilize materials	Inside/On	[38, 42, 46, 54]
Surface alteration	O2 plasma treatment, silylation with MTMS, UV-grafted modifications	Improve tissue adhesion and biocompatibility	Inside/On	[10, 53, 56]
Nanoparticle Integration	Silver nanoparticle reduction, copper sputter coating, n-HA dispersion	Antimicrobial properties and enhanced bioactivity	Inside/On	[37, 48, 56]
Structural Processing	Freeze-casting, freeze-drying, and CNF extraction via ultrasonication	Preserve natural structure for tissue ingrowth	Inside/On	[38, 49, 53]
Precision Manufacturing	Cutting to specific dimensions, steam softening	Achieve a precise fit for orthopaedic applications	Inside/On	[10, 43, 46]

(Figure 8b). A clear distinction exists between devices used on the body and those used inside the body, largely driven by invasiveness and regulatory requirements. Bamboo is more commonly used in non-invasive, on-body devices, partly due to the challenges associated with sterilising natural materials and ensuring long-term biocompatibility for internal use [52, 56]. Devices worn on the body pose a lower risk of infection or systemic harm and are therefore subject to less stringent sterilisation and safety requirements, allowing greater flexibility in material selection [14]. Devices used inside the body are predominantly associated with orthopaedic applications, such as bone fixation and tissue regeneration. In these cases, bamboo is typically employed as a major component, often in fibre or whole form, functioning as a structural matrix or scaffold.

Bamboo's intrinsic porous architecture and bone-like mechanical properties support bone integration and regeneration [51–53, 56]. In contrast, on-body devices show a more varied use of bamboo as the only major or minor component. Examples include prosthetic pylons made entirely from bamboo for mechanical support [46], fibre-reinforced composites for orthoses to enhance strength [40], and BF substrates used in flexible strain sensors [38]. These differences reflect functional requirements: internal devices rely on bamboo's intrinsic structure to support biological processes, whereas external devices exploit its mechanical properties, such as strength, elasticity, and low density, for load-bearing and supportive roles.

Overall, bamboo is most frequently used in protective medical textiles as a major component, while it appears as a minor component in on-body devices and as a major component in internal devices. The literature highlights that different applications prioritise different bamboo properties. In medical textiles, emphasis is placed on antibacterial behavior, breathability, moisture management, and reusability [13, 15, 26, 30]. In medical devices, bamboo is selected for its high strength, elasticity, low density, biocompatibility, and sustainability [41, 45–47, 52, 56]. Within textiles, bamboo is exclusively used in fibre form. Treatment textiles primarily incorporate bamboo as a minor component, whereas protective textiles more often use it as a major component (Figure 8a). This difference reflects application priorities, which can be achieved through tailored bamboo compositions rather than relying solely on bamboo's intrinsic structure [39–41, 45–47].

For applications inside the body, bamboo is further tailored to meet specific orthopaedic objectives. Jiang et al. (2017) [48] focus on stabilisation and load-bearing fixation, using BF as a reinforcing filler in a polymer matrix to enhance mechanical strength. In contrast, Xue et al. [52] employ delignified bamboo as a bio-template to create a hierarchical porous scaffold for tissue regeneration [60]. Although both approaches incorporate calcium phosphate to promote osteoconduction, the role of bamboo differs according to the intended function. Devices used outside the body are largely health care facility products and typically feature robust designs, using whole bamboo as the only component or BF as a minor component [33, 34]. As these devices are non-invasive, they require less extensive processing and pose a lower risk of infection or systemic harm. The mechanical implications of these application-specific design strategies are further summarized in Table 2.

The mechanical data summarized in Table 2 provide a direct basis for comparing bamboo-based materials with conventional biomedical materials across relevant applications. For hard-tissue applications, the CaP-mineralized bamboo scaffold exhibits compressive strengths of 104–118 MPa, flexural strengths up to 246 MPa, and elastic moduli of 3–9 GPa [52], which fall within or near the lower range of cortical bone compressive strength 100–230 MPa; modulus 7–30 GPa [61, 62]. In contrast, metallic implants such as Ti-6Al-4 V and 316L stainless steel exhibit significantly higher moduli, 100–210 GPa, resulting in a pronounced stiffness mismatch with bone [61]. This comparison indicates that bamboo-based mineralized scaffolds provide a more favorable bone-matched mechanical profile for load-sharing applications. Similarly, BF/nHA/PLGA composites, with bending strengths of 131–148 MPa [48], exceed those of conventional biodegradable polymers such as PLA and PLGA [63], further supporting the reinforcing role of bamboo fibers in bone-related systems. For non-load-bearing bone regeneration, nHA/BF scaffolds, compressive strength: 1.11–42.74 MPa [51] and nHA/BF membranes, tensile strength: 13.96–36.32 MPa, exhibit lower strength than cortical bone.

For prosthetic and assistive applications, 3D-printed bamboo fiber/PE composites, tensile strength: 6.3–15.6 MPa; modulus up to 116 MPa [10], show a mechanical behavior comparable to low-modulus thermoplastics, but remain inferior to high-performance implant polymers such as PEEK [64], limiting their use to low-load, patient-specific biomedical components. For soft biomedical applications, bamboo-derived CNF aerogels, silicone composites, and nonwoven fabrics exhibit mechanical properties in the kPa-to-low MPa range [2, 30], consistent with soft tissues and elastomeric biomaterials [62], and are therefore suitable for wound-contact materials, cushioning interfaces, and wearable systems. Overall, Table 2 highlights the mechanically tunable nature of bamboo-based materials across hard and soft biomedical applications.

Differences in mechanical performance between bamboo used as a major and minor component are illustrated in studies combining bamboo with nano-hydroxyapatite (n-HA) [48, 49, 51]. When bamboo is used as a minor component, optimal mechanical strength is achieved at relatively low fibre ratios [48]. In contrast, when bamboo serves as a major component, higher optimal ratios for achieving maximum strength [49, 51]. This can be explained by bamboo's structural role: low reinforcement volumes may maximise strength, while excessive fibre content can cause aggregation and poor interfacial bonding, reducing performance. When bamboo forms the bulk structure, the optimal composition reflects a balance between the BF matrix and the dispersed n-HA phase.

Although bamboo possesses a hierarchical fibrous structure and favorable mechanical properties, its performance in composites depends strongly on processing and structural integration [52]. When used as a structural template, bamboo can retain its aligned architecture and achieve properties comparable to cortical bone [52]. In contrast, when incorporated as a reinforcing phase, its effectiveness is often reduced by fibre agglomeration, which limits dispersion and structural uniformity. This has been observed in bamboo/nano-hydroxyapatite systems, where blending methods caused particle clustering compared with precipitation techniques [51]. In addition, reinforcement efficiency is influenced by interfacial bonding, fibre characteristics, and preprocessing steps such as delignification, bleaching, and drying [37, 65].

Variations in feedstock properties, including species differences such as Dendrocalamus asper, as well as culm age and moisture content, may further contribute to inconsistent performance across studies [9]. As a result, bamboo does not consistently outperform conventional materials in terms of mechanical performance [45], particularly where poor fibre dispersion or weak surface coatings compromise structural integrity [37, 48]. Its broader clinical implementation also remains limited, partly because bamboo is sensitive to environmental conditions

TABLE 2 | Summary of bamboo-based materials with reported numerical mechanical properties and their potential biomedical applications.

Bamboo-based material	Reported mechanical properties	Main biomedical application	Refs.
CaP-mineralized bamboo scaffold (CaP-Bamboo)	Compressive strength: 104.3 ± 10.2 to 118.6 ± 11.7 MPa; Flexural strength: 234.4 ± 23.4 to 246.2 ± 18.7 MPa; Compressive modulus: 3.1 ± 0.3 GPa; Flexural modulus: 8.7 ± 0.5 GPa	Bone scaffold	[52]
Delignified bamboo (D-Bamboo)	Flexural strength: 178.5 ± 7.7 MPa; Flexural modulus: 4.6 ± 1.2 GPa; Compressive modulus: 2.5 ± 0.4 GPa		
BF/nHA/PLGA composite	Bending strength: ∼131–148 MPa	Bone scaffold/biodegradable fixation material	[48]
nHA/BF composite scaffold	Compressive strength: 1.11–42.74 MPa, Tensile strength: 13.96–36.32 MPa	Non-load-bearing bone scaffold/osteoconductive filler	[51]
Bamboo fiber–reinforced silicone bio composite	Compressive stress: up to 83.16 kPa	Soft biomedical component/cushioning interface	
3D-printed bamboo fiber/PE composite	Tensile strength: 6.3–15.6 MPa; Elastic modulus: 31.0–116.5 MPa	Orthotic/assistive biomedical parts	[10]
Cu-sputtered bamboo fiber bundle	Tensile strength: 375.6–858 MPa	Conductive biomedical textile/wearable sensor substrate	[2]
Bamboo-derived CNF aerogel	Compressive stress: ∼24–45 kPa; Apparent modulus: ∼5–45 kPa	Soft biomedical interface/cushioning	
PDMS@ZIF-67@BNF bamboo nonwoven	Tensile strength: 12.51 MPa	Medical textile/wound-contact material	[30]

such as moisture and temperature, which can cause softening, warping, or degradation of internal bonding [24, 51]. For invasive applications, extensive processing is often required to achieve suitable mechanical and biological properties, particularly through treatments such as chemical delignification [37, 40, 52, 53, 56]. However, these processing steps are time-consuming, costly, and may reduce the environmental advantages that often justify the use of bamboo in medical applications.

4.2 | Temporal Distribution and Future Perspective

The increase in publications on the use of bamboo in medical applications is evident, as shown below in (Figure 9). Since 2008, there has been a rise in documented medical applications of bamboo, indicating a broader spectrum of applications and material compositions. The first paper on medical bamboo applications was published in 1994, and interest surged after 2008.

While early applications predominantly focused on medical textiles, recent research has shifted toward more technologically sophisticated applications, including bamboo-based tissue engineering and medical monitoring devices (Figure 9a). In recent years, the scope of bamboo use has become more diverse and complex (Figure 9b), likely due to the integration of advanced technologies.

One underexplored area is the use of bamboo-based composites in 3D printing. Recent work has shown that bamboo-reinforced printable composites can exhibit favorable mechanical properties, including increased tensile strength and Young's modulus, supporting their potential as sustainable feedstocks for additive manufacturing [66]. However, important processing limitations remain in extrusion-based printing; fiber orientation is difficult to control, and shear-induced misalignment, fiber breakage, and agglomeration may produce anisotropic properties [66, 67], irregular filament quality, and nozzle clogging. Bamboo fibers are also susceptible to thermal and moisture-related degradation, which can weaken the fiber–matrix interface when drying and printing temperatures are not carefully optimized [68]. Current mitigation strategies include alkali pretreatment to remove lignin and hemicellulose and improve wettability, alongside surface modification approaches such as dopamine-assisted treatment to enhance interfacial adhesion [66, 69, 70]. Process optimization, including controlled heating and suitable nozzle dimensions, has also been proposed to improve extrusion stability and fiber impregnation [66, 71]. Although no clinical bamboo-based 3D-printed medical devices have yet been reported, the growing use of additive manufacturing in orthopedics and tissue engineering suggests clear potential for the future development of bamboo-based bio-fabricated medical components [51–53, 56, 72].

4.3 | Limitations and Recommendations

Despite a systematic and broad search strategy, relevant studies may have been missed due to restrictive search terms and database coverage, particularly for bamboo-based medical devices reported without explicit biomedical terminology or published outside major databases. Traditional and region-specific applications, especially from developing countries, may therefore be underrepresented. Future reviews should expand database selection and search terms to address this gap. Additionally, inconsistent reporting of bamboo species across studies limits comparability, as material properties vary by species and region.

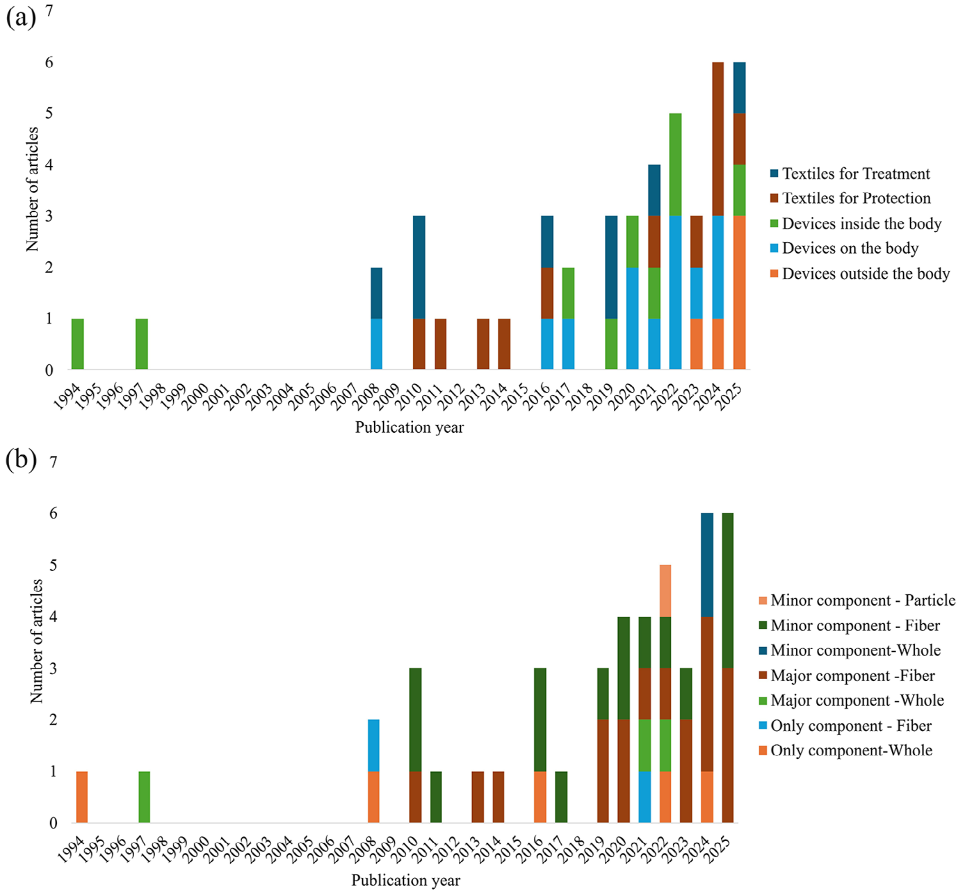

FIGURE 9 | Temporal distribution of the included articles, classified on (a) medical application and (b) material utilization.

To move forward, several improvements are needed. In the near term, researchers should standardize how bamboo materials are prepared and reported, including clear identification of species, origin, and treatment methods, since these factors strongly influence performance [73]. Mechanical properties must also be optimized, particularly in composite materials where bamboo fibers are combined with other substances, as problems such as fiber clumping and weak bonding can reduce strength [37, 48]. More direct comparisons with existing medical materials under the same testing conditions are also necessary to prove real advantages.

In the midterm, future work should focus on long-term durability testing and in vivo studies to better assess biocompatibility, stability, performance under physiological conditions, and combined with advanced manufacturing technologies such as 3D printing. Recent work has shown that bamboo-reinforced composites can achieve high tensile strength and stiffness when 3D printed [66]. Since 3D printing is already being explored for personalized bone implants and spinal devices [72]. Clearer cost–benefit analyses will also be important to support industrial and clinical interest.

In the long term, progress will depend on the ability to scale up production and establish clear regulatory pathways to ensure the safe use of bamboo-based materials in medical applications. Over the next five to ten years, healthcare may benefit from more sustainable and potentially lower-cost material options, with bamboo-based materials gradually transitioning from experimental research to selected, practical applications in everyday clinical use.

5 | Conclusions

This review provides an overview of the current use of bamboo in medical applications. A classification was used to identify medical applications and material utilization in the current literature. Textiles for treatment mainly use bamboo as a minor component, combined with antimicrobial or mechanical strengthening components. In contrast, protective textiles primarily use bamboo as a significant component, leveraging its inherent comfort and breathability. Medical devices exhibited greater variability in material utilization; devices inside the body often incorporated bamboo as a significant structural element, whereas devices outside the body typically used bamboo as reinforcement. Across all applications, bamboo was selected for its mechanical, antimicrobial, and breathable characteristics. Several studies have shown a rising use of bamboo materials in medical applications, with increasing complexity in material use and manufacturing methods to ensure antimicrobial performance and unique mechanical characteristics. Although various research studies address this topic, these applications have not been implemented in current healthcare. Bamboo still has some limitations to overcome regarding manufacturing and treatment complexity for more invasive devices, and in proving superiority over standard materials. However, bamboo holds great potential to replace materials in standard healthcare as an affordable and low-cost alternative. Additionally, recent advances in bamboo material use present new possibilities for its incorporation into more technically advanced medical applications.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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