Fibre reinforced composite materials in modern orthopedic medicine and prosthetics

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ABSTRACT
The implication of fibre reinforced composite materials for biomedical purposes has been conceptualized. In modern age, the advancement in the area of polymer composite materials has led to scientific and technological progresses in current orthopedic medicine and prosthetic devices. Thus Fibre Reinforced Composites (FRC) characteristically possesses a superior strength to weight features compared to monolithic materials and shows exceptional biocompatibility. Consequently they became universally promising material for hard- and soft-tissue applications as well as in the design of prostheses. Future orthopedic medicine expects the development of modernized materials for tissue engineering and metallic implants.

KEYWORDS: *Fibre reinforced composites, orthopedics, prosthetics, medicine*

1. INTRODUCTION

Composite material based design of orthopedics and prosthetics has drawn immense attention nowadays. Combined fibre reinforced polymer composites can thus be effectively employed in orthopedics and as modern upper and lower limb prostheses with underlying polymer matrices [1-3]. Optimal composite performance depends on structural and surface compatibility alongwith other aspects like surgical technique and patients' health [4]. Custom-made polymer matrix composites can mimic the properties of bone and can be substituted in place of conventional titanium and stainless steel based replacements [5-10]. Furthermore, Fibre reinforced polymer composites are responsive to apt update regarding fibre arrangement or variation in the volume fraction [11, 12]. Third generation composites achieved specific cellular responses on a molecular level forming biodegradable scaffolds and organised body architecture [8, 13, 14]. Frequent trials will commendably increase cost effective commercialisation of new devices particularly within surgical practices [3, 15]. Here the different usages of fibre reinforced polymer composite materials have been explored in relation to technological advances in modern orthopedics.

2. APPLICATION OF FIBRE REINFORCED COMPOSITES IN VARIOUS AREA

The improvement of quality composite materials regarding safe biocompatible orthopedics and prostheses is an enduring practice of multidisciplinary research activities.

Thus materials are tested on the basis of selected criteria like toxicology, biocompatibility, biostability or biodegradability, mass transfer, surface properties, hygienic design, costs and other physical or biochemical properties.

2.1 HARD-TISSUE USAGE

Hard-tissue applications are applicable in case of skull reconstruction, bone fracture repair and other joint replacements, as well as dental applications. An outline of the same is given below.

2.1.1 APPLICATION IN BONE FRACTURE REPAIR

Here external fixation targets right alignment of bones through casts, splints, braces etc. These days traditional casting materials have been substituted by breathable casts to prevent skin irritation and/or weakening of the patient's skin [3, 16, 24]. Modern light weight and low density carbon fibre reinforced plastic designs alleviates patient's agility, gait and walking speed and reduces artefacts in radiographs [17, 18].
In contrast, internal fixation employed resorbable bone plate which lowered stress shielding and a possible extermination of osteopenia. Completely resorbable composite implants made up of poly(l-lactic acid) (PLLA), poly(glycolic acid) (PGA) or their copolymers and poly(l-lactic-co-glycolic acid) (PLGA) are more satisfactory for human clinical purposes [19, 20]. Improved mechanical performance of such resorbable polymers has been attained by making them fibre-reinforced (partially-resorbable) [19].
Former material combinations of carbon fibre/epoxy (CF/epoxy) and glass fibre/epoxy (GF/epoxy) have become less important now due to their toxicity. Meanwhile, researchers inclined towards thermoplastic composites and biologically inert carbon fibre/poly ether ether ketone (CF/PEEK) designs [3, 21]. Knitted and braided CF/PEEK compression plates have been fabricated further [21-23]. Recently, Carbon fibre reinforced liquid crystalline polymer (LCP/CF) and GF/PEEK material combinations have been systematically studied for long bone fractures [3, 24].

2.1.2 USAGE IN TOTAL KNEE REPLACEMENT

In recent times crosslinked polyethylene is of utmost importance over ultra-high molecular weight polyethylene based knee joints replacement [25, 27]. Additionally, total joint replacement materials attained expected characteristics like high strength, corrosion resistance, good surface finish yielding low friction, and above all good wetting at the bearing surface/synovial fluid interface for lubrication in the body [26, 27].

2.1.3 TOTAL HIP REPLACEMENT APPLICATION

Improvement in computational methods aided in simulation and analysis of the performance of unique carbon fibre/polyamide 12 (CF/PA12) and carbon fibre/polyamide 12/hydroxyapatite (CF/PA12/ HAP) composite hip stems [28-31, 36]. Therefore the progress in application of composite materials in hip joint fixation reflects the approaches of cementing and bone in growth [32-35, 36].

2.1.4 APPLICATIONS IN DENTAL ARENA

Composite resins mimicking biological tissue has now substituted conventional restorative material, namely amalgam, gold, alumina, zirconia etc. [37, 41]. The major shortcomings are their longevity, polymerisation shrinkage, thermal expansion mismatch and toxicity that need further introspection [37, 38, 41]. Incorporation of ceramic microwires of aluminium oxide into poly(methyl methacrylate) (PMMA) resulted into a higher diffusivity and hence minimizes the poor thermal conductivity in orthodontic prosthetic composites [39-41].

2.2 SOFT-TISSUE USAGE

The implication of composite material to replace soft-tissue needs careful attention over the inherent properties like molecular weight, charge, optimisation of porosity and acceptance by the host tissue etc. [42, 43].

2.3 TISSUE ENGINEERING APPLICATIONS

In recent times application of biocompatible, osteoinductive, osteoconductive and mechanically compatible scaffolding constructs aided in prospective integration with native tissue which decrease implant failure [44, 45, 50]. Further, initial treatment with mesenchymal stem cells also cures diseased tissue which decreases the need for lifelong treatment.
PGA and β-tricalcium phosphate (β-TCP) compounds based composite scaffolds imitates the natural bone components and therefore successful integration into the surrounding tissue is obvious [46, 50]. Afterward, fabrication of reproducible scaffolding networks were in action by combining poly(e-caprolactone) (PCL) and esters of hyaluronic acid [47, 50]. A number of nanometric bioactive glass particles or fibres such as poly(hydroxybutyrate-2-co-2-hydroxyvalerate)/biomimetically synthesised nano-sized bioactive glass (PHBV/BMBG) porous composites have recently drawn attention to produce extra flexibility [42, 43, 48-50].

2.4 FOCUSING ON PROFESSIONAL SPORTS

In 1981, Seattle foot first introduced carbon fibre reinforced polymer (CFRP) composite with enhanced flexibility and high strength [51-55, 57]. Further modification came by differing laminate lay-up, fibre orientation and/or laminate thickness. Current sprint prostheses possess an articulated long keel design [54, 57]. Interestingly, a fibre glass and nylon made arm prosthetic kit helped one Canadian athlete for active participation in 2008 Paralympic Games [56, 57]. Nowadays fibre composite materials have favourably influenced the progress of modern artificial limbs.

2.5 BIOMIMETICS, ACTUATORS AND ARTIFICIAL MUSCLE APPROACHES

Here ionic polymer-metal composites (IPMCs) draw utmost interest following characteristic properties like softness, flexibility, lightweight, exceptional biocompatibility, large bending deformation, low power consumption and high frequency operation [58-62, 65]. Several noteworthy applications in biomedical science are artificial ventricular, sphincter and ocular muscles, artificial smooth muscle actuators, correction of refractive index in the human eye, peristaltic pumps, incontinence assist devices, and surgical tools [62-65]. An alternative novel actuators based on sulfonated poly(ether ether ketone) (SPEEK) and poly(vinylidene fluoride) (PVDF) is of immense interest [58].

3. CONCLUSIONS

Fibre reinforced composite materials with exceptional strength and biocompatibility nowadays portrays massive commercialization in modern orthopedic medicine. Besides that it holds major technical advancement in the area of cosmetic dentistry and lower-limb prostheses. Researchers now aim to develop value-added control over present-day prostheses by implementing sensory feedback systems to improvise natural response.

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