Review article

Medical textiles in orthopedics: An overview

Raju Vaishya, Amit Kumar Agarwal*, Manish Tiwari, Abhishek Vaish, Vipul Vijay, Yash Nigam

Department of Orthopaedics and Joint Replacement Surgery, Indraprastha Apollo Hospitals, New Delhi 110076, India

ARTICLE INFO

Article history:

Received 16 June 2017

Received in revised form 9 October 2017

Accepted 26 October 2017

Available online 27 October 2017

Keywords:

medical textiles

surgical gowns

face masks

shoe covers

sterilization wraps

suture anchors

fiber cast braces

Cotton

Nylon

Silk

Ultra-high molecular weight polyethylene

Polyester

Polypropylene

Poly tetra-fluoro ethylene

Polyether ether ketone

Polyether ketone

ABSTRACT

The use of textile in the medical field is not new; this has given rise to a new branch known as medical textiles. These are being used to repair or replace various other musculoskeletal tissues. The most common uses of biomaterials are to create aseptic conditions for protection, general health care, and hygiene including bedding and clothing, surgical gowns, face masks, head and shoe covers, sterilization wraps, suture anchors, fiber cast and braces/orthotics. These are also used as materials for preparation of wipes, swabs, wound dressings, bandages, gauzes, plasters, pressure garments, orthopedic belts and for new applications, such as heart valves, vascular grafts, artificial veins, artificial ligaments, artificial joints, artificial skin, and artificial cartilage. The truth is that nowadays the use of biomedical textiles is more rampant than anyone realizes. Commonly used materials for preparation of biomedical textiles includes Cotton, Nylon, Silk, Ultra-high molecular weight polyethylene, Polyester, Polypropylene, Poly tetra-fluoro ethylene, Polyether ether ketone, and Polyether ketone. These are prepared from various monomers in varying proportions as per the requirement of the material to be used. Various methods are used in their preparation like Braiding, Knitting, and Weaving, which helps in the development of certain kinds of materials with different specificity and character. Other important measures in the preparation of the medical textile include Denier (the filament counts in multifilament fibers), Tenacity (the strength per denier) and Heat shrink (the amount of shrinkage at a particular time and temperature).

© 2017 Delhi Orthopedic Association. All rights reserved.

1. Introduction

The use of textile in the medical field is not new; this has given rise to a new branch known as medical textiles. Novel use of new and existing biomaterials in musculoskeletal procedures ranges from bone grafting to segmental fusion for spinal instability [1–3]. These are also being used to repair or replace various other musculoskeletal tissues like articular cartilage, meniscus [4] ligaments [5–7], and tendons [8]. The focus is now shifting towards lighter and softer implants instead of the old hard material implants.

The human body has dynamic complex biomechanical processes and therefore the material implanted or used over the human body should be inert and harmless. Mechanical properties

play a significant role in the selection of materials for human use. Analysis of the biological behavior of synthetic materials is used to check the biocompatibility, using various in-vitro and in vivo standardized tests. Hench et al. [9] divided biomaterials into three different generations based on the evolution in the field of biomaterials and also as a result of learning from failed implantation.

2. First generation biomaterials – bioinert materials (1960–1980)

The choice of the material for a particular product is governed by matching the material properties with the indication of its implementation. Biological properties need to be added in the case of biomaterials, to the mechanical, chemical and physical properties. In the recent past, other conditions such as foreign body reaction (particularly due to wear debris), stress shielding, biocompatibility, bioactivity, and osteoinduction have also been introduced for the biomaterials used to design various implantable devices. Hench et al. [9] were the pioneers in introducing the

* Corresponding author.

E-mail addresses: raju.vaishya@gmail.com (R. Vaishya), amitorthopgi@yahoo.co.in (A.K. Agarwal), tiwari.manishjoy@gmail.com (M. Tiwari), drabhishekvaish@gmail.com (A. Vaish), dr_vipulvijay@yahoo.com (V. Vijay), doc_yash_nigam@yahoo.com (Y. Nigam).

Table 1

Classification of medical textiles based on their use.

Polymers	Used in preparation of
Polymethacrylic acid (PMMA)	Acrylic bone cements, anchoring of hip prostheses vertebroplasties and kyphoplasties
Polyethylene (PE)	Liner of acetabular cups in hip arthroplasties, tibial insert and patellar components in total knee arthroplasties
Polydimethylsulphoxide (PDMS)	Replacement for small joints in hand and foot
Polysulphone (PS)	Bone fixation devices, total joint arthroplasties
Polypropylene (PP)	Bone fixation devices
Polycarbonate (PC)	Bioabsorbable fixation devices and bone regeneration drug delivery
Polyglycolic acid (PGA)	Bioabsorbable fixation devices and bone regeneration drug delivery
Polylactic acid (PLA)	Bioabsorbable fixation devices and bone regeneration drug delivery
Polycaprolactone (PCL)	Bioabsorbable devices for bone regeneration
Polydioxanone (PDS)	Bioabsorbable fixation devices, bone regeneration

Table showing the various polymers along with their uses.

Fig. 1. Poly-insert used in total knee arthroplasty for stabilization of implants and smooth movement.**Table 2**

Classification of Medical textiles based on their uses, type of fabric used, and fabric structure.

Utility	Advantages
1. Creating aseptic conditions	1. Can be adapted to any part of the body and in any situation (flexible, soft and comfortable.)
2. Closure of wounds	2. Reduces the stiffness and are comfortable to wear
3. Immobilisation and support for fracture segment	3. Can be used as an emergency immobiliser for accident victims
4. Improved outcomes and rapid healing	4. Can be re-used (cost effective)
5. Ability to engineer tissue integration	5. Removal of these material does not require any specialised instrument
6. Optimal tissue support	6. Cross infection is reduced
	7. Protection of care providers
	8. The comfort level is higher e.g. gowns
	9. Breath-ability of non-woven is better
	10. Engineered to have high barriers to blood and other body fluids.
	11. Compatible with various types of sterilization techniques
	12. In OT's they protect the user from static electricity
	13. Surgeon friendly

Table showing the utility and advantages of the medical textile

materials which fit the first generation. According to them, the implanted material should do the job which the original structure was performed with no or minimal host response, and these materials were essentially 'inert.' They made use of metallic,

ceramic materials and polymers such as silicone, rubber, polyethylene (PE), acrylic resins, polyurethanes, polypropylene (PP) and polymethyl methacrylate (PMMA) (Table 1). The most widely used amongst orthopedics is PE and ultra high molecular weight PE

Table 3
Summary of polymeric biomaterials used in various orthopedic applications.

Used on the body of the Patient (Removable)	Used inside the body of the Patient (Removable/Biodegradable)
1. Draping clothing	1. Sutures
2. Crepe Bandages	2. Mesh
3. Stockings	3. Inserts
4. Dressing materials	4. Suture anchors
5. Sutures	5. Bio-degradable Screws
6. Immobilisers,	6. Artificial tendons, ligaments
7. Braces,	7. Artificial heart valves
8. Splints,	8. Spine Cages
9. Fibre Casts	

Table showing the classification of medical textiles.

Fig. 2. Bio-inference screw used in ACL reconstruction.

(UHMWPE) as liners for acetabular cups in total hip arthroplasty (THA), as tibial inserts (Fig. 1), a patellar component in total knee arthroplasty (TKA), and as a spacer in intervertebral artificial disc replacement. These materials became popular in quick time due to their superior mechanical properties such as low friction, high abrasion resistance, toughness, low density, ease of fabrication, biocompatibility, and biostability [10,11] (Table 2). Swanson et al. popularised silicone polymers in small joint replacements [12]. The most common complication faced with this material is a fracture, apart from the other drawbacks such as bone and implant abrasion, subluxation and loosening of the implant [13–15].

Another widely used biomaterial gaining quick popularity is carbon fibers. These have been mainly used to reinforce polymers for different applications such as in THA and internal fixation. The long-term benefits of these implants have been reported in surgeries of the ear with satisfactory results [16,17]. The primary concern regarding the use of carbon implants was the release of carbon debris into the surrounding tissues causing an allergic reaction. There could be adverse cell response in some cases, such as collagenase synthesis, cell detachment, lysis and the release of cell-activating factors that activate other cells in the culture [18–20].

Ligamentous injuries are very common nowadays. In athletes, there are incidences of multiple ligament injuries due to high-intensity training. Hence materials like polyester and poly tetra fluoro ethylene come into play. These are used to manufacture synthetic cruciate ligaments. After implantation, proteins get adsorbed over the implant surface which activates the graft versus host reaction. It throws fibrous tissue which engulfs the implant completely over a period. This was the reason why scientists explored the possibility of second-generation biomaterials.

3. Second generation biomaterials (1980–2000)

Bioactive materials can enhance the biological response and the surface bonding of the tissue. At the same time, they degrade quick enough while new tissue regenerates and heals. Biodegradable materials which showed gradual chemical breakdown was being rampantly tested such as polyglycolide (PGA), polylactide (PLA), polydioxanone (PDS), poly-3-caprolactone (PCL), polyhydroxy butyrate (PHB), poly-2-hydroxyethyl- methacrylate (PHEMA), and hyaluronic acid (HA) (Table 3). These materials are extensively used in orthopedics from bone substitution to replacement of ligaments, cartilage, meniscus and intervertebral discs. These are also used in spine and trauma cases widely [21]. Biodegradable implants hold the advantage as they reduce the stress shielding effect by gradually getting absorbed and also eliminates the need for implant removal surgeries (Fig. 2). After resorption, any post-operative diagnostic imaging does not show any residual artifacts.

Table 4

Summary of advantages and benefits of using medical textiles.

Medical textile	Fabric used	Fabric structure
Surgical dressings	Cotton, viscose, lyocell, polyester, polypropylene, polyurethane foam	Woven, knitted
Splints, Compression bandages	Cotton, viscose, lyocell, elastomeric fiber yarns	Woven, non-woven, knitted
Plasters	Cotton, viscose, plastic film, polyester fiber, polypropylene fiber, glass fiber	Woven, non-woven, knitted
Non absorbable sutures	Nylon, prolene, silk, stainless steel	
Absorbable sutures	Vicryl, monocril, chromic cat gut	
Artificial Tendons	Ptfe fiber, polyester fiber, silk, collagen, polyethylene fiber, polyamide fiber	Woven, braided
Artificial Ligaments	Polyester fiber, collagen, carbon fiber	Braided
Artificial joints/bones	Silicone, poly-acetyl fiber, polyethylene fiber	
Artificial skin	Silicone, poly-acetyl fiber, polyethylene fiber	
	Low density polyethylene fiber, chitin	Nonwoven

Table showing the fabric used and their structure in various types of medical textiles.

Fig. 3. Sterile gowns and drapes used to create an aseptic environment during surgeries in operation theatre.

4. Third generation biomaterials (2000–2017)

These materials mainly stimulate specific cellular responses at the molecular level and must be biocompatible [22]. Its degradation by-products should resorb at the same rate as the tissue is repaired and should be non-cytotoxic. The scaffold should be biodegradable and must possess a highly interconnected porous network, formed by a combination of macro and micropores that enable proper tissue ingrowth, vascularization, and nutrient delivery. However, during the initial stages of the new bone formation, these materials must keep their structural integrity. Important methods in the preparation of medical fabrics include braiding, knitting, and weaving. Medical textiles have also been described based on the use, type of fibers used and the structure of the fibers (Table 4).

5. Braiding

Braiding is completed by interlacing fibers to achieve a customized construction or more basic pattern. Combining fibers is common mixing polyester with an absorbable material for partial degradation over time is one example as are complex engineering alterations to produce a customized structure with specific measurement requirements. Braiding around mandrels to create hollow tubes or flat braiding is also possible. Because it enables precise dimensions and exact geometry, the technique can be used for applications such as ligament and tendon repair.

6. Knitting

Knitting is a common textile process. The techniques involved include warp knitting and weft knitting (the latter, like braiding,

Fig. 4. Bandages used to cover wounds.

also common for making tubes). Involves more individual fibers than braiding (to provide either machine- or cross-machine-direction strength or stretch, depending on the application), the intricacy of the resultant structure is greater, and the performance capabilities, therefore, are even higher. Applications that require a higher degree of performance and undergo more severe instances of movement and stretch include containment sleeves for spinal disk repair and replacement, and implantable and procedural assistance pieces for the knee, shoulder, and spine.

7. Weaving

Longitudinal fibers held together by perpendicular cross-fibers. A woven fabric will provide thickness and strength without the stretch of knitted or braided fabrics. With high tenacity, woven structures are lightweight and stable but hold their shape for support/repair or replacement functions that must retain their original form. Spinal Restoration and tendon repair are two orthopedic applications that benefit from these advantages. Moreover, because they must be strong and require a certain amount of space to retain their form even during joint or system movement, density is also a necessity.

Other important measures in the preparation of the medical textile includes

1. Denier – the filament count in multifilament fibers, which can affect density and processability.
2. Tenacity – the strength per denier, which is often necessary regarding implant performance.

3. Heat shrink – the amount of shrinkage at a particular time and temperature, which can be an important factor for decisions based on further downstream processing including sterilization.

The most common uses of biomaterials are to create aseptic conditions for the protection, general health care, hygiene, bedding, clothing (Fig. 3), mattress covers, surgical gowns, face masks, shoe covers, apparel, sterilization wraps (Fig. 4), dressing materials (Fig. 5), suture anchors (Fig. 6), incontinence care pads, nappies, tampons, fiber cast for immobilisation of the fracture (Fig. 7), and braces/orthotics (Fig. 8). These are also used for the preparation of wipes, swabs, wound dressings, bandages, gauzes, plasters, pressure garments, orthopedic belts and for new applications, such as heart valves, vascular grafts, artificial veins, artificial tendons and ligaments, artificial bones, artificial skin, and artificial cartilage.

The demand for these medical textiles is rising exponentially as it offers a variety of technical & functional properties rather than for just their aesthetic or decorative characteristics.

Commonly used materials for preparation of biomedical textiles includes Cotton, Nylon, Silk, Ultra-high molecular weight polyethylene (UHDPE), Polyester, Polypropylene, Poly tetra-fluoro ethylene, Polyether ether ketone (PEEK), and Polyether ketone (PEKK) (Table 3).

The advantages of using biomaterials in medicine are tremendous such as they may reduce the incidence of cross infection apart from being cost-efficient and recommended by the WHO surgical material usage guidelines. The ability to modify the structure at

Fig. 5. Sterile bandage with cotton pad used for dressing.

Fig. 6. Suture anchor, used in repair of tendons and ligament avulsion.

molecular level gives a cutting edge in seeking the desired interaction with the biological environment.

The problem which was faced in the initial years with implants was its reaction in the host as well as the longevity. However, with the advent of third generation biomaterials, this problem has been taken care off. Now the biggest problems in the postoperative period are multifactorial rather than implant based. The difference perhaps was mainly due to research in the field of textiles and applying these to manufacture more biocompatible and sturdy implants. For instance, there was a significant reduction in abrasion by the introduction of highly cross-linked polyethylene

(PE), antioxidant stabilized PE, new ceramics and the development of ceramic and protective surfaces.

8. Conclusion

The truth is that nowadays the use of biomedical textiles is more rampant than anyone realizes. Therefore an adequate knowledge about these materials is of paramount importance. It will help in the better management of patients by further improving its usage. There are numerous papers available freely which discuss the mechanical and chemical properties of the variously available biomaterials. Therefore, this is not touched upon in this article as the main aim here was to instill awareness and curiosity in the reader's mind. In future, it is possible to acquire an ideal biomaterial which is inert, wear resistant, durable, affordable and easily available if the quest for learning and delivering prevails.

Conflict of interest

The authors declare that they have no conflict of interest.

Fig. 7. Fibre cast, used for supporting and immobilizing a fractured limb.

Fig. 8. Orthotics used for supporting and immobilizing a limb.

References

- [1]. Ambrosio L, Netti P, Iannace S, et al. Composite hydrogels for intervertebral disc prostheses. *J. Mater. Sci. Mater. Med.* 1996;7:525–530.
- [2]. Vaccaro AR, Singh K, Haid R, et al. The use of bioabsorbable implants in the spine. *Spine J.* 2003;3(3):227–237.
- [3]. Jiya TU, Smit T, van Royen BJ, et al. Posterior lumbar interbody fusion using non-resorbable poly-ether-ether-ketone versus resorbable poly-L-lactide-co-D, L-lactide fusion devices. Clinical outcome at a minimum of 2-year follow-up. *Eur. Spine J.* 2011;20(4):618–622.
- [4]. Iuchi R, Mae T, Shino K, et al. Biomechanical testing of transcapsular meniscal repair. *Exp. Orthop.* 2017;4:2.
- [5]. Ahlfield SK, Larson RL, Collins HR. Anterior cruciate reconstruction in the chronically unstable knee using an expanded polytetrafluoroethylene (PTFE) prosthetic ligament. *Am. J. Sports Med.* 1987;15:326–330.

- [6]. Pasa L, Pokorný V, Adler J. Arthroscopic treatment of the unstable knee joint by ligament reconstruction using allografts. *Acta Chir. Orthop. Traumatol. Cech.* 2001;68(1):31–38.
- [7]. Schepesis AA, Greenleaf J. Prosthetic materials for anterior cruciate ligament reconstruction. *Orthop. Rev.* 1990;19(11):984–991.
- [8]. Andrish JT, Woods LD. Dacron augmentation in anterior cruciate ligament reconstruction in dogs. *Clin. Orthop.* 1984;183:298–302.
- [9]. Hench LL. Biomaterials. *Sci.* 1980;208(4446):826–831.
- [10]. Fisher J, Dowson D. Tribology of total artificial joints. *Proc. Inst. Mech. Eng. H.* 1991;205(2):73–79.
- [11]. Sutula LC, Collier JP, Saum KA, et al. The Otto Aufranc Award. Impact of gamma sterilization on clinical performance of polyethylene in the hip. *Clin. Orthop. Relat. Res.* 1995;3(19):28–40.
- [12]. Swanson AB. Silicone rubber implants for replacement of arthritic or destroyed joints in hand. *Surg. Clin. North Am.* 1968;48(5):1113–1127.
- [13]. Blair WF, Shurr DG, Buckwalter JA. Metacarpophalangeal joint implant arthroplasty with a silastic spacer. *J. Bone Joint Surg. Am.* 1984;66(3):365–370.
- [14]. Bass RL, Stern PJ, Nairus JG. High implant fracture incidence with sutter silicone metacarpophalangeal joint arthroplasty. *J. Hand Surg. Am.* 1996;21(5):813–818.
- [15]. Hirakawa K, Bauer TW, Culver JE, et al. Isolation and quantitation of debris particles around failed silicone orthopaedic implants. *J. Hand Surg. Am.* 1996;21(5):819–827.
- [16]. Adams D, Williams DF, Hill J. Carbon fiber reinforced carbon as a potential implant material. *J. Biomed. Mater. Res.* 1978;12(1):35–42.
- [17]. Podoshin L, Nodar RH, Hughes GB, et al. Long-term histologic study of a new carbon–carbon ossicular replacement prosthesis. *Am. J. Otol.* 1988;9(5):366–375.
- [18]. Olson EJ, Kang JD, Fu FH, et al. The biochemical and histological effects of artificial ligament wear particles: in vitro and in vivo studies. *Am. J. Sports Med.* 1988;16(6):558–570.
- [19]. Shiratsuchi A, Kaido M, Takizawa T, et al. Phosphatidylserine-mediated phagocytosis of influenza A virus-infected cells by mouse peritoneal macrophages. *J. Virol.* 2000;74(19):9240–9244.
- [20]. Greis PE, Georgescu HI, Fu FH, et al. Particle-induced synthesis of collagenase by synovial fibroblasts: an immunocytochemical study. *J. Orthop. Res.* 1994;12(2):286–293.
- [21]. Ciccone WJ, Motz C, Bentley C, et al. Bioabsorbable implants in orthopaedics: new developments and clinical applications. *J. Am. Acad. Orthop. Surg.* 2001;9(5):280–288.
- [22]. Hench LL, Polak JM. Third generation biomedical materials. *Science.* 2002;295(5557):1014–1017.