Effect of textiles structural parameters on surgical healing; a case study

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Abstract. Medical Textiles is one of the most rapidly expanding sectors in the technical textile market. The huge growth of medical textiles applications was over the last 12 years. “Biomedical Textiles” is a subcategory of medical textiles that narrows the field down to those applications that are intended for active tissue contact, tissue regeneration or surgical implantation. Since the mid-1960s, the current wave of usage is coming as a result of new fibers and new technologies for textile materials construction. “Biotextiles” term include structures composed of textile fibers designed for use in specific biological environments. Medical Textile field was utilizing different materials, textile techniques and structures to provide new medical products with high functionality in the markets. There are other processes that are associated with textiles in terms of the various treatments and finishing. The aim of this article is to draw attention to the medical field in each of Vitro and Vivo trend, and its relation with textile structural parameters, with regard to the fiber material, production techniques, and fabric structures. Also, it is focusing on some cases studies which were applied in our research which produced with different textile parameters. Finally; an overview is presented about modern and innovative applications of the medical textiles.

1. Introduction
The major challenges in the field of medical textiles are summarized in many items like understanding the relationship between the structure-property and the novel textile products, tissue engineering research, scalable and multidisciplinary cooperation [1].

The consumption of Medical Textiles worldwide was 1.5 million tons in 2000 and is growing at an annual rate of 4.6%. The field of medical textiles is not only included traditional materials, fabric structures, and manufacturing techniques but also includes all the processes that are associated with textile in terms of the various treatments, finishing and innovative new materials (see figure1) [2-4].

![Figure 1. Procedures for Access to Medical Textiles.](image-url)
Trends in world trade of medical textiles depends on many factors like; population growth rates, changes in demographics and living standards, increased awareness about the risks to health, the continuing dominance of the leading suppliers and brands, ongoing enhancement in product performance, and the increasing share of nonwovens on the medical global market in relation to traditional textile materials [5].

Medical textiles can be divided into three main groups according to the importance of their usage as follows; Higher range as extra-corporeal devices and most of the implantable materials, Middle range as non-implantable materials, sutures and artificial ligaments, and Lower range as healthcare and hygiene products and bandages [6,7].

Medical textiles must provide several requirements, which determine how the body reacts with the implants or external fabric supports. First; Biological properties like non-toxic, non-allergic, non-carcinogenic, biocompatibility, the ability of sterilization and time’s biostability or biodegradability. Second; Physical properties as good dimensional stability, flameproof, air permeability, and absorption/repellancy. Third; Mechanical properties as tensile strength, elasticity, durability, tenacity, flexibility, softness and optimum fatigue endurance. Forth; Chemical properties as material combinations, free fiber from contamination, impurities, lubricants and sizing agents, fast and non-irritant dyes, good resistance to alkalins, acids and micro-organisms. Finally; Performance properties as specific surface design, 2D and 3D-structures [6, 8-10]. These properties differ from one medical product to another according to the purpose of the use.

The textile main function is biocompatibility, which refers to the reaction of the textile with blood and tissue in the body. While the cost of raw materials, manufacturing process product end-use, and approval depends on the own regulations of each country and standards for medical textiles, all of these factors control the design of biomedical textiles [11]. Textile parameters that control biomedical textile applications are as follows [12]. First; the fibers used to create permanent and bio-absorbable textile structures for use in medical device design contain many characteristics as a denier, density, tenacity, abrasion resistance, hydraulic response, heat shrink, elongation, and many others directly affect the fiber ability to specific types of engineering processes for textile development. Second; textile engineering techniques enable device developers to benefit from each material through processes as strength, texture, flexibility, and other characteristics that create customized textile fabrics. The forms textile techniques include braiding, knitting, weaving, and nonwoven structures.

- Braiding process; produces a structure with a high strength and flexibility, but without a large surface area. Additionally to light structures those are able to expand and compress as necessary without sacrificing axial strength when bearing a constant load. There are many uses for this technique especially in vivo application like sutures, as well as supporting for the knee, shoulder, and small joint arthroscopic procedures.
- Knitted textiles; are based on a chain of organized loops hooked together using different processes such as warp or weft yarns. They have good stretching and high strength properties, due to the interstitial spaces between fibers that provide a concentration of power. Flat knitted textiles with high conformability are designed apertures to allow for cutting or other alteration without sacrificing edge integrity. The medical applications of knitted technique require a higher degree of performance and undergo more severe instances of movement and stretch to suit for containment sleeves for spinal disk repair and replacement or implants and assistance pieces for the knee, shoulder, and spine.
- Weaving; allows for a wide range of textile structures, from single plain to thicker, stronger, or shaped multidimensional weaves. Woven structures consist of longitudinal fibers held together by perpendicular cross-fibers, which allows them to provide thickness and strength without the stretch property. The high tenacity, low elongation, lightweight and stable properties are using as a support, repair, and replacement functions that must keep their original forms, such as vascular grafts, spinal restoration, and tendon repair.
- Nonwoven; designed as a felt created by a carding process and many other techniques to hold fibers together, the famous technique is needle-punched, for the production of medical textiles in nonwoven route. Three main technologies are employed namely Hydroentanglement (Spunlace process),
Spunbonding and Melt-blow process [13,14]. Nonwoven structures provide greater surface area than most other textiles techniques, as well as a unique 3D architecture. The construction of nonwovens helps to support cellular ingrowth and proliferation for repair functions with carefully designed layers of entangled fibers and extensive pore size.

Nonwovens are used extensively in the medical field because of relatively high absorption abilities and allowing sterilization of the fabric at high temperatures. Nonwoven materials with improved finishes such as liquid repellent, virus proof and bacterial resistance have been developed for applications such as surgical masks, gowns, drapes, baby diaper/adult incontinence products, wipes, bacteria–proof cloth...etc (figure2). In general, cellulosic fibers are preferred for their high strength, pliability, plastic deformation resistance and water insolubility [13,15].

**Figure 2.** Some applications of nonwoven spunlace technology.

Third; twist and Shape in order to totally take advantage of the characteristics of each manufacturing technique, structures and processes that can maximize performance to fixed specifications which contain texturing, twisting, plying, and precision cutting techniques such as a die, laser, ultrasonic, and staple cutting. Shaping is a finishing method for molding and allows for different geometries shapes such as tubes, cones, disks, and cylinders for implantation, while blending between two dissimilar materials into a single structure, lead to creating a heterogeneous material to weaving [12].

2. Materials and methods

Fibers with different materials are used in a variety of applications depending on the characteristics required, as ineffective repairs of the body like wound closure with sutures or replacements surgery.

Fibers in the medical field include natural fibers like; cotton, wool, silk ...etc, and synthetic fibers. All bioabsorbable fibers are not created equal [6]. Synthetic polymers used widely, they can be divided into permanent fibers e.g. polyamide, polyester, polyethylene, polypropylene, polytetrafluoroethylene, polyurethane and carbon fibers which is used for its strength in artificial ligaments and for its lubricity in orthopaedic cushioning and biodegradable fibers which are mainly used in sutures and tissue engineering structures e.g. polycaprolactone, polyglycolic acid and polylactic acid. As well natural biological fibers like chitin, collagen and alginate fibers [2,11].

Different methods are used to evaluate medical textile product suitability for the application. These methods include many properties that must be present according to the characteristics of textile, yarn and fibers like; analysis of fiber components, tenacity, softness, tensile strength, elongation, absorption, dimensional stability, stiffness, abrasion resistance, antistatic resistance, crease recovery, air permeability, weight and thickness of fabric, porosity, bursting resistance, antimicrobial resistance and materials components analysis in case of whether the product is subject to treatments or finishing before it is set to the final use. Additionally; the biological analysis were applied as clinical examination, x-ray, sonar, blood analysis, immune analysis and histopathological changes.

Currently, researchers are conducting to know the compatible extent between new materials and different tissues organs in the body live. This is through the planting of different materials with stem cells, the follow-up to the changes that occur, and analyzing these changes. This enhances the field of application of new materials outside the human body (Vitro tissue engineering), whether as an alternative to the application on animals or the next stage of the animal experimental to make sure the suitability with the human body. It is considered one of the phases, which passes by the application or medical product before its adoption and set it in the medical market.
3. Results and discussions

3.1. First case based on nonwoven technique.
This study performed by A. Abou-Okeil et al. It had investigated of wound dressing based on nonwoven viscose fabrics for raising the healing of tissue [16].

Three types of the nonwoven web were produced with a random distribution of fibers. These webs differ among themselves according to the blend ratios between materials and weights as (100% Viscose with weight 45 g/m², 30% Viscose: 70% polyester with weight 30 g/m², and 70% Viscose:30% polyester with weight 45 g/m²). The three types of webs are treated with a chitosan solution ranging (0.2 - 0.8%), adding polyvinyl alcohol solution ranging between (2-14 ml), then the webs were sunken in 30 ml of silver micro granules solution, finally were disposed of extra solution and dried [17]. Small rabbits are used for applying the experimental surgical and divided them into three groups according to the factors in the study (figure 3); the first group had used three fabrics without treatment, the second group had used three fabrics treated using chitosan/polyurethane vinyl alcohol, the third group had used three fabrics treated using chitosan solution/polyvinyl alcohol with silver nanoparticles.

The results that pointed to the 100% viscose sample without treatment achieved the best consequences of healing cells, and the body absorbed it completely. Whereas, the best sample after complete treatment was (30% Viscose:70% polyester) after 21 days from the experimental work [16].

3.2. Second case based on woven technique.
This study about woven technique performed by Inas N. El-Husseiny et al. It had investigated of surgical management of patellar ligament rupture in dogs using a prosthetic woven fabric [18].

A woven fabric produced using a blend of two biomaterials, polyamide 6.6 for weft yarns and polyester for warp yarns (50:50) %, with plain structure 1/1. Were used monofilament microfibers for each of the warp and weft yarns, the yarn count for each material is 40 dtex. All samples were used raw without treatment. Twelve skeletally mature mongrel dogs with no evidence of clinical signs of lameness were used in the study. Surgical intervention was performed by primary suturing of the severed patellar ligament ends by diameter 3mm, and applying a synthetic fabric to act as a supportive internal splint. Satisfactory results were obtained concerning the tendon healing and the return to limb normal function without complications (figures 4&5). Continued subsistence from three to six months, then the death by using merciful dies, in order to carry out biological analysis [18].

![Figure 3. Wound healing stages during 21 days.](image)

![Figure 4. (A) The application of the twisted synthetic fabric, (B) The lateral view of the stifle.](image)

![Figure 5. (A) An experimental case just surgery, (B) after 180 day’s post operation.](image)
3.3. Third case based on woven technique.
Another study about woven technique performed by Marwa A. Ali et al. It had investigated of grafting prop for the stomach and duodenum wall with woven fabrics from different materials and structures [19,20].

Twelve woven samples were produced and weaved with plain 1\1, basket and leno structures. They were divided into two categories according to raw materials type; first carbon and glass fiber materials as a synthetic category, and second cotton and flax fibers as a natural category [19, 20]. Sterilization for the samples was done by autoclave, and then treated with 2% glutaraldehyde solution as sterilization immediately before surgery [21]. The surgical experiments were carried out to support stomach and duodenum in different places as (A) subserosa, (B) all through the gastric wall and (C) ball through the duodenum wall (figure 6). As a medication for some of the problems that afflict the stomach and duodenum, which require a surgical intervention as chronic erosive gastric, chronic gastric ulcer, chronic stress erosion, persons are infected with Zollinger-Ellison syndrome and perforation in the stomach wall [22]. The experimental study was applied on male dogs, and continued of subsistence 21 days for experimental animals with notation of clinical observation daily, after the merciful death of animals was performed biological analysis like X-ray, Blood analysis and Histopathological changes [19, 20]. The results showed the samples produced from carbon fibers achieved the high significant healing cells; especially the samples formed using plain 1/1 and leno structures(figures 7) [19]. The cotton sample with leno structure achieved the best result comparing with flax samples, whereas the flax samples contains another component such as oil, ash, grease and pectin (figures 8&9) [20].

![Figure 6. Transplantation places of woven fabric on the stomach and duodenum wall.](image)

![Figure 7. Healing tissue (A) carbon fibers, (B) glass fibers with different structures.](image)

![Figure 8. (A) External healing, (B) Internal healing of cotton.](image)

![Figure 9. (A) Stomach with plain 1\1 structure weaved with cotton, (B) Duodenum with leno structure; (a) shows the normal gastric mucosa.](image)

4. Recent Medical Applications
There are many recent applications in the field of surgical healing. These applications include new products that are used in the body reinforcements and supporting for critical external wounds.

4.1. Absorbable Bidirectional Barbed Suture
This type of suture appeared in 1992, it was made of Polydioxanone and doesn’t need to be removed and doesn’t require knots to make it suture. So it can be used in cosmetics surgery, dermal tissue approximation, internal wound closure, and tendon repair (figure10). The specification of the
absorbable Bidirectional barbed suture are the diameter of (0.30 - 0.39mm), containing up to 78 barbs manufactured around the circumference and two sets of barbs in two sections, right and left [23].

Figure 10. (A) Barbed polydioxanone suture. (B) Bi-directional barbed.

Figure 11. Artificial limbs.

Figure 12. (A) Artificial heart valves, (B) Artificial blood vessels.

4.2. Supplementary Devices or Prosthetic

Artificial Limbs that prostheses are intended to restore a degree of normal function to amputees. It was used modern plastics such as polyethylene, polypropylene, acrylics, polyurethane, polyester, epoxy matrices with glass fiber and carbon fiber as composites. With better pigments, they are responsible for creating a realistic-looking skin. It became the most important characteristics that must be achieved as strong, lightweight and realistic (figure 11) [24]. Recently; using electrical signals from the patient's muscles and amplifies the nerve signal to move the limb with only their thoughts [25-27].

4.3. Heart Surgical

Artificial Heart Valves that it is manufactured from high molecular weight polyethylene or 100% polyester produced by weft knitting with a metallic housing material (figure 12A). This product used to transcatheter Aortic Valve Replacement or transcatheter Aortic Valve Implantation surgery [5,28]. And Vascular Graft (blood vessels) that it is used to replace segments of the natural cardiovascular system that are blocked or weakened, the replace damaged thick either arteries or veins to be 6mm, 8mm or 1cm diameter (figure 12B). Straight or branched grafts produced by using either the weft or warp knitting technology with porous structure [28]. In 2010; Produced filaments thinner than a human hair and four times stronger than polyester for use in next-generation of vascular devices.

4.4. Ligaments and tendons Repair

Artificial ligaments that are made from the multilayered or tubular shape and it made from carbon fiber and polyester. The ligament is produced with woven or knitted performs. Tendons are made from man-made fibers of woven or braided porous structures and coated with silicon [1].

5. Conclusion

We will illustrate the most important points that are regarding the healing cell, when using different textile parameters; Small circular fibers are a better supports for living tissue than larger irregular cross sections fibers. The yarns produced from multifilament with high twists are better than the yarns with few twists. The regular and balance woven structures of fabrics leads to increasing of the proliferation of tissue. Low thickness and weights of textile samples gave good results for implementable surgical application and external support application. Porosity is a very important property that determines the rate of healing tissue. An application of medical textile and comfortably of the body with different fabric materials should be taken into consideration that the performance physiology of this organ’s reduced without any complications or effect on the function performance. There are many applications still in the experimentation stage for preparation to be appeared and used in the global market such as fabrics used in limitation of myocardial hypertrophy, pillars of fabrics to use in the pharynx, esophagus, smart fabrics in the devices field of hearing, producing synthetic spider silk, use spider silk to action the growth of skin cells...etc.
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