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Review Article

Exploring the Potentiality of Knits for Newer Areas of Medical Applications -

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ABSTRACT

Knits play a crucial role in the area of medical applications as recent research show. Knitted meshes have been developed from synthetic and natural materials. When used singly, they can patch soft tissues, and when used in combination, they can replace or repair damaged tissues or organs, and thereby hold promise in tissue engineering and regenerative medicine. A knit garment has been designed through integration of the knitwear technique, garment design skill, chinese acupuncture therapeutic method and Transcutaneous Electrical Nerve Stimulation(TENS) technology and has been found to be more effective than garments already incorporating TENS device in the management of body pains. Cardiac stents made of knitted and braided textile material have been developed recently. The knitted stent was found to be superior in mechanical properties and was able to fulfil the requirements better than that of metallic ones owing to better flexibility. Knits made from poly lactic acid filaments have been evaluated for suitability in urinary bladder reconstruction. Warp knit spacer fabrics have been used effectively in atrial mitral valve therapy by means of suture less technique. Weft knits from polydioxanone have been used as stents in treating intestinal stenosis as well. Shape memory weft knit single jersey structure has been developed as shape memory fabric and holds promise in the biomedical areas such as artificial tendons, artificial corneas, hernia repair, artificial bone joints, orthodontics, scaffold material and wound dressing. Knitted compression garments have proved effective in the treatment of burns and lowering of blood pressure etc.

Keywords: Knits; Medical applications; Stents; Scaffolds; Pressure garments; Shape memory

INTRODUCTION

The role of knits has been well explored in the area of medical textiles. A knitted mesh possesses highly ordered loop structures and versatile mechanical properties that can provide sufficient internal connective space for tissue growth [1]. Knits have the potential to provide tissue engineering with many kinds of knitted meshes or to participate in the construction of tissue-engineered scaffolds. TENS therapy has been used in the treatment of different types of pains, diseases and disorders of the body [2]. Commercially available TENS products help to reduce skin resistance but suffer setbacks such as the inability to target back of the body, discomfort due to stickiness, unlaunderability which prove unhygienic by over repeated use. Stents are found to be useful in the treatment of arterial diseases [3]. An important consideration in the design of stent is radial force which is resistant to collapsing during expansion. Studies on tensile tests for the knitted fabrics have also shown that the structures produced with the thicker yarn have a greater stiffness and biocompatibility. The stent performance of braided structure has been found to be better than the knitted one. Scaffold is a 3D space for new tissue formation with suitable structures which also help in the development of new tissues with specific functions [4]. A scaffold material intended for human urinary bladder should possess elasticity, porosity, drapability and good mechanical properties. The knitted scaffold developed from polylactic acid fulfils these requirements which are also biodegradable [5]. In the interventional mitral heart valve therapies, the placement of a biological valve which anchors the heart valve poses practical problems. In order to deal with this problem, a hollow body has been evolved and equipped with a heart valve that completely utilizes surrounding structures inside the heart to anchor or to permit an additional valve to cure the underlying disease. In the design of the new hollow body, nitinol material has been used as a skeleton and polyvinylidene chloride material has been warp knit as prosthesis [6]. Though metal stents have been used in the treatment of the obstruction and stenosis of bowel and vessels over many years, biodegradable stents have proved advantageous since they could avoid serious long term complications and need not be removed, and thus avoid subsequent surgeries and potential morbidity [7]. Polydiaxanone weft knit stents are found to be more advantageous compared to other polymers with regard to flexibility, elasticity, appropriate absorption rate, suitable biocompatibility and minimal inflammatory response [8-10]. Shape memory polymers can abruptly change their shapes in defined ways under the influence of heat, electricity, light, pH, ionic strength and magnetic field. Dimethyl formamide used in synthesis of polyurethane has been weft knit and the resulting shape memory fabric has been evaluated for biomedical applications [11]. Compression garments as one type of special wearing morphology have been widely used in medical and sports fields to accommodate certain physical or physiological demands through the provision of engineering designed support and pressure and tactile characteristics to targeted areas of the human body [12-14]. Compression stockings are one type of typical compression garment which have been established as a cornerstone mechanical method in the prophylaxis and therapeutic management of varicose veins, venous thrombosis and lymphoedema [15-17]. Inlay yarn and laid-in stitches are the key knitting elements in the fabrication of compression textiles which play a critically important role in managing and controlling pressure magnitudes and influencing fabric durability, flexibility, wearing comfort and expected bio functional effectiveness in practice.

Knits in tissue engineering and regenerative medicine

Knitted meshes for long have been used to surgically reinforce weak tissues in cases like hernia [18]. The biomaterials used in the knitted mesh have earlier been considered to be inert. Eventually their biocompatibility and tissue inducing regeneration properties have been considered to be important [19]. The cell behaviour and scaffold bioactivity are considerably influenced by mechanical properties of scaffolds [20]. Hence, improvement of mechanical properties is of laboratory interest and offers a challenge in clinical practice. In the area of technical textiles, knits with special structures and mechanical properties play a crucial role. In the case of tissue engineering and regenerative medicine knitted meshes that are designed in warp or weft way or both offer good prospects. A knitted mesh serves as a basis for improving the mechanical strength of scaffolds and as the skeleton of grafts to maintain a porous microstructure, promote cell alignment and induce tissue regeneration. Knitted mesh have been used in different applications of tissue engineering like repair of ligaments, tendons, cartilages, skin and pipe like organs. A number of these applications are still under study. The problems related to knitted meshes and knit mesh scaffolds need further study. Despite knitted meshes having relatively homogenous structures, versatile properties, and controllable biological properties, an ideal knitted mesh for tissue regeneration is yet to be developed [21]. A knitted mesh has variable parameters such as knitting materials, knitting techniques and fabric characteristics. A good deal of research related to knit mesh application in tissue engineering is required to optimize biomaterials for knitting, evolve suitable knitting techniques to prepare biomimetic meshes for specific tissues/organs, match the rates of tissue degradation and neo tissue formation. Despite the fact that a number of knitted structures are commercially available, the knit structures suitable for tissue engineering are in the inceptional stage of development. This could possibly be attributed to the knit structures being chosen to achieve improved functioning in place of their appearance. Knitted mesh scaffolds designed specifically to match the mechanical properties of native tissue or cells give proper mechanical cues, prove very helpful for investigating the roles of mechanical properties in tissue generation. A number of biomaterials like silk, polylactide-co-glycolide, PLACL have been knitted into fabrics with different biophysical properties [22]. The question arises relating to understanding the effects and mechanisms of knitted mesh scaffolds on cell activity and tissue regeneration. This could possibly be answered in the following ways a) Knitted meshes with outstanding mechanical properties alter the tension distribution and pressure on knit mesh scaffolds and further maintain the 3D porous structures *In vitro* and *In vivo*. b) The diffusion of nutrients and the waste products elimination are enabled by well maintained porous structures which facilitate adequate space for cell migration and vascular in growth. c) As the adherence of cells around pores have specific surface areas, the mechanical properties can influence the surface areas by maintaining porous structures which can regulate cell behaviours and tissue formation. As the 3D scaffold microstructure has a crucial function in the cell activity regulation and tissue regeneration, there may be a good relationship between the 3D microstructure and the mechanical properties of scaffolds during the event of scaffold induced regeneration. Also there is a need to establish criteria for knitted meshes for evaluation of their use in tissue engineering and routine clinical practice. From the theoretical point of view knitted mesh can be designed and fabricated into different required shapes so as to match the particular tissues/organs [22]. A number of techniques have been evolved to integrate a mesh into a scaffold. The most important of these are one step molding and assembly. It involves simultaneous incorporation of the knitted mesh and knitted mesh scaffolds. A very common technique of making these scaffolds is called lyophilisation. It is possible to control the quantity, shape and position of the mesh in the knitted mesh scaffold as required. The thickness of the knitted mesh scaffold can be adjusted suitably. The influence of PLGA mesh/collagen mesh hybrid scaffolds on cartilage regeneration has been systematically studied [22]. Lyophilisation has been adopted to design three types of hybrid scaffolds- thin, semi and sandwich scaffolds which varied depending on the position of the PLGA knitted mesh. On the other hand, many innovative practical scaffolds have been evolved for ligament tissue engineering by forming a collagen microstructure in the pores of a silk based knitted mesh using a freeze drying process [23]. Another technique adopted is in the preparation of a composite vascular graft reinforced by a tubular weft knitted fabric. Subsequently the fabrication of the knit mesh scaffold is completed by assembling many units along with the cell elements having an auxillary part as the knitted mesh. A quicker and simpler method has been adopted for making a multilayered scaffold through compression of a hyper hydrated collagen gel onto a flat warp knitted poly (lactic acid-co-caprolactone) mesh [24]. An assembly technique has been evolved in the preparation of bilayer skin equivalents by first peeling off fibroblast sheets and folding them over a PLGA knitted mesh to form a 3D dermal matrix and implanting keratinocytes to form a skin substitute in the air-liquid culture. Attempts have been made to fabricate more complex scaffolds by combining one step molding and assembly. PLGA mesh/collagen hybrid scaffolds, tube stents, and basic fibroblast growth factor impregnated gelatin hydrogel sheets have been used to repair tracheal defects. Though the scaffold combining basic fibroblast growth factor and reinforcement induced incomplete regeneration of tracheal cartilage, it represented an improved method for fabricating better scaffolds. In scaffold construction, the required mechanical support has been an important consideration. In order to improve the mechanical performance of scaffolds, different techniques have been evolved by using naturally derived materials. The mechanical strength is required to sustain adequate spaces for cell in growth and functionalization *In vitro* and temporarily withstand *In vivo* stresses and loading. Mechanical strength alone does not appear to contribute to scaffolds but is conjunct with properties like porous structures [25]. Different fabrication methods have been evolved in designing various scaffolds characterized by porous structures, good biocompatibility and outstanding mechanical properties. Some instances include introduction of poly (glycolic acid) fibre into collagen sponge, combination of collagen with poly (L-lactic acid) braid, incorporation of collagen micro sponges into the pores of synthetic polymer sponges or the interstices of knitted meshes and so on [26]. The synthetic polymer sponge, braid, fibres and knitted meshes act as skeleton to reinforce the entire scaffolds, while the collagen or silk sponges provide the scaffolds with porous structures. But porous synthetic materials intended for engineering applications can exhibit outstanding elasticity but low shear resistance to shearing. Twisted or braided scaffolds may have very good mechanical properties that are comparable to native tissue, but their limited internal space often hinders the in growth of neotissue. Fiber formed scaffolds provide a larger surface for cell attachment and a rapid diffusion of nutrients, but have structural instability. On the contrary, a knitted mesh is ordered and has stable loop structures and internal connective spaces. Alteration of the geometrical fabric factors such as yarn spacing, thickness and fiber material which enable the attainment of the desired mechanical properties [27]. In the fabrication of knitted mesh scaffolds synthetic/biological meshes have been used [28]. Weft knitted structures though inelastic have loops across the fabric width possessed a great degree of compression and support. On the contrary, warp-knitted meshes show better flexibility and elasticity owing to loop formation along the fabric length [29]. Knitted meshes incorporated into porous scaffolds can serve as a support structure to reinforce combined or hybrid scaffolds and provide mechanical support to resist a physical load. Incorporation of a polymer matrix in a knitted mesh bonds together the filaments can influence the mechanical properties. Despite a knitted mesh being able to promote homogenous cell distribution and tissue formation has been rarely reported as a scaffold, it has occasionally been considered as a control. It has been used as an auxiliary tool in the construction of scaffolds for tissue engineering. Knitted mesh scaffolds find the following clinical applications:

- Patches for soft tissues
- Ligaments and tendons
- Cartilage - Skin - Blood vessels

Multivaried knitted structures can be produced to suit varied requirements. The weft-knit structures distort and stretch more easily whereas the warp-knit ones are more stable and less formable. Generally, the weft-knit structures include three primary classifications: jersey structure and its derivatives, rib fabric and its derivatives, and purl fabric and its derivatives and the entire fabric can be fabricated from one yarn. In contrast, in warp knitting, one yarn is required for each wale. A typical piece of a knitted mesh may incorporate hundreds of wales. Therefore, the production rate of warp knitting is significantly higher than that of weft knitting, and warp knitting is more suitable for large-scale production. To obtain particular macroscopic properties and more complicated fabrics, float and tuck stitches are often used to modify the structure of the knitted fabric. Nowadays, knitting has reached a high level of mechanical automation which has been well documented. Warp knitting is performed by Tricot or Raschel knitting machines, and weft knitting may be finished by circular and flat-bed knitting machines. Different types of synthetic knitted meshes made from propylene, poly (ethyleneterephthalate) and polylactic acid have been used for hernia treatment, pelvic organ prolapsed, pelvic floor dysfunctions, body wall defects etc. The different materials used in the knitted mesh should be able to resist erosion defect recurrence besides good mechanical properties in such applications [30]. Such materials are generally inert and exhibit slow degradation and the implanted meshes are replaced gradually by newly formed or surrounding tissues. But they are known to create many problems [31]. The ligaments and tendons when damaged cannot regenerate and heal which results in fibrotic scars. The advances in tissue engineering and regenerative medicine gives hope in the treatment of ligament and tendon injuries. Among the available biomaterial grafts designed as ligament and tendon scaffolds, knitted scaffolds possess mechanical properties identical to the biological tissues and hence hold good promise in the reconstruction of ligament and tendon. An innovative ligament scaffold has been developed comprising of a plain knitted silk structure and a collagen matrix [32]. A combined scaffold with web like microporous silk sponges formed in the openings of a knitted silk mesh has been designed and then seeded with mesenchymal stem cells derived from adult human bone marrow for *In vitro* ligament tissue engineering. The combined scaffold promotes greater cell activity in comparison with a simple knit scaffold. A knitted PLGA scaffold has been used to repair tendon in a rabbit. The tendon defects healed better with the knitted mesh induced tendon regeneration loaded with bone marrow stromal cells. With regard to cartilage tissue engineering, there is a basic need to develop a suitable scaffold that gives adequate structural support to withstand the large forces applied to the new tissue. Knitted PLGA mesh/collagen hybrid scaffolds have been used in a number of *In vitro* and *In vivo* investigations for cartilage reconstruction [33]. The hybrid scaffolds utilizing both the natural and synthetic scaffolds have been prepared by integrating the collagen sponges with the knitted PLGA mesh with adjustable thickness. The polymer mesh has facilitated cell seeding and cell distribution. Such investigations showed that the PLGA mesh/collagen scaffolds improved chondrocyte adhesion, proliferation, enabled the redifferentiation of the dedifferentiated multiplied chondrocytes and promoted chondrogenicmesenchymal stem cells. The tissue so engineered adopting this method matched the native cartilage both histologically and mechanically. In order to act as a substrate for epidermalization and enable tissue regeneration, collagen based sponges have been evolved [34]. Even though the collagen based scaffolds provide support they possess low mechanical strength. Hence there is a need to improve the mechanical properties in such scaffolds to induce skin tissue regeneration and decrease wound contraction. An innovative porous scaffold has been evolved by hybridising a knitted PLGA mesh and naturally derived bovine collagen. The hybrid scaffold exhibited good biocompatibility and high mechanical properties. Neonatal fibroblasts have been spatially distributed in a PLACL mesh/collagen gel composite which duplicated interstitial or epithelial tissue and showed homogenous cell distribution and good biocompatibility which exhibited no macroscopic signs of contraction. A hybrid matrix has been evolved through lyophilising collagen within a weft knitted PLGA mesh. It simulated the mechanical properties of native dermis, supported cell attachment and profileration *In vitro* and evoked minimal host tissue response *In vivo*. A PLGA mesh has been incorporated into a collagen-chitosan sponge to construct a hybrid scaffold. It had little effect on the microstructure of the collagen-chitosan sponge, but improved the mechanical strength of the hybrid scaffold similar to the native dermis. A greater extent of tissue formation has been seen near to the mesh side than the collagen-chitosan sponge side. Although it is difficult to develop an ideal substitute for blood vessels, incorporation of a weft knitted fabric into a polyurethane vascular graft can improve elasticity and strength [35] of the available polymeric materials that provide required mechanical properties for vascular scaffolds, the knitted mesh holds promise for use in routine clinical practice [36]. A tissue engineered patch has been developed comprising of collagen microsponges, an interior layer of PGA knitted mesh and an exterior layer of woven PLA fibres for reconstructing vascular walls. Animal trials have revealed that the patch enabled *In situ* in venous or arterial walls without complications, and also the architecture of the neotissue was similar to that of the native tissue within 6 months of implantation. A knitted mesh also finds other applications such as scaffolds for the bladder, ureter, hernia, trachea and oesophagus [37].

Knit garment for nerve stimulation

The electrical stimulation is beneficial for treating different physical disorders that cause pain in the body and is applied on the affected areas. It is even more useful to stimulate the nervous system. The TENS (Transcutaneous Electrical Nerve Stimulation) treatment is applied to the affected part of the body where the associated nerves are stimulated by electrical current by means of conductive silica gel hydropads [38]. The existing TENS products made of conductive silica gel hydro material helps in decreasing the resistance of the skin but are normally available in two to four pieces and do not readily target the back of the body. Also their stickiness causes discomfort and they are unlaunderable, and also prove unhygenic over repeated use. With the progress in technology, intelligent garments are an important innovation in the textile industry particularly in the area of intelligent medical and athletic textiles [48]. TENS is applicable in different painful body conditions. The effectiveness of TENS on different body conditions has been proved by a number of investigations provided it is used continually and properly. It stimulates the large afferent fibers which may reduce the transmission of pain signals through the small receptive afferent fibers, consequently inhibiting pain discrimination and perception [39]. Subsequent investigations have shown that treatment with TENS and acupuncture yielded better results [40]. The commercially available electrodes have properties that render them unsuitable for the use in intelligent garment. In the case of smart clothing, fabric electrodes have been used commonly needing a good contact to skin like acquiring breath, temperature and electrocardiogram signal. The increase in contact area and pressure is an easy method to achieve good contact. But, the bulky electrode has less flexibility and high contact pressure can create discomfort. Hence, water filler is more frequently used to increase the moisture and conductivity of skin which compromises with convenience.

A wearable TENS garment has been developed and incorporates Chinese acupuncture therapy for long term continuous treatment and establish an innovative treatment technique for healthcare [41]. Knitting yarn comprising of 100% pearl fiber and silver coated yarn having electrical resistance have been used, and flat knitting has been adopted using intarsia stitches. 2x1 rib knitting stitch has been used in the fabric. The knitting yarn was made with 100% pearl fiber of 40 S/2 Nm and the conductive yarn was made with silver-coated yarn of 40 S/2 Nm with electrical resistance of 1.58 Ω/cm. This knitwear was knitted on a 14 G flat knitting machine comprising mainly of intarsia stitches and the wale and course densities were 9.3 and 6.9 unit loops per 10 mm respectively. The garment has not been washed or ironed before testing. Four types of washable electrodes have been designed in comparison with original electrodes. A metal button has been fixed at the electrode of this textile material which could be buttoned with the knitwear. The tests on the four newly designed electrodes show that the electrodes made of conductive fabric generally demonstrate satisfactory performances as compared to the metallic ones.

The newly developed TENS knitwear has been assessed for repeated use, wash ability and conductivity. Testing of the 4 newly developed electrodes revealed that the electrodes made of conductive fabric exhibited satisfactory performance over their metallic counterparts. The electrodes with adhesives got hardened and tended to create skin irritation. The second electrodes wrapped in conductive mesh fabric could not retain water well as water evaporated through the mesh. The third and fourth electrodes have been found to suit well as textile electrodes for the garment owing to their water sustainability [41]. As the fourth one had better skin contact, it has been selected for the study. The chosen electrode has an effective resistance more than half that of the original electrode for fabric. The conductive fabric of the electrode and the conductive stitch indicated minor changes in electrical resistance after 10 washes. Such sensitive changes are insignificant to the overall resistance of the textile electrode which are negligible compared to the overall resistance of the textile electrode. The proposed electrode had good wash ability and it was also able to retain medicine inside for treatment. It can be used in smart clothing for long functional duration in clinical application. It did not demand skill but user friendly and easy to focus on specific area of the body. Practically the electrode could be rendered slender without affecting its properties. Comparisons have been made with regard to the waveforms of the original and proposed electrodes. The original and proposed electrode had almost the same output without the phase distortion. Most of the applied TENS signal was dropped across the electrode rather than the conductive yarn. Hence the focused areas of the body received were able to successfully receive most of the power. As the electrical properties of the proposed and the original electrodes are identical, the proposed electrode holds a good promise as a textile electrode for future TENS intelligent knitwear. The electrodes size and the wiring routing in the fabric decide the number of textile electrodes. With the increase in the number of electrode pairs, the total equivalent resistance reduces and higher current is drawn for the same supply voltage. The lower the resistance of the conductive yarn and textile electrode, the higher the available power delivered to the treatment region by an electrode pair. For the same skin resistance, the proposed electrodes gave higher power efficiency than the original electrodes. There have been problems for wearer's acceptance of the wearable technology. The TENS wearable garments could be technical products rather than fashionable ones [41]. The experimental results show that the knitwear can satisfy the basic functions. The garment design skills when adopted can easily overcome this problem and enhance the aesthetics by concealing the conductive yarn through the use of intarsia knit pattern. The future technology of the TENS knitwear targets on specific treatment of group points including neck pain, shoulder pain, low back pain and so on. The treatment points can be controlled individually or in groups by textile switches based on the theory of acupuncture point for treating pains on the different areas of the body.

Knits for cardiac stents

Stents have also been utilized in the treatment of coronary arterial diseases. A catheter can be used to implant the stents to compress the plaque and open the artery lumen for effective blood flow. The stent needs to be flexible as to enable it to be carried to the place in the artery the injury is located [42]. The stent should keep the artery open by allowing flow of blood and it should also be elastic so that it may accompany contraction and expansion of the arteries during normal heart functioning. The radial expansion force is the resistance of the stent to collapsing during expansion. This is a determining factor of the capacity of the stent to keep the adequate artery geometry for the blood to flow. The structural design and the type of material determine the radial elasticity and the flexibility of the stent. Another important aspect of the stent is its fluoroscopic visibility, which enables its exact detection in the affected area of the artery. This is related to the material used to make the stent to its dimensions. Stainless steel has a low fluoroscopic visibility, while tantalum has a good fluoroscopic visibility owing to its radio opacity. If the stent is too small, its fluoroscopic ability is also poor. Yet another aspect to be considered is that the stent should be able to be sterilized so as to avoid being contaminated by bacteria. A textile stent should necessarily have lengthwise flexibility, high radial expansion force, and high elastic recovery after radial expansion, resistance to corrosion, good fluoroscopic visibility and high biocompatibility. The important criteria that decides the effective use of a stent is biocompatibility [43]. The performance of a stent will depend on its interaction with human cells and fluids. Recent developments have focused on developing a stent that minimizes the occurrence of restenosis (blocking of artery). The problem is common with metallic stents and could be improved by applying textile materials over the metallic stent or by the application of special substances over the metallic structure. Polyester is generally used in covering metallic stents. In other cases, the metallic stent is impregnated with anti blood clotting substances. By covering metallic stents with textile fibres the restenosis occurrence can be reduced and it has led to the development of 100% textile stent, as pointed out by researchers. Modern day stents are textile materials that could be designed with improved properties over the metallic ones. Both knitted and braided textile stents could be easily compressed, resulting in blocking of artery and thus lead to heart attack or other problems such as stent migration etc [44]. The flexibility of a stent is one of the most important characteristics, as without this property it may not be possible to reach the harmed part of the artery. However, to obtain the ideal flexibility of the stent, the radial compression force may be compromised. The latter property refers to the resistance to collapse when the stent expands and the stents capability to maintain the lumen geometry. Another critical property of the stent is its biocompatibility which has to be very high to minimize the risk of thrombosis or a neointimal proliferative response. Recent studies have focused on the development of 100% textile stents to replace commercially available metal or hybrid materials [45]. Because of its economical cost and compatibility in physical properties, polypropylene fiber is found to be suitable. It is versatile, effective, readily available and cheap. The use of monofilament will enable greater stiffness and better results when the stent is subjected to compression, tensile and bending forces as these will be directly borne by the yarn. In the case of braided and knitted fabrics, investigations on the radial compression tests have shown that the best results have been achieved for the braided fabrics with a marginal increase of heat set at 140°C. The increase in the fabric cover causes the resilience of the structures to increase. Bending tests carried out for both knitted and braided samples for bending angle of 90° have shown that the best results have been obtained for the braided fabrics with the effect of the heat setting temperature showing small and unclear differences [46]. As the fabric cover increases, the resilience also increases. The structures produced from thicker yarn exhibit higher stiffness, as indicated by investigations on tensile tests for the knitted fabrics. For the same yarn diameter, the shorter loop length resulted in the stiffer structure. The braided structure with the thicker yarn has a greater stiffness. For the same yarn diameter, the higher the braid angle the stiffer is the structure. The braided structures were considerably stiffer than the knitted structures and therefore it performed better. The braided structures exhibited superior mechanical properties, or higher stiffness in comparison with the knitted ones which could be attributed to their structure being made up of straight yarns rather than loops. Since more fibres/unit area is available to resist the loads, the tightness of the construction increased the stiffness in all cases. The fabric thickness (stent wall) is found to increase with the increase in yarn diameter which could explain the increase in the stiffness of the stents with yarn diameter due to an increase in the thickness of the stent wall.

Knits for urinary bladder reconstruction

During the recent years, biomaterials have been explored for specific applications such as tissue engineering which is concerned with evolving biological substitutes that could assist in tissue functioning [47]. Scaffolds which have been developed not only provide space for the growth of tissues but also enable new tissues to grow with specific functions [48]. A number of polymeric materials have been used for scaffolds. The tailoring of scaffold is usually not generic but it is always application specific [49]. The production of scaffolds involves consideration of a number of parameters [50]. The most common methods of producing scaffolds include phase seperation, particulate leaching, freeze drying, composite foam preparation and other techniques [51]. Each technique has its own merits and demerits. Hence, scaffolds are designed in accordance to the areas of application. Ideally, the scaffold material suitable for urinary bladder should have porosity, elasticity, drapeability and good mechanical characteristics. Earlier, bioreceptive PET films have been used as scaffolds [52]. Bioreceptive PET knits have been developed for urinary bladder construction which was however non biodegradable. A biodegradable knitted scaffold has been produced for urinary bladder reconstruction, using polylactic acid [53]. The PLA fiber has been produced by adopting the dry jet wet spinning technique. The spinning solution of PLA has been prepared by dissolving it in chloroform. The two stage hot drawing of spun PLA monofilament has been carried out to develop the PLA filament with the desired properties. The flexural rigidity of the PLA filament has been determined by ring loop method. The 2, 4 and 8 ply PLA yarns have been prepared by doubling process prior to knitting. The knitting has been carried out on single end weft knitting machine of the diameter 3.5 inch and gauge 14 needles/inch. The knitted fabric so produced has been investigated for mechanical properties and porosity. This has opened up new possibilities in the field of development of textile structures in tissue engineering. These materials perform the function of the scaffold which guides the cells for their harvesting into a tissue leading to the subsequent human organ reconstruction. Textile knits could be designed with different porosities and mechanical strength as well as elasticity which would be useful for the urinary bladder repair. The area is wide open with enormous possibilities in the field of bio textiles toward textile designing with required chemical features. The flexural rigidity of the filament influences its bending properties which is a requisite in knitting. It therefore affects the loop size, loop formation and the knit fabric behaviour [54]. It is observed that the flexural rigidity decreases with the increase in draw ratio. The flexural rigidity decreases with increase in draw ratio owing to thinning of the filament. This affects the bending behaviour of the filament which could influence its knit ability. Ply yarns with two, four and eight plies have been used to produce knitted structures with PLA yarns with uniform loop size. Investigations on in vitro and mechanical properties have been conducted for the three structures [68]. The behaviour of the knitted fabric under pressure has been tested adopting the ball bursting technique which almost simulates the behaviour of the urinary bladder in the urine filling process. The stress value obtained by the bursting test for knitted fabric is considerably higher than the required value. The extension of the knitted fabric is also found to be high. The maximum load to burst the fabric is influenced by the number of plies in the yarn. The cyclic loading at half the bursting load is another method adopted to assess the performance of the knitted structure. As the knitted fabric is to be used as scaffold material for urinary bladder reconstruction, the cyclic test has therefore been performed so as to test the deformation property of the knit fabric [5]. It is observed that after 4-5 cycles of loading, the material gets stabilized and the load extension curve starts repeating for further loading cycles. In case of cyclic loading, initially fabric shows higher extension. It is because at initial cycles of loading individual loops give the contribution toward the extension in addition to the elasticity of the yarn. After few cycles of loading, the contribution from the loops decreases due to their deformation and the residual extension is the result of the inherent extension in the yarn. The fabric gets deformed in all the cases after 4-5 cycles of loading. The ratio of the void volume to total volume has been used to find the porosity of the knitted fabric. Its value is found to be 80% with 8-ply yarn knits within the required range. The area of the individual pore decides the openness of the knitted structure [5]. The pores are present within and between loops of yarn in the knit structure, and the areas of these pores are different. In the case of cell structure, the porosity of the scaffold plays a crucial role as it enables easy passage of nutrients as well as the three dimensional growth of the tissue culture. The knitted structure is highly porous and the porosity decreases with the increase in the ply of the yarn. The size of pore is also influenced by the number of yarn plies. With the increase in the number of ply in the yarn the fabric openness reduces. The PLA knitted samples have been treated for a certain duration at pH of 4.6 to 8.0 at 37°C (required for urine), since they are meant for using as a scaffold for urinary bladder. Examination of the surface degradation of the samples through SEM shows lower pH increases the degradation which shows the catalytic influence of hydronium ions on hydrolysis process [5]. The catalytic effect of hydronium ions on hydrolysis process is confirmed by the increase in degradation at lower pH. The investigation reveals the suitability of knitted structures for using as a scaffold for urinary bladder and also provides the means for the potential use of different textile materials in various areas of medical applications such as cardiovascular prosthesis, compression bandaging etc.

Knits in mitral valve therapy

With the advent of interventional valve therapies that are gaining medical importance, prosthesis has been used in the treatment of aortic and pulmonary valves [55]. In the treatment of regurgitation (very common mitral valve disease), reconstruction of the valve is preferred over replacement for a number of reasons. Very little study has been done in the interventional placement of a biological valve in the mitral position because it poses a challenging anatomy to anchor it [56,57]. The reason is that anchoring of a biological valve poses a challenge from the anatomical point of view. Attempt has been made to create a hollow body equipped with a heart valve that utilizes all surrounding structures inside the heart to anchor or permit the additional valve to cure the underlying disease. This kind of prosthesis needs self expansion after compression in all dimensions and adjustment to the atrial valve with approximated blood tightness through the prosthesis wall to permit exclusion of the left atrium. Hence, a new complex body has been designed from the materials Nitinol and polyvinylidine fluoride. Basically, the intended prosthesis should cover the entire left atrial wall from the pulmonary veins down to the mitral annulus and contain a biological heart valve. Attempts have been made to design a prosthesis realizing the following requirements: compressible with strong self expansion after release; stability towards compression vertical to the valve plain; approximated blood tightness and low thrombogenity inside. A single wall has been designed as a result of many preliminary trials. The prosthesis hollow body was designed out of a warp knitted PVDF (Polyvinyledene Fluoride) fabric for the prosthesis wall and an external Nitinol skeleton for the stability and self expansion. Medical grade PVDF was used for fiber production. The polymer was melt spun into multifilament fibers comprising 30 filaments and having a yarn titre of 320 dtex. In order to produce a blood tight and elastic textile structure, warp knitting technology was chosen. In addition to the possibility of adjusting the design parameters such as size, shape, Young's modulus and porosity of the textile structure, warp knitted fabrics have the advantage of being fray proof. A double raschel warp knitting machine has been used for knitting the fabric. This production machine has 16 guide bars and enables the production of three dimensional textiles with different yarn materials and counts. For fabrication of a dense structure with adequate elastic properties, a two bar tricot pattern was chosen. A needle gauge of 30 was used and the loop density was adjusted to 12 loops/cm. With these parameters the PVDF yarns were fabricated to a tubular bifurcation. Regarding durability, PVDF exhibits properties even superior to those of polypropylene which is used routinely in cardiac surgery. For the production of the external skeleton, medical grade Nitinol wire with a diameter of 200 mm has been used. The Nitinol was tempered in the super elastic phase at 500°C for 15 min. Hence the Nitinol wire was fixed to the desired shape using a mould representing the porcine left atrium from the pulmonary veins as far as the mitral valve. Subsequently, the super elastic nitinol skeleton in the shape of the porcine left atrium was sutured onto the PVDF tubular bifurcation fitting the mould while the two branches fitted the pulmonary vein ostia. The assembled PVDF–Nitinol composite structure results in a new self-expandable hollow body customized to the porcine anatomy. The resulting prototypes were made up of a biological heart valve and nitinol brackets joining the prosthesis rim up to the pulmonary vein-stents. The load from the valve is displaced *via* the nitinol skeleton to the atrial wall and the pulmonary vein ostia. Eight such prostheses were manufactured. Eight prototypes of the newly designed prosthesis have been designed, functionality tested *In vitro* and the overall performance studied in a porcine model of mitral incompetence [58]. The designed prosthesis should cover the entire left atrial wall from the pulmonary veins down to the mitral annulus and contain a biological valve. Attempt has been made to develop a prosthesis that would fulfil the following conditions: a) Compressibility with good self expansion after release b) Compression stability vertical to the valve plain c) Approximated blood tightness and thrombogenity inside d) Single wall design Polyvinylidine Fluoride (PVF) of medical standard has been warp knit to form the hollow body of the prosthesis to represent the wall and nitinol skeleton for stability and self expansion. The warp knitted fabric having two bar tricot structure and 12 loops/cm is intended to produce a blood tight and elastic structure and fabricated into a tubular bifurcation. The yarn has been knitted on a double raschel warp knitting machine with 15 guide bars. Trials have been carried on 8 pigs. All prosthesis have been observed and tested in the pulsatile circulatory mock loop simulator. Hence an elastic silicone model of the porcine left atria has been generated including the pulmonary veins and the upper part of the mitral valve.

Despite the fact that surgical repair has proved very effective in the treatment of atrial mitral valve disease, the interventional fixation of a prosthetic valve in the mitral position has not been adequately studied due to anchoring problem [59]. Hence there has been a need to develop a self expanding hollow body for the entire atrium to permit a suture less fixation of a biological heart valve in the mitral position. This hollow body should exclude the entire left atrium and tighten directly above the valve up to the inflow of the pulmonary veins. In order to fulfil the requirements of the prosthesis a flexible textile body has been used so that it could adjust well with the surrounding structures inside the heart. Also the textile surface is expected to be biocompatible without major thrombotic properties. A warp knitted PVDF (Polyvinylidene Fluoride) structure has been selected as it is biocompatible in nature and suited for surgical purposes which would fit the best three dimensional fitting of the textile body [58]. Despite lacking full tightness for blood, a functional tightness of the valve has been achieved. The initial blood tightness can be more enhanced by preclotting of the prosthesis or external textile coating with degradable biomaterials such as collagen or gelatine. It is assumed that in growing of the endocardium could facilitate further fixation. Even though it is desirable that an inner skeleton should press the PVDF against the atrial wall, it has been considered practical to suture the nitinol skeleton very close to the textile body from the outside. However, it has been made possible to create a rather complex textile body having self expansion characteristics and an ability to press the valve on the annulus to transmit the load from the valve up to the pulmonary vein ostia. The fabricated prosthesis samples have been subjected to the pulsatile circulatory mock loop simulator. A specially designed transparent silicone model of the left atrium has been constructed and permitted visualization of the prosthesis and its behaviour as in a transparent medium. In the duration of study spanning over 3 hours, negligible impairments of the prosthesis have been observed. Collectively, it has been practically possible to show the stability of the prosthesis in the atrium and the function of the biological valve. The prosthesis had been successfully implanted on eight animal specimens chosen. Open access to the heart has been selected due to transcatheter implantation problem. Considering from the circulation point of view, the implanted prosthesis was supposed to perform reasonably well. But visualization of the prosthesis with its valve has not been easy, and rendered the analysis of the prosthesis complicated. However, putting all the visualizations together it could be shown that the prosthesis filled the complete left atrium tightly and the overall position of the prosthesis in relation to the insufficient native valve was as intended (as revealed by autopsies on animal specimens). As no thrombus formation has been observed on or inside the prosthesis, the PVDF material along with the nitinol appears to be very prospective combination that can be used for larger complex implants inside the heart. The practical limitation of the investigations is that the duration for which the newly developed prosthesis has been subjected to load conditions was quite short when compared with the durability required during the ensuring years. Another constraint is the potential side effects of the prosthesis involving perforation of the inner wall of the heart. Hence, more long term investigations are needed to deal with these issues. From the aforesaid discussions, it can be inferred that the combination of PVDF with nitinol appears to be prospective for development of complex intracardiac prosthesis. More investigations are required for technical refinement and predict the long term behaviour.

Weft knitted intestinal stents

In the case of patients with intestinal cancers, intestinal obstruction and stenosis have been commonly observed under clinical conditions [60]. Investigations have shown that stents can avoid intestinal obstruction and stenosis [61]. For over a long period of time, metal stents have been used for treating obstruction and stenosis of bowel and vessels [62]. They can prevent further treatment and reduce image quality of magnetic resonance imaging. In the treatment of obstruction and stenosis, biodegradable stents can be considered as alternative. Biodegradable stents are advantageous over stents in that they can prevent serious long term complications and do not require removal, thereby avoiding further surgeries and potential morbidity [63]. Aliphatic polysters like polyester, polylactic acid, poly (L-lactide), poly (lactic-co-glycolic acid), and polydioxanone are very commonly used as biodegradable polymers for stents [64]. Polydioxanone has many merits that include good flexibility and elasticity, appropriate absorption rate, suitable biocompatibility and minimal inflammatory response [65,66]. The main function of the stent is to provide mechanical support to obstructed intestines to enable smooth flow of intestinal lumen and waste. Hence it becomes imperative to study and optimize the mechanical properties of stents. Various models have been used in the study of mechanical properties of stents and there exists adequate literature on these [67]. However, very little work has been done regarding the weft knitting parameters on the mechanical properties of intestinal stents [68]. The weft knitted intestinal stents have the merit of easy removal by pulling one yarn to unravel the structure. A number of factors relating to production affect the geometrical characteristics and mechanical performance of weft knitted stents [69]. The radial force and circumferential strength of weft knitted stents tend to get strongly influenced by the different yarn, process and fabric parameters [70]. The influence of these different factors can be identified through the use of fractional factorial design of experiments and thereby the optimal process settings determined [71]. An attempt has been made to identify the influence of weft knitting parameters on the mechanical properties of stents by adoption of the statistical modelling, and thereby arrive at the optimum settings of the key factors. A physical model of the human intestine has been used to study the abdominal and intra-intestinal pressure. The complete factorial design has been used to identify the most appropriate parameters and the optimum processing factors for the stent mechanics. It is possible to avoid obstruction and stenosis by incorporating stents into the intestine lumen. Stents are able to withstand the radial force during the functioning of the intestine. The durability of the stent is determined by the radial force, as they withstand compression in the abdomen of patients. Owing to the abdominal pressure during function process the implanted stent gets compressed, such that it requires proper radial force to restore its tubular shape against the compression. Also, the stent withstands the expansion by the intestinal pressure due to the solid faces and intestinal movements. Thus it becomes crucial to have proper circumferential strength and radial force in the choice and design of stents. The diameter and intestinal pressure of the small intestine are smaller than that of the larger intestines, which means that both the diameter and mechanical properties of larger intestines are larger and better than those of small intestinal stents [72]. The pressure existing within the abdominal cavity is known as abdominal pressure. It is considerably influenced by the necessary radial force of implanted intestinal stents. The radial force test is conducted to determine the force exerted by a stent on the vessel in the implanted condition during expansion and compression. Patients having higher pressure require stents with higher radial force. The normal abdominal pressure is between 2-8 kPa. In severe cases it can be above 30 kPa. Surgical decompression would be required in the case of patients with moderate or severe abdominal pressure [73]. The radial force and circumferential strength of stent can also be calculated. Polydioxanone polymer has been synthesized by conventional ring polymerization technique. An extrusion process has been used for producing the PDO yarn and has been followed by drawing process resulting in a self reinforced structure. The PDO yarn was produced by an extrusion process immediately followed by a drawing process to create a self reinforced structure (Horcon Ltd Co., China). Currently, only five types of the PDO yarns can be fabricated due to the limitation of melt-spinning machines. Two PDO yarns with linear density at 100 ± 10 and 150 ± 10 tex were selected, which are suitable for the needle size in the machine. The PDO yarns have been knitted into a tubular form on a circular special weft knitting machine with needle number 22, 90 mm machine diameter, and gauge of 7. The stent dimensions can be adjusted based on the computer tomography check of the intestine with stenosis or obstruction in patients. Factorial design has been adopted in order to decide the factors that significantly influence the radial force and circumferential strength. The factors considered are stitch cam setting, fabric tension, yarn tension and yarn linear density. The stitch cam setting has a major influence on the fabric mechanics [6].

Studies have revealed that the optimum stents with radial force ranging between 1.3 - 2.5 cN/mm and circumference ranging between 20-50cN/mm have been obtained at stitch cam settings in the range of 3.2 to 3.4 mm, and fabric tension value between 140 -160 cN, when the yarn tension and linear density have been maintained at 1.2 cN and 150 tex respectively. It is possible to design different stents with specific mechanical requirements by the use of the proposed model of factorial design. There are two practical constraints encountered [6]. One is that the mechanical properties of stents can get altered during *In vivo* degradation process or after sterilization by ethylene oxide gas or cobalt radiation before clinical use. Hence the mechanical changes after sterilization and *In vivo* requires further study. The other constraint is that the optimum stent could not attain the high level of circumferential strength and radial force value for small and large intestinal stents owing to material and machine constraint. Hence it is necessary to alter the yarn diameter and machine along with the cylinder and needle size. But the stent stitch density or yarn diameter cannot significantly be increased to enhance the mechanics of the stent, as too high a stitch density of the stent is difficult to compress into a catheter through the intestinal passage smoothly which would result in high displacement rate clinically. Considering the study done, modelling the actual structure for stents by the factorial experimental model has also been recommended for improving the prediction accuracy of stent mechanics. In order to engineer the development and evaluation of stents, there is a need to closely cooperate with intestinal surgeons more than relying on clinical trials and experience. 8 Knit smart shape memory fabrics for biomedical applications Shape memory polymers are those that are capable of changing their shapes quickly in predetermined ways under the influence of heat, electricity, light, pH, ionic strength, and magnetic field [74-79]. Hence they have gained scientific interest owing to their biocompatibility coupled with large shape deformation and recoverability. An example of the biomedical application of shape memory polymers is a laser or activated shape memory device for the mechanical removal of blood clots [80-83]. The device may be compressed into a small temporary shape and inserted by minimally invasive into a blood vessel. Due to laser or magnetic activation the device gains its predetermined shape which renders removal of blood clots. Other applications include treatment of intracranial aneurysm, biodegradable suture, drug delivery in the treatment of disorders and diseases in the stomach or intestine, and orthodontic appliance [84-86]. Very little work has been done in the development of shape memory fabrics for biomedical applications. Dimethyl formamide has been used in the polyurethane synthesis as the solvent. It was then spun as fibers [11]. The shape memory fibers so produced has been knitted into a single jersey structure. The shape memory fibre has been tested for the following a) thermal properties b) mechanical properties – fibre tenacity c) shape memory effect of fibre and fabric d) *In vitro* cytotoxicity test e) *In vitro* haemolysis test f) sensitization test g) dermal irritation test The shape memory fiber showed good shape memory effect with a recovery ratio of up to 90% and a fixity ratio of up to 90% and a fixity ratio above 80% with a triggering temperature at 36.5°C. Also the prepared shape memory fabric showed good shape memory effect demonstrated by bagging recovery. The switch temperature of the prepared fiber was 35.9°C, which was close to body temperature, so that shape change could be triggered at 36.5°C, close to body temperature. In addition, the switch temperature could be facially tunable by varying soft segment fraction, hard segment type, extender type and contents the prepared shape memory fiber had much higher mechanical strength than that of shape memory films which is attributed to the molecular orientation in the shape memory fiber due to the spinning process [11]. Therefore, the shape memory fibre and the prepared fabric can be used in body parts where high stress tolerance is required. The biological evaluations of the prepared shape memory fabric were preliminarily evaluated in terms of cytotoxicity, haemolysis, sensitization and dermal irritant. Based on the test results, the shape memory fabric was not considered cytotoxic, haemolytic, or dermal irritant. With higher compatibility on human bodies compared with the shape memory film or bulk, the shape memory polymer in the fiber/fabric format may find broad application in the biomedical area, such as artificial tendons, artificial corneas, hernia repair, artificial bone joints, orthodontics, scaffold material and wound dressing. 9. Knit Pressure Garments the medical compression fabrics made from Nylon/Spandex have been studied for mechanical properties. The knit fabrics had structure in which the face side of the fabric had raised wales while the back side is smooth. Observation through microscope showed that spandex is only present in the wale direction. A flat fabric back surface would reduce stress concentration upon compression and also provide a comfortable smooth surface to contact with the skin. The compression force is usually produced through one dimensional fabric stretching which means that the wale direction with spandex is normally used for producing effective pressure in compression garment design. Evaluation of the tensile properties showed that the compression fabrics are strong with a breaking load greater than 200 N, and possess high stretch ability with breaking extension above 200% in both wale and course directions [87]. As the fabric is elongated to 100 %, its stretching force is proportional to extension. Also the high bursting strength and extension render the fabrics to be used as compression garments. The average recovery of compression fabric immediately after fatigue stretching is more than 95%. The average elastic recovery after an extended period of relaxation of 1 day is at least 98%. The compression fabrics have about 2% residual extension after 3 week service and a few hours relaxation. Compression garments are used to apply pressure on the body in cases of medical, sports and body shaping [88-90]. In the case of medical applications they have been used to treat conditions such as burns (scar management), low blood pressure, muscle strains and sprains and speed up the healing process and prevent deep vein thrombosis during long haul flights. The elastic recovery is a key aspect to determine the performance of compression garments. It is influenced by factors such as compression force applied, the time duration of applied force and the time allowed for fabric recovery. A compression is expected to last for many months. Garments for preventing hypertropic scarring after serious burns can be used up to 2 years. The residual extension of compression fabrics should be as small as possible after fatiguing. Hence it is necessary that the compression garments maintain good durability and do not stretch out of shape after repeated wear and laundering. Focus has been directed for better understanding of the mechanical properties of some knitted compression fabrics used in durable compression garments. Four types of knit fabrics made from nylon/spandex in the ratios of 75/25, 72/28, 67/33, and 63/37, with varying thickness and areal density have been used. The fabrics have been studied for tensile behaviour, elastic recovery and bursting strength [87]. The spandex is in the wale direction. The figure below gives the appearance of the fabrics from different views.

During the evaluation of tensile behaviour of the compression fabrics, they should not be stretched to the breaking point as they have a high proportion of spandex and are very elastic. In determining the maximum breaking force of the fabrics, they have been found to have breaking load higher than 200N, and a breaking elongation higher than 200%, particularly along wale direction which implies that they are stronger in the wale direction with outstanding stretchability [87]. Studies on the load elongation behaviour indicate that for a given level of extension, the stretching force is higher in the course direction than in the wale direction which arises from the unique structural design aspect, during spandex filaments run along in the wale direction. The fabric structure permits high deformation, and the load is mainly borne due to the extension of spandex during elongation up to 150%. As the fabric is elongated up to 100%, the relation between load and extension is found to be almost linear. In the case of the compression garment, it is rather unusual for the constituent fabric to stretch beyond 70%. It is possible to predict the degree of compression necessary and thus design gradual compression garments through choice of suitable material and fabric length. During the initial extension, even though the stretching force is found to be slightly lower in the course direction compared to that in the wale direction. However beyond 170% elongation, the stretching force in the course direction exceeds that in the wale direction, following the trend explained previously. In the design and engineering of garments, the wale direction is more suitable in providing necessary compression, since the spandex offers a gradual linear stretching force. The average immediate recovery values ranged between 98.5% - 99.5% (nylon/spandex 75/25 and 63/37) after fatigue cycling the fabrics between zero extension and specified force of 30N along wale direction. Other compression fabrics have been studied and found to have good stretch and recovery performance. After fatigue, cycling again between zero extension and specified force of 50N, the average immediate recovery exceeded 95%, and the average elastic recovery after an extended period of relaxation ranged between 98% - 100%. When measured in the course direction, the average immediate recovery has been found to be same as for wale direction. But, there has been a low stretchability accompanied by a small residue extension which could exist after relaxation [87]. The elastic recovery performance of the test fabrics has been further studied by stretching them to 25% elongation for 5 days and found that the immediate recovery for the fabrics is more than 96% (nylon/spandex 75/25 and 63/37). The average residue elastic recovery is less than 2%, after the relaxation period is extended up to 4 hours. After 21 days of stretching, the average immediate residue extension has been found to be 4% (nylon/spandex 67/33). But relaxation for few hours permitted the fabric to recover fast, and the residue extension was around 2%. The experimental studies indicate that compression garments from knit fabrics tested should maintain good serviceability at around 25% extension, and thus the fabrics are found to be suitable for compression garment materials with regard to stretch and recovery. The compression load extension behaviour reveals that the fabric (nylon/spandex 72/28) extended beyond 40mm before bursting and bursting force increased rapidly with extension. Some fabrics(nylon/spandex 67/33 and 63/37) were so strong and elastic that they withstood even beyond 50 mm compressing extension owing to higher percentage of spandex. The bursting strength is found to be more than 200 N for all fabrics and the fabric (nylon/spandex 60/37) is the strongest and the fabric (nylon/spandex 75/25) is found to be the weakest [87]. The areal density and fabric thickness attribute to the difference in bursting strength. In the design of various compression garments, the factors such as bursting strength, compression extension and thickness and weight become crucial. In the case of clothing comfort, the garment pressure is considered to be an important aspect, since suitable clothing pressure optimizes the efficiency of physical exercise and heals hypertrophic skin burn scars [91]. A number of factors such as material, design, wearing type, and physical features determine the extent of clothing pressure. Stretch fabrics have been classified as comfort stretch (25–30 %) and power stretch (30–50 %). Medical compression garments and functional body shaping underwear design that are made with high stretch fabric are used in compression therapy. A number of researchers have reported on the evaluation of clothing and material stretch properties [92]. But limited research work has been done in relating the structural characteristics of high stretch knitted fabric and clothing pressure. There is little knowledge available on the correlation of fabric size, stretch properties and clothing pressure of high stretch knitted fabric [93]. The relationship between the structures of polyester SCY knitted fabrics and fabric size, stretch properties and clothing pressure have been investigated [94]. A suitable knit structure and arrangement approach has been proposed in consideration of fabric size and stretch properties of high stretch knitted fabric and correlation with clothing pressure. The findings revealed that a variety of clothing pressure effects could be implemented by a combination of knit structure using principles of knitting and a proper knit structure arrangement in engineering compression garments based on economics. A useful market data has been provided for the effective development of more diverse garment compression-related products along with the localization of manufacturing for functional and medical compression garments. Compression garments made from elastic fabric have been used for operational reasons and clinical applications in the treatment of venous ulceration, deep vein thrombosis or burns [95]. The constant pressure of compression garments exerted on human body is very essential, and the success of the application is extremely dependent on this pressure. However, elastic fabric has a characteristic of hysteresis which contributes to the pressure decay during wearing. The dynamic pressure attenuation has been investigated experimentally [96]. Dynamic pressure decreases with the repeated extension and recovery; its pressure attenuation increases as the extension level varied from 10% to 40%. The effects of fabric parameters on dynamic pressure at 1st test cycle and on dynamic pressure attenuation are also analyzed, such as spandex feeding rate and fabric structure. The findings enable a better understanding of characteristics of elastic fabric used for making compression garments, and prove useful for practitioners with scientific developments and for effective applications. Further work is necessary to extend the investigation of pressure attenuation to real trials, and also examine the deformation of human body to external compression. Other applications Knits have also been used as artificial blood vessels in the replacement of damaged blood vessels. Large diameter (greater than 6 mm in diameter) artificial blood vessel is generally made of woven or knitted fabric, the former has better stable structure, while the elasticity of the latter is better. The materials used mainly are polyester, PTFE, real silk. At present, the main problems existing in the design and application of large, from material selection to production technology, have been basically solved. Artificial blood vessels with diameter greater than 6 mm have been commercialized while preparation of small calibervascularis with diameter less than 6 mm is still an international problem [97,98]. Another interesting area of application of knits is in vascular implants. The basic purpose of a vascular implant (graft and stent) is to act as an artificial conduit or substitute for a diseased artery. However, the long-term healing function depends on its ability to mimic the mechanical and biological behaviour of the artery. This requires a thorough understanding of the structure and function of an artery, which can then be translated into a synthetic structure based on the capabilities of the manufacturing method utilised. But the ability to match attributes of a vascular substitute to those of a native artery still remains a challenge. Similar to woven grafts, knitted grafts also underwent design trials to improve their elastic behaviour. The first report on the use of spandex filament knitted graft as a dog abdominal aorta (diameter 8–10 mm) was presented by Wagner et al. [99]. However, the solo use of spandex fibre as graft material was observed to cause long-term dilatation defect in the graft and is attributed to homogenous single layer structure of the graft. Some of the latest studies tried to use a composite polyester/spandex filament yarn to improve graft elasticity [100,101]. This type of material composition allows load sharing among both components and can prevent dilatation issues if structural design pattern is also modified. However, these studies only report basic improvements in mechanical properties of a plain weft knit structure and lack the ability to be considered as a significant design improvement to mimic arterial mechanics in a knitted graft. In a recent study, an innovative knitted stent-graft design was reported which closely mimics the natural artery mechanical behaviour [102]. The design is based on the concept of longitudinal structural segmentation or metamerism in which the knitted tube is divided into multiple low and high modulus segments arranged in alternating sequence (Figure). The low modulus (knitted polyurethane) sections tend to remain contracted (reduced diameter) when unpressurised while high modulus (knitted polyester) maintain the as-knit configuration. Therefore, at low internal pressure, the expansion of low modulus segments controls the stress response of the knitted tube until their circumference equals that of high modulus segments. At high pressures, the combined response of both the segments increases the stress response sharply, exhibiting an incremental elastic modulus property similar to natural arteries. The low modulus segments act as intermittent "buffer zones" which assist in radial expansion as well as to provide a kink-free configuration to the knitted tube. The compliance of this new design (volumetric: 0.056 ± 0.006 mL/mmHg; radial: 9.8 × 10-4 mmHg-1) is nearly 7 and 15 times better compared to a conventional knitted stent (radial: 1.45 × 10-4 mmHg-1) and a commercial woven Dacron graft, respectively, and falls well within the physiological range of aortic vessel [102,103]. However, the in vivo performance of this design is still unavailable to demonstrate its clinical performance.

CONCLUSION

Knitted fabrics possessing unique structures and mechanical properties are an important element of the technical textile field. Knitted meshes properly designed in warp/weft or both; hold the key in tissue engineering and regenerative medicine. A shape memory fabric knitted as single jersey structure made of polyurethane has been tested and found to be free from cytotoxicity, nonhemolytic and non irritant on skin. The polyurethane shape memory polymer in fiber/fabric form offered higher compatibility with human body in comparison with shape memory film or bulk, and has scope for wider areas of biomedical applications that include artificial tendons, artificial corneas, hernia repair, artificial bone joints, orthodontics, scaffold material, and wound dressing. An innovative design of intelligent garment made from flat knit fabric having intarsia stitches has been designed through integration of medicine, garment design, and wearable electronic technique using transcutaneous electrical nerve stimulation. It could greatly improve daily pain management, not only facilitating new therapeutic methods, but also enhancing life style of patients who wear the clothing. The future research in this area is focused on massage and therapy for shoulder pain, neck pain, and low back pain and so on through switch controls in different positions. It could also pave the way for future research and development of other symptoms or disease treatments. The design of polylactic knitted scaffold provides a new avenue in the development of scaffolds for tissue engineering. Textile knits can be designed with varying porosity and mechanical strength as well as elasticity which would be useful for the human urinary bladder. It also holds great promise in the area of bio textiles with regard to textile designing having necessary physico-chemical characteristics. Warp knit from polyvinylidene fluoride and coupled with nitinol skeleton appears prospective in the construction of complex intracardiac prosthesis. However, more investigations are required for technical refinement and predict the long term behaviour. Polydioxanone weft knit stents can be used for treatment of intestinal obstruction and stenosis. It is possible to tailor various stents with specific mechanical requirements. However, there are inherent practical constraints which need to be refined with clinical trials and experience. Knits as compression garments have proved to be useful in multiple areas of medical applications, especially in the treatment of burns and scars. The discussions clearly indicate that knits play a crucial role in various areas of medical applications and holds prospect in the treatment of many ailments in the days to come. Over and above, knits have made a great contribution in the revolution of tissue engineering.

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