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Mini Review: Advances in Medical Knits

Abstract

Knits play a crucial role in the area of medical applications as recent research show. 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 fulfill 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. Knits have also been used as artificial blood vessels in the replacement of damaged blood vessels. Large diameter (greater than 6mm 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. Another interesting area of application of knits is in vascular implants.

Keywords: knits, medical applications, stents, pla scaffolds, vascular implants

Volume 3 Issue 2 - 2017

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Received: April 04, 2017 | **Published:** November 03, 2017

Introduction

The role of knits has been well explored in the area of medical textiles. 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.[1] A scaffold material intended for human urinary bladder should possess elasticity, porosity, drapability and good mechanical properties. The knitted scaffold developed from polylactic acid fulfills these requirements which are also biodegradable.[2] Cardiovascular implant market (grafts and stents) is growing at a fast pace due to increasing number of patients with vascular diseases and limited biological replacement options available. Thus, synthetic implants offer off-the-shelf solution in a range of design specifications. Synthetic vascular implants are currently manufactured using standard textile manufacturing techniques such as weaving, knitting, braiding and electro spinning. A number of reviews have reported on the mechanical property comparisons of different types of vascular grafts and their clinical performance.[3–5]

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.[6] 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.[7] 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.[8] 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.[9] 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˚C 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.[10] 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.[11] Scaffolds which have been developed not only provide space for the growth of tissues but also enable new tissues to grow with specific functions.[12] A number of polymeric materials have been used for scaffolds. The tailoring of scaffold is usually not generic but it is always application specific.[13] The production of scaffolds involves consideration of a number of parameters.[14] The most common methods of producing scaffolds include phase seperation, particulate leaching, freeze drying, composite foam preparation and other techniques.[15] 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.[16] 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.[17] 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 3.5inch and gauge 14needles/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 biotextiles 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 behavior.[18] 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 behavior of the filament which could influence its knittability.

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.[19] The behavior of the knitted fabric under pressure has been tested adopting the ball bursting technique which almost simulates the behavior 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.[2] It is observed that after 4-5cycles 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 4-5cycles 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.[2] 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.[2] 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 as artificial blood vessels

Knits have also been used as artificial blood vessels in the replacement of damaged blood vessels. Large diameter (greater than 6mm 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 caliber vascular is with diameter less than 6 mm is still an international problem.[20,21]

There are two methods to form artificial blood vessel: textile process and nonwoven process. Textile process mainly includes organic weaving and knitting. Among all knitted artificial blood vessel, warp knitting vascular prostheses integrated the advantages of woven and knitted artificial blood vessel, becoming the one most widely used in clinical at present. The nonwoven process mainly has the injection molding and the electrostatic spinning method. No matter is the textile or the nonwoven artificial blood vessel, the properties of anti-thrombotic, antileakage and biocompatibility have not yet reached the ideal state. The main structural units of the human tissue vessel wall cells are fibrous collagen and elastin, which cause good mechanical properties and adaptability. Generally speaking, artificial vascular materials should have three basic requirements, such as lasting strength, proper pore and good compliance. The basic properties of artificial blood vessels are in order to meet the requirements of anticoagulation and anti-thrombosis. The research progress is mainly embodied in three aspects: selection of new materials, modification of blood vessels and coating, and artificial vascular endothelium.

From a material point of view, the artificial blood vessel is in fact a biological composite material, textile or non-woven material in which play the role of the skeleton. Artificial blood vessel has a porous structure, which can make the cell growth and cover on its surface, so as to make the vascular with biological activity.[22] Fiber used in artificial blood vessel can be natural fiber or chemical fiber, natural fibers, such as natural mulberry silk, synthetic materials in use mainly are polyester (PET), polyurethane (PU), PTFE (PTFE). The artificial blood vessels made of pan (PAN) and nylon will be degraded in human body, so these two materials have already been eliminated. 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 the latter is better; the materials used mainly are polyester, PTFE, real silk. Small diameter (diameter less than 6mm) of artificial blood vessels is generally made of non-woven materials; the materials used are mainly PTFE and polyurethane. 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 6mm have been commercialized, while preparation of small caliber vascular is with diameter less than 6mm is still an international problem. Diameter less than 6mm for artificial blood vessel replacement arteries and veins has not received satisfactory clinical effect. The main reason lies in the thrombus formation and neointimal thickening which can cause blockages and graft failure.[23]

Knits in vascular implants

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 behavior 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 utilized. 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 8-10mm) was presented by Wagner et al.[24] 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.[25,26] 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.[27] 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 1). 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±0.006mL/mmHg; radial: 9.8×10-4mmHg-1) is nearly 7 and 15 times better compared to a conventional knitted stent (radial: 1.45×10-4mmHg-1) and a commercial woven dacron graft, respectively, and falls well within the physiological range of aortic vessel.[26,27] However, the *in vivo* performance of this design is still unavailable to demonstrate its clinical performance.

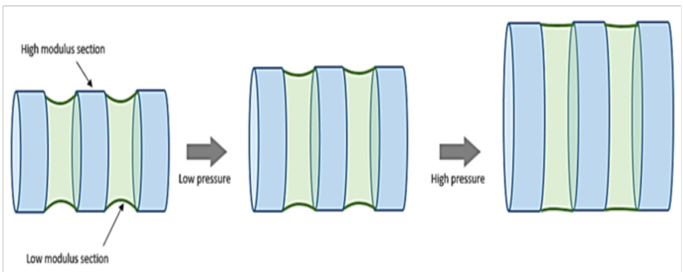

Figure 1 Segmented design concept proposed to improve the compliance property of a knitted vascular implant.[26,27]

Nitinol based knitted structures have offered more promising mechanical features than other mesh designs owing to their unique loosely looped construction. However, the conventional plain knit

Citation: Gokarneshan N, Dhatchayani U. Mini Review: Advances in Medical Knits. *J Textile Eng Fashion Technol.* 2017;3(2):621–625. DOI: 10.15406/jteft.2017.03.00095

construction still exhibits limitations (radial compliance, deployment ease, flexibility, and bending stresses) which limit this design from proving its real clinical advantage. A new knitted mesh design has been developed and is based on the concept of composite knitting utilising high modulus (nitinol and polyester) and low modulus (polyurethane) material components. The experimental comparison of the new design with a plain knit design demonstrated significant improvement in biomechanical (compliance, flexibility, extensibility, viscoelasticity) and procedural (deployment limit) parameters. The results are indicative of the promising role of new mesh in restoring the lost compliance and pulsatility of vein-graft at high arterial pressures.[28] This way it can assist in controlled vein-graft remodelling and stepwise restoration of vein mechanical homoeostasis. Also, improvement in deployment limit parameter offers more flexibility for a surgeon to use a wide range of vein diameters, which may otherwise be rendered unusable for a plain knit mesh.

Conclusion

Knitted fabrics possessing unique structures and mechanical properties are an important element of the technical textile field. 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 biotextiles with regard to textile designing having necessary physico-chemical characteristics. 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. Other important areas of applications include artificial blood vessels in the replacement of damages blood vessels. Knits have also been used in vascular implants. But a good deal of trials is necessary in order to match the knits with the function of arteries.

Acknowledgements

None.

Conflict of interest

Author declares there is no conflict of interest.

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Citation: Gokarneshan N, Dhatchayani U. Mini Review: Advances in Medical Knits. *J Textile Eng Fashion Technol.* 2017;3(2):621–625. DOI: 10.15406/jteft.2017.03.00095