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SMART BIOMATERIALS - A REVIEW

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Abstract. Smart biomaterials are designed to act as an 'on-off' switch for various applications from macro- to nanometer scale which self-heals or responds to the changes in the environment when one of its property changes by the external conditions like temperature, light, pressure or electricity. This change is reversible and can be repeated for several times. When used for healthcare, it improves its performances in medical devices thus promoting desired biological responses like healing, tissue growth etc. Smart materials can deliver therapeutics to the designated site of the body. It is a challenging task to sketch out the classification of smart materials due to its different approaches and quantity of publications related to this topic, is almost impossible to provide a comprehensive review. There are various types of smart materials namely – piezoelectric materials, shape memory polymers or alloys, temperature responsive polymers, photomechanical materials, self-healing materials, thermoelectric materials etc. The current review has been focused on smart biomaterials primarily on auxetic materials which are automatically adjustable with strength and thickness in response to the applied forces as they have memorial ability to return to its original state on dissipation of the stresses. Here, the main emphasize is on biomedical applications of auxetic materials which comes under the category of 16 smart materials of the twenty first century having a great impact in biomedical area. The information provided through this review may be beneficial for the future development of biomedical devices and their clinical applications consequently improving the quality of patient's life.

1. INTRODUCTION

Biomaterial improves the quality of life on increasing number of people each year with increasing demands on biomaterials with higher expectations related to quality of life arising from an aging population, whether it is replacement of dysfunctional or arthritic hips, atherosclerotic arteritis and decaying teeth or repair of injured tissues such as cartilage and skin. As the population ages, there is a growing demand to replace and repair soft and hard tissues such as bones, cartilage, blood vessels or even entire organs. The goal of biomaterial research is accomplished with appropriate combination of chemical and physical properties matched with tissues replaced with minimal foreign body response in the host. There is a vast application ranging from joints and limb replacements, artificial arteries and skin, contact lenses and dentures. Implementing, these materials for medical reasons replacing the diseased tissues extends its life expectancy or motivated by esthetic reasons (e.g. breast implants).

Inert biomaterials elicit no or minimal tissue response, biodegradable or bioresorbable materials integrated into the tissue dissolves completely with respect to time. Metal implants such as cobalt-chromium alloys are classified as inert, ceramics may be inert, active or resorbable while polymers may

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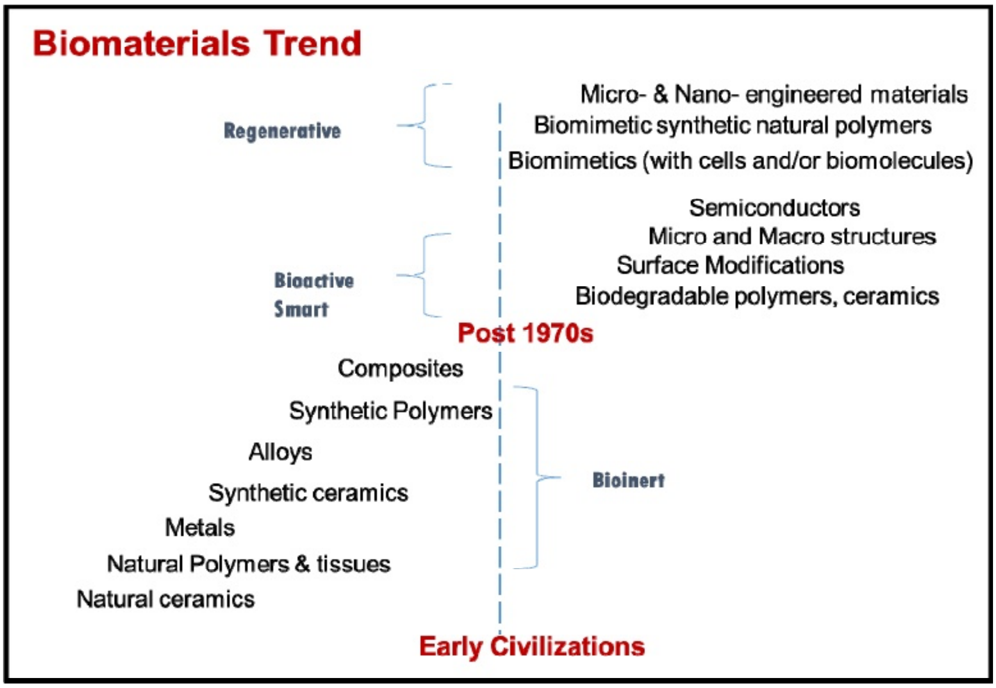

Fig. 1. Illustrates the trend on biomaterials.

be inert or resorbable. Currently, orthopedic implants made up of bulk of all devices implanted (approximately 1.5 million per annum worldwide) at a cost of around $10 billion. However, estimation of expenditure on biomaterials and devices for the treatment of cardiac disease shall double the amount due to the increasing number of patients suffering from cardiac arrest treatment.

Within metallic systems plain carbon and vanadium implants, demonstrates overt corrosion being replaced by superior stainless steels, followed by strong passivated cobalt-chromium alloys. With respect to polymers, nylons and polyesters substituted materials with polytetrafluoroethylene (PTFE), polymethylmetacrylate (PMMA), polyethylene and silicones are less likely to degrade. In 1980's more than hundred implants and devices in clinical use were made from 30 different materials. The biomaterial industry is currently worth $ 28 billion with an annual growth rate of 15% expected for the next few years, while the market is expected to be worth $ 58.1 billion by 2014. Currently scale independent (macro to nano) metals, polymers, ceramics and composites in their woven and non-woven form [1] are the key players on biomaterial market whereby the biomaterial trend has been illustrated in Fig. 1 below whereby given the description of its timeline.

During 1960 and 1970's, first generation of biomaterials was developed for routine use as medical implants and devices improving the quality of life of millions of patients. Extensive medical devices have been greatly improved the patients care like artificial joints, dental implants, ocular lenses or vascular stents. However, many of them were accidentally successful rather than many materials designed for other applications. In 1980 and 1990s the field of biomaterials started to shift away mainly using inert materials towards the development of bioactive components to elicit specific biological response at the interface of the material. By mid-1990's bioactive materials reached, in clinical usage like various types of orthopedic, dental and cardiovascular applications which includes various types of compositions of metals (titanium, alloys, etc) and bioceramics. The field of biomaterials has developed with novel strategies in surgery for the creation and expansion of more effective and less invasive treatment options. In the present decade, is the emergence of fourth generation of biomaterials, so called "***smart***" or "***biomimetic materials***".

It is generally believed the synthetic biomaterials has better control over physical and mechanical properties and can be used to tailor for better medical care for both, soft and hard tissues. Moreover, since 1980's there has been the overarching focus on studying of smart materials called "***auxetic materials***" which involves contribution to biomedical industries. These structures have shape memory and ability to return automatically to its original shape. It has been demonstrated through studies and experiments the auxetic materials offers a huge

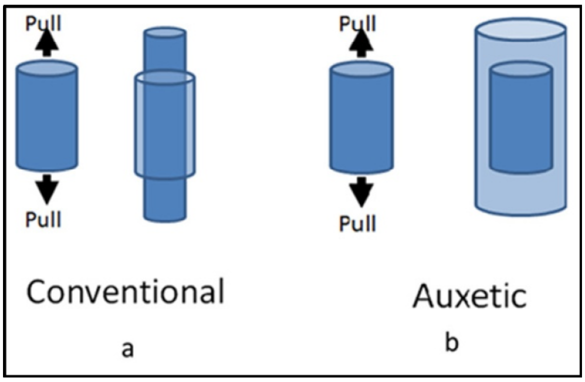

Fig. 2. Shows (a) Non-auxetic (conventional) and (b) auxetic material behavior.

potential in biomedical industry (but not limited to) including scaffold [2] stents [3-5] implants and prostheses [6]. Possessing negative Poisson's ratio has the ability to tailor its improved mechanical properties [7,8] and unique deformation mechanism [9]. The auxetic materials have opposite behavior compared to conventional materials as they become wider on stretching [10-12] and with extreme properties such as indentation resistance [13,14], good absorption [15], and higher fracture toughness [16] as they are already making a significant impact on (but not limited to) the biomedical industries globally. They behave opposite to the conventional materials as they become wider on stretching, thinner on compression and exhibit a synclastic behavior as illustrated in Fig. 2.

Bending is achieved tuning through Poisson's ratio hence representing key opportunity for future [17-20]. These benefits offered by auxetic materials have been fairly wide in scope and by researchers worldwide seen as an endless range of applications not only for biomedical but for engineering and structural industries as well. A large number of research papers [21-25], thesis [26] and patents [27-31] considered as auxetic medical implants, stents, smart medical dressings scaffolds published in international journals and exist in literature. A brief introduction to auxetic materials is given in Section 1.1.

1.1. Auxetic materials

Materials or structures when expanded laterally are stretched or contracted in the transverse direction under uniaxial compression are known as "***auxetic materials"***. This behavior is observed due to negative Poisson's ratio which does not contradict the classical theory of elasticity. Based on the thermodynamic considerations of strain energy, Poisson's ratio is bounded by two theoretical limits: it must be greater than -1 and less than or equal to 0.5, i.e. $-1 < \nu \leq 0.5$ and Poisson's ratios of isotropic materials does not only take negative values, but can have a range of negative values twice as wide as that of positive ones [32]. The mechanisms of auxetic materials depends on either micro or geometrical and deformed structures and the correct co-operation between the internal structure of the material and the way it deforms when loaded gives rise to auxeticity. This is a major breakthrough to induce auxeticity in materials and structures through their design. However, auxetic materials have been known for over 100 years and the key to this auxetic behavior is the negative value of Poisson's ratio [33]. In early 1900s, a German physicist Woldemar Voigt was the first to report this property [34] and his work suggested that the crystals somehow become thicker laterally when stretched longitudinally nevertheless it was ignored for decades. In 1927, A. E. H. Love [35] described a material with negative Poisson's ratio and presented an example of a cubic single crystal pyrite having the Poisson's ratio, $\nu = -0.14$. Gibson [36] in 1982 realized the auxetic effect in the form of the two-dimensional silicone rubber or aluminum honeycombs is deformed by flexure of the ribs. The concept of auxetic materials was matured internationally in 1987 when Roderick Lakes fabricated auxetic polyurethane foam from an commercially availability whereby one gets fatter when stretched and thinner when compressed [12,37,38]. This has been a major breakthrough displaying its performances on inducing auxeticity in materials and structures through their design. However, natural auxetic materials do exist, examples single crystals of arsenic and cadmium, α-cristobalite, and many cubic elemental metals [39-43]. In addition, some of the biological materials have been found to be auxetic, including certain forms of skin, for e.g. cat skin, salamander skin, and cow teat skin and load-bearing cancellous bone from human shins [44-47]. With the discovery of auxetic effect, researchers have started to realize auxetic materials tend to possess vast number of applications. In view of this, a significant effort has been made towards designing these materials and finding its new applications. Since then, a whole range of synthetic auxetic materials have been produced for all major classes of materials, such as metals, ceramics, polymers and composites from macro to nanoscale and to molecular level [48-67] as illustrated in Fig. 3 [68]. Today auxetic materials stimulate biomedical system development including tissue engineering, stents, scaffolds, implants and other medical devices. A number of reviews on this subject are made available, [69-74] with main focus

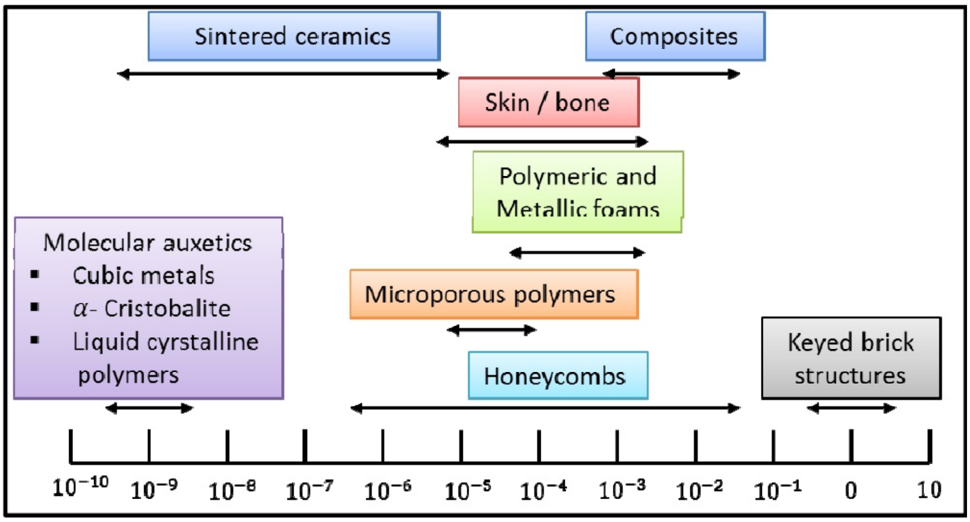

Fig. 3. Auxetic materials and structures from the macroscopic down to the molecular level, modified version of the scheme suggested in [68].

on fabrication, structures, deformation mechanism, mechanical properties and its applications.

In the current review a brief introduction on auxetic materials, with their applications particularly on biomedical industries has been reviewed here and concluded with a short summary.

2. CLINICAL APPLICATIONS OF SMART BIOMATERIALS

Synthetic polymers include uniformity, less immunogenicity, well-known structures and properties, and the reliability of source materials. Polytetrafluoroethylenes (PTFE), ultra-high molecular weight polyethylene (UHMWPE) and polyurethanes foams (PU) are a class of materials with properties ranging from very brittle and hard to very tough, soft and tacky, and viscous. Their molecular structure can be tuned with their ability to be modified for desired properties. They are generally easier and cheaper processing is considered over conventional materials as a candidates for the development of nano to macro structures for biomedical and engineering industries. These biocompatible synthetic materials are already in existence for their applications. However, biomaterials tailored with auxetic patterns attain appropriate mechanical properties and unique deformation mechanisms known as auxetic biomaterials offering a huge benefit (but not limited to) for biomedical industries.

2.1. Implants and Prostheses

2.1.1. Arterial prostheses

For the blood vessel implant and prosthesis patient's own artery or vein is the best treatment which is not always possible due to unavailability or some other health problems. Synthetic biomaterials matching mechanical and elastic properties with native tissue performs well as a replacements and more cost effective. Compared to primary amputation of limb [75] arterial prostheses with synthetic biomaterials offer better quality of life to the patients. Polytetrafluoroethylene (PTFE) and polyethylene terephthalate (PET) are highly crystalline and hydrophobic polymers been used for synthetic arterial prostheses for more than 50 years [76]. Auxetic biomaterials behave in a similar manner to that of native arterial material which not only offers as a good candidature for blood vessel prostheses but overcomes issues of wall thinning as well. It has been well studied by authors [77] the expanded polytetrafluoroethylene (ex-PTFE) offers auxetic effect when pre-conditioned by the application through-thickness compression. An auxetic arterial material because of its unique deformation mechanism becomes thicker in response to the blood flow as illustrated in Fig. 4b which is favourable factor to minimise wall thinning and also decreases ruptures of blood vessel prosthesis due to enhanced mechanical properties such as fracture toughness. On other hand when blood flows through non-auxetic blood vessel results in getting thinner because of positive Poisson's ratio which is the usual behaviour of materials and increases the chances of damages as illustrated in Fig. 4a.

2.1.2. Implants

Auxetic structures have potential application in implants such as in knee, hip and intervertebral disc replacement [25, 78,79]. One of the enhanced me-

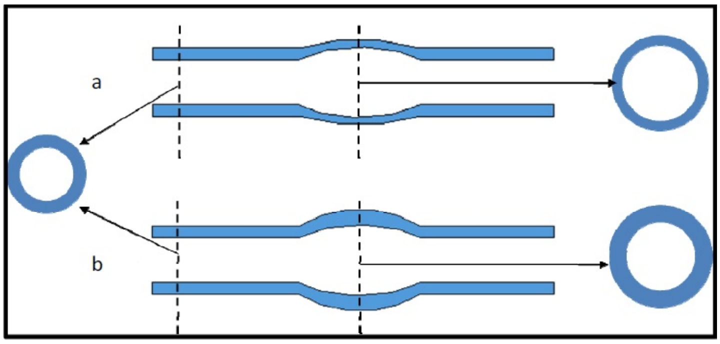

Fig. 4. Schematics of medical devices exploiting the auxetic effect –pulse of blood flowing through a (a) non-auxetic arterial prosthesis; (b) an auxetic arterial prosthesis, modified version of the scheme suggested in [77].

chanical properties is indentation resistance which is almost thrice compared to conventional biomaterials theoretically and experimentally reported by other authors [80-82]. This is a real life configuration in replacement of femoral component of total hip or replacement total hip arthroplasty. Furthermore, auxetic materials when wrapped around the indenter provides more cushioning to the area where the implant is inserted. Likewise, their improved fracture toughness along with indentation resistance proves their candidature for implant linings by improving wear resistance. The implant loosening and implant failure are other challenges caused due to stiffness mismatching between bone and implant materials [83,84]. To overcome these issues matching of structural implant and mechanical properties to the stiffness and architecture with natural bone is essential. It was reported by researcher's human cancellous bone [47] and arterial endothelium tissues [48] have auxetic effect.

Recently the potential use of auxetic structures in biomedical implants has been explained through a 3D FEA model using ANSYS to evaluate its effective stiffness and strain behavior cellular structures such as periodic regular hexagonal, auxetic re-entrant hexagonal and FGA honeycombs with different structures and porosities in [85]. As reported the bone load in the proximal region can be improved by using auxetic structures owing to its continuous contact between the stem and bone.

2.2. Auxetic stents

For the open blockage, providing strength to the artery wall and to prevent elastic recoil follows arterial dilatation a tiny cylindrical wire mesh structures, called *cardiovascular stents*, is inserted into the artery mostly through balloon angioplasty procedures. However, vascular injury occurs during stent deployment and/or recognition of the stent as a foreign material triggers neointimal hyperplasia, causing re-closure of the artery. A recent advancement to counteract restenosis is to employ drug-eluting stents to locally deliver immunosuppressant and anti-proliferative drugs [86]. Over the last two decades much attention has been paid to the research, development of stents in improving the quality of life of patients suffering from arterial blockage. Through many generations of stents such as balloon angioplasty, bare metal stents, drug-eluting stents and bioresorbable stents, particularly drug-eluting stents have reduced at earlier stages and delayed complications with stenting and the restenosis rate by 80 percent [87]. To overcome the existing risks further development towards enhancing long-term safety and efficacy of stents needs to be focused. The current major challenge is to develop, design and manufacture such stents which are compatible to physiologically relevant strain conditions; elastic and mechanical response of a biomaterial ought to be matched with the biological function and mechanical properties of native tissues; and minimising major threats of stenting such as thrombosis, restenosis, in-stent restenosis and others early and delayed problems. Auxetic stents tailored with enhanced mechanical properties tuned through their Poisson's ratio offers potential in stenting procedure. Furthermore, they exhibit high circumferential strength in their expanded configuration and low flexural rigidity in their crimped configuration which makes insertion procedure easier. A number of research papers, thesis and patents including designing, fabrication and applications of auxetic stents has been published in international journals and exists in literature [3-5,26,28,30-31,88-91]. Recently, polyurethane auxetic oesophageal stents and stent-grafts relevant to the palliative treatment of squamous cell carcinomas of the proximal and mid oesophagus

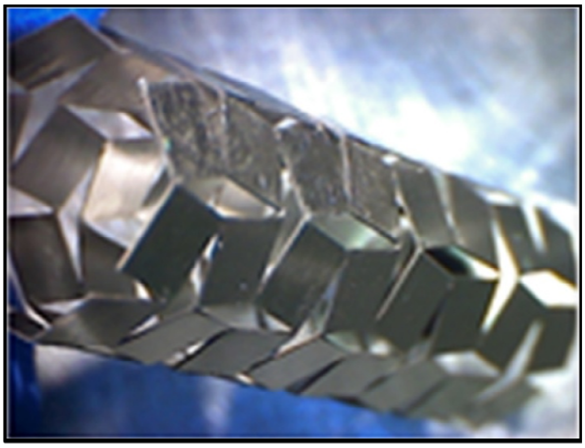

Fig. 5. Auxetic stent with drug delivery system, [90].

and the prevention of dysphagia were recently reported [92]. The flexible polyurethane tubular grafts were also attached to the inner luminal side of the seamless auxetic oesophageal stents, thus preventing tumour in-growth [92]. Deployable auxetic stents includes origami stent grafts [91], utilizes small volume of a folded crease structure in delivering the device to its correct location. The creases disappears when the stent is deployed providing the required expandable radial support to the diseased arteries. The design of auxetic truss-like liner structures for stents has been reported elsewhere [25].

In addition, biomedical application of auxetic materials orginated from macrostructures and today extended to micro to nanostructures. Designing and fabrication of a microstructured auxetic stent with non-woven nanofibrous drug delivery system as illustrated in Fig. 5 has been reported [93].

2.3. Auxetic scaffolds

Bone tissue regeneration using scaffolds is receiving increasing interest in tissue engineering applications. The elastic properties of scaffolds are critical to its efficacy in regenerative tissues and reducing inflammatory responses matching with the elastic properties of the native tissue before implantation. Since many tissues undergo mechanical stress and strain, their mechanical properties should be considered to be important. This is especially true for the engineering of weight bearing orthopaedic tissues, and the scaffolds which is able to provide support for the forces applied to it and by the surrounding tissues. In some applications in tissue engineering auxetic scaffolds are more suitable for emulating the behaviour of native tissues and accommodating and transmitting forces to the host tissue site [21,22,94-97]. It has been reported the auxetic scaffold could be effective for chondrocyte proliferation with compressive load stimulation [94]. A three-dimensional polyethylene glycol auxetic scaffolds has been fabricated using Digital micromirror device projection printing (DMD-PP) to print single-layer constructs composed of cellular structures (pores) with special geometries, arrangements, and deformed mechanisms [95].

On using polyethylene glycol-based biomaterials a multilayered with simultaneous negative and positive Poisson's ratio behavior scaffold has been fabricated [95] which could be applicable in a various biomedical applications. Furthermore, in a very recent study it has been shown that during the transition, the nuclei of Embryonic Stem Cells (ESCs) have auxetic behavior [98]. The authors reported the auxetic phenotype of transition ESC nuclei is driven by global chromatin decondensation and through the regulation of molecular turnover in the differentiating nucleus by external forces; auxeticity could be the key element in mechanotransduction.

2.4. Dilators

In biomedical applications coronary angioplasty (heart surgery) and related procedures an auxetic dilator for opening the cavity of an artery or similar blood vessel has been studied [99] as illustrated in Fig. 6. It was discussed by authors the axial expansion applied by movement of a central guide wire using a simple finger–thumb mechanism opens the lumen of an artery. This mechanism is same as the hypodermic syringe works, hence radial expansion is easily, manually controlled by the physician. The advantages of using auxetic expansion members over conventional balloon catheters is that there is no need to inflate a balloon and no leakage of the inflation medium are additional benefits of auxetic sheath.

Furthermore, a dilator [100], employs expanded ultra-high molecular-weight polyethylene (UHMWPE), including auxetic variant [101], as a liner component. UHMWPE is stronger than PTFE and allows a thinner lining to maximise the diameter of the inner lumen with respect to the outer profile of the catheter. UHMWPE too provides high lubricity, flexibility, abrasion resistance and lower

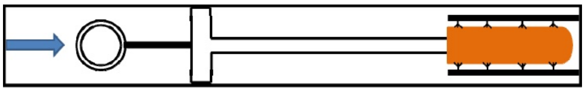

Fig. 6. Dilator device with auxetic expansion member modified version of the scheme suggested in [99].

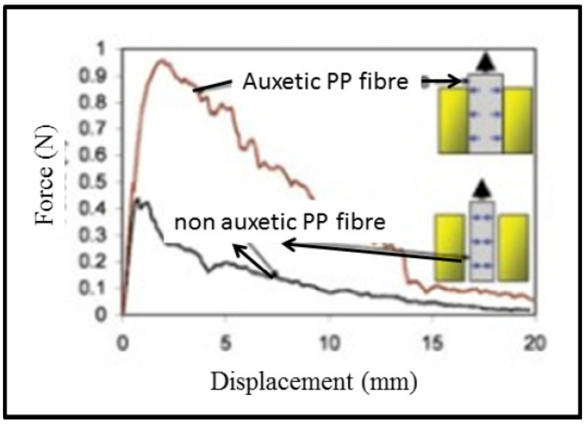

Fig. 7. Auxetic and non-auxetic single-fibre pull-out data and schematics demonstrating anchoring potential, reprinted with permission from Y. Liu, H. Hu, J.K.C. Lam and S. Liu // *Text Res J* **80** (2010) 856, © 2010 SAGE Publications.

processing temperature than PTFE. In addition allows catheter sterilisation by gamma rays or electron beam, thus reducing manufacturing time compared with the PTFE-based devices, requiring gas sterilisation.

2.5. Sutures and ligament/muscle anchors

Anchoring potential properties of auxetic material promotes them as a good candidate for biomedical applications such as sutures and ligament/muscle anchors. An axial compression [102] applied to an auxetic anchoring device is facilitated by lateral contraction due to the auxetic effect. It has been demonstrated the extraction of the device due to applied axial tension is resisted through lateral expansion, which tends to lock the device into the surrounding material. Recently, fabrication of auxetic polypropylene (PP) monofilaments as published whereby a single fibre pull-out tests demonstrates its beneficial anchoring properties [103]. It is well known, the auxetic fibre specimens can withstand more than twice the maximum load and required up to three times more energy to extract the fibre than the equivalent positive Poisson’s ratio fibre specimens as illustrated in Fig. 7.

2.6. Prosthetic linings

Auxetic materials undergoes a higher change in volume under mechanical loading than conventional materials and synclastic (dome shape) curvature when subjected out-of-plane bending rather than the anticlastic (saddle-shape) curvature adopted by normal materials as illustrated in Figs. 8a and. 8b [68,104]. Auxetic materials does not only wrap around the indenter but densify under the location of an indenter providing enhanced energy absorption capabilities. These properties have been very well studied [104] where the auxetic materials offers as a lining material for prosthetic limb sockets. The authors states that it can provide fixation and adjustable volume control in response to variations in stump volume over a period of time and the ability to conform optimal to the contours of the dome-shaped stump and prosthetic limb socket, more supportive, cushioning and reduces transmission of vibrations and loads.

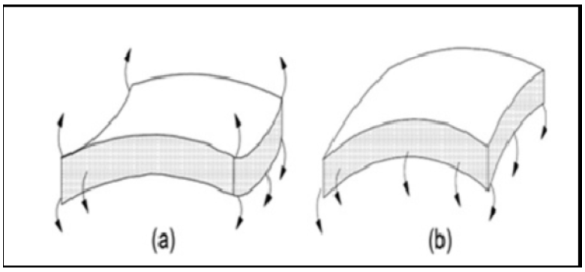

Fig. 8. Pure bending of (a) auxetic material (synclastic curvature) and (b) conventional material (anticlastic curvature), , reprinted with permission from Y. Liu, H. Hu, J.K.C. Lam and S. Liu // *Text Res J* **80** (2010) 856, © 2010 SAGE Publications.

2.7. Auxetic bandages

The ability to design auxetic behaviour into the structure of a fabric and foam offers potential for use in smart compression bandages and drug delivery bandages respectively. The mechanism of these smart auxetic bandages is due to shape memory ability and unique deformation mechanism under auxetic effect. The drug loaded bandages placed on an infected wound swelling causes the auxetic bandage to stretch and deliver drug and on healing pores get closed reducing the swelling and hence drug delivery is ceased as shown in Fig. 9 [105-107]. Increased porosity and breathability makes the wound-healing to process faster. The research studies on smart wound dressing of auxetic foam has been well established [106-107] controlling the release of guest active pharmaceutical ingredients (APIs) from within the microstructure of host auxetic fibres present in the bandage itself as reported by the authors.

The auxetic textiles are used as smart compression bandages. Based on the conventionally available fibres various techniques such as a solid warp

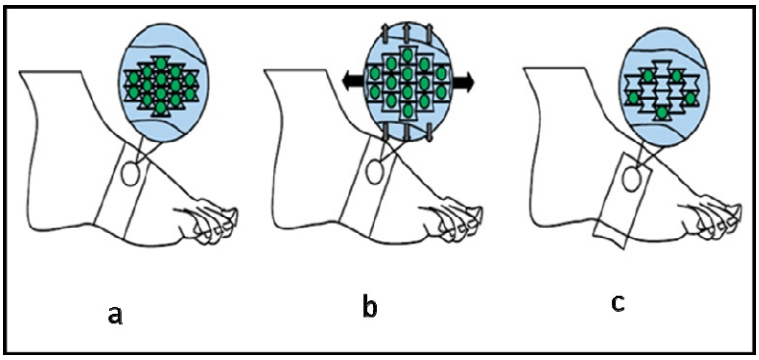

Fig. 9. Mechanism of Auxetic bandages loaded with drug (a) Bandage applied to wound (b) Infected wound swells and pores open up (c) wound heals and pores closed, modified version of the scheme suggested in [107].

knit fabric, an alternative auxetic knit fabric and auxetic fabric prepared by double helix yarns has been studied [108,109].

2.8. Other auxetic applications

Other applications of auxetic materials over conventional materials includes ultrasonic sensors and imagers [110,111], ophthalmic devices (double curvature) [112] and piezomorphic auxetics for artificial muscles has been proposed earlier as well [113]. Furthermore, it was known that the double curvature dome shaped on bending (synclastic behaviour) offers better resilience of auxetic foams compared to the conventional foams providing additional cushioning and comforts [11,27,114]. These properties of auxetic foam promot their candidature ~~for~~ to mattresses with optimum support for the double curved human body [115]. In addition, car and wheel chair seats with auxetic cushion foam might be beneficial in reducing pressure inducing discomfort for people who sit for longer period of time [116]. Auxetic textiles offer potentials in different fields like knitted and 3D knitted spacer structures with auxetic effect introduced [117,118] have applications in sportswear, medical care [119], sound absorbent such as coverings with curved surfaces and a number of practical applications, such as functional garments, protective pads and sportive shoes [120-122], food packaging and fashionable knitwear [123]. As reported the helical auxetic yarns provide pore-opening effect suitable for filtration while color change auxetics cloths can be used for indicative or aesthetic purposes and in fashion [124,125]. Improved mechanical properties of auxetic materials such as toughness [126], shear resistance [127,128], enhanced acoustic properties associated with vibration [129,130] makes them a good candidate for defense industry such as personal protective equipment. Due to their unique deformation mechanisms getting thinner on stretching auxetic materials are lighter but may offer more or equal protection compared to current stiff and heavy protective materials. Bending of auxetic materials take dome shape which is beneficial to manufacture curved surfaces such as nosecone of aeroplanes and protective clothing such as helmets and knee-pads. Furthermore, auxetic materials are well known for their indentation resistance which is almost three times more over the conventional materials. They have potentials for energy absorption materials which may be anything from an explosion resistant coating (ERC) to the energy dissipating material (EDM) [131]. Auxetic fabric exists are useful in military applications such as shelters, tents, canopies, buildings, and other critical infrastructure requiring blast protection; military vehicles, ranging from supply trucks to Humvee's to tanks, could benefit from auxetics' increasing blast protection and overall survivability; in armor applications, especially for blast resistance and fragmentation protection; and provide more comfort and utility designing and manufacturers of gloves, boots, and uniforms [132] (need to modify the sentence too long) These properties of auxetic materials such as expanding perpendicular to force and contraction while compression makes them a good candidate for ideal press-fit fasteners and rivets sealing itself more effectively [125] and projectile materials [133]. As reported [134] a projectile when moves down the barrel, thrusting force potentially results in ~~a~~reduction in lateral expansion. Auxetic multifilaments may be used in auxetic blast curtains or blast-resistant blankets [135]. Furthermore low bulk modulus makes them more sensitive to hydrostatic pressure and higher ability to pull out the fiber as a composite in the design of hydrophones and other sensors [136-139], for piezocomposite devices [140]. Auxetic composites used for sandwiching panels and curved body parts for cars and aircraft [141-143]; feed gear rotation [144]; auxetic fibre-reinforced composite skis, possess lower resistance to motion [145]. Auxetic foams are proposed as good filters because of their ability to tune the pore size for respective applications, as well as using tensile strength to open up pores for cleaning.

3. SUMMARY

Based on the steady research understanding on the biological event at the interface between human body and materials has been steadily growing in development of bio inert and bio active devices. It has been shifted to next stage which involves molecular design based on material science and nano-biotechnology. Nanostructured materials contribute in fabricating new medical devices. One of the examples of smart biomaterials is auxetic materials which responds to small changes by external stimuli with a larger change shown by its physical properties. They are designed to act as ‘on-off” switch. Our focus is particularly on clinical applications of auxetic materials which is an integral component of smart biomaterial, like iimplants and prosthesis such as arterial prosthesis, auxetic stents and scaffolds, dilators, sutures and ligament/muscle anchors, prosthetic linings to limb sockets, auxetic bandages, etc. A smart bandage of a porous auxetic component as loaded with drug and anti-inflammatory agent releases drug through opening of the pores when the bandage is stretched by wound swelling. A loosening of the prosthetic limb sockets leads to skin irritation, tissue breakdown and discomfort. An auxetic material as a lining is capable to wrap around the indenter thus providing more cushioning and minimizes the problems of loosening of the prosthetic limb sockets. A very small diameter in crimped form and maximum expandable diameter of auxetic stents provides an elegant and practical alternative to the existing conventional stent on offering easier insertion and higher radial strength.

The current review has been focused on smart biomaterials, specifically emphasizing on auxetic materials which has shape memory ability. Auxetic materials is promising new area of research to be exploited as “*smart biomaterials”*. This review paper paves biomedical applications achieved through tailored enhancement of mechanical properties due to their unique deformation mechanism. Though an abundance of research papers, patents and thesis does exist in literature, unfortunately a cost-effective, large-scale production for commercialization are the limitation with microporous auxetic materials [146,147]. Therefore, in near future more exploitation on further benefits from auxetic materials is essential for implementing its potential applications and their production at commercial scale level. To conclude or summarize our review paper despite of exciting smart biomaterials have tremendous impact on biomedical device applications still, there is a challenge for today to develop commercially viable auxetic materials in appropriate form for future biomedical applications.

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