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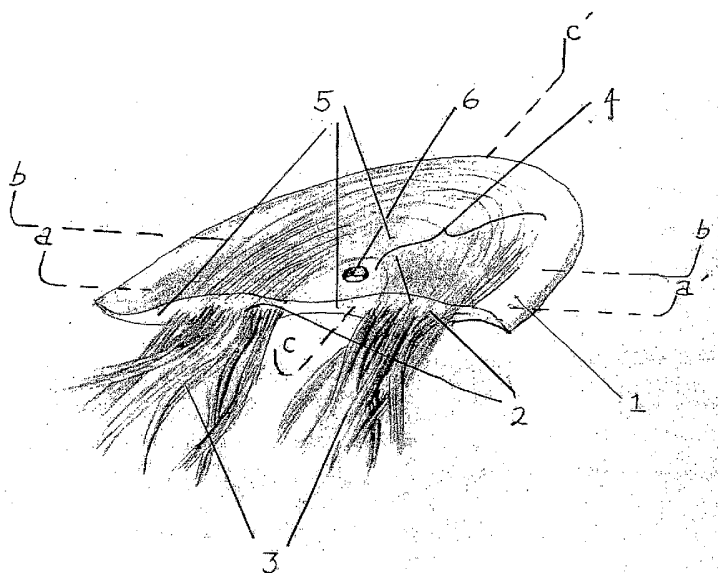
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(54) Title: PROSTHETIC ANCHOR AND METHOD OF MAKING SAME



(57) Abstract: The present invention is directed towards a prosthetic anchor (36) including a central layer (1) through which embedded fibers (2), such as artificial tendons, pass in defined pathways (4), a 'deep' surface membrane (7) which interfaces with a hard structure, whether that is a prosthesis, a bone, or other hard tissue, and a 'superficial' surface membrane (8) which interfaces adjacent tissue and may be configured to adhere or not to adhere to that tissue. The central layer (1) is positioned intermediate the surface membranes (7, 8) which are mechanically and/or adherently attached thereto. Also, non-limiting examples of methods of fabrication and of affixing the anchor (36) to a relatively rigid structure, natural or prosthetic, in a human or animal body with improved stress distribution in the fixed tension member end are taught.

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**PROSTHETIC ANCHOR AND METHOD OF MAKING SAME****RELATED APPLICATION**

[0001] This application claims priority from U.S. Provisional Application Serial No. 60/642,016 filed January 7, 2005.

**FIELD OF THE INVENTION**

[0002] The present invention relates generally to fixation of artificial tendons, transmitting force from skeletal muscles, either to energy converters powering cardiac or other devices, or to natural or prosthetic bones, and more particularly, to a prosthetic anchor, to methods of fabrication, and to means of fixing thereof to a relatively rigid structure, natural or prosthetic, in a human or animal body with improved stress distribution in a fixed tension member, e.g. fixed fibers defining a tendon or ligament.

**BACKGROUND OF THE INVENTION**

[0003] Fixation of prosthetic flexible tension members, such as tendons or ligaments, to relatively rigid structures is a serious problem. A notable example is the use of artificial ligaments, such as the Leeds-Keio anterior cruciate ligament replacement in the knee. In that example, published experience with the usual means of bone fixation—drilling a hole in the tibia, inserting the ligament, and securing with a suture or pin—has included several instances of fragmentation of the polyester fibers of the prosthesis within a few months to a few years. A compression plate fixation has been used whereby tension members are cut and the end

grasped between two plates, generally textured and held together by compression screws to grasp the tension member. While this allows greater control of local stress concentration than does a simple bone-hole, in theory it delivers extremely high shear stresses to the tension member locally, which may cause fatigue failure and breakage over the immense number of stress cycles expected to be required.

**[0004]** A knob-loop fixation device has been previously disclosed to address the stress-concentration issue, but requires a substantial thickness that may be disadvantageous. Such thickness could be problematic in some cardiac surgical, plastic and reconstructive surgical, or orthopaedic surgical devices, for example, in regions where skin is quite close to a coupled bone (e.g., the frontal bone in the case of a cosmetic surgical 'brow lift' prosthesis and the olecranon in an orthopaedic surgical elbow prosthesis). Further, for either of these applications, for other plastic and orthopaedic surgical applications, or for some potential configurations of mechanical energy converters for cardiac power applications, the surface to which the coupler is attached may vary in its contour. Therefore a much thinner adapting terminus, which maintains sufficient flexibility to allow a finite number of size/shape models to conform to anatomy of reasonable individual variation, would be of benefit. Further, a structure with a soft flexible interface to fibers (reducing stress concentration) and yet a harder external surface (to interface with other tissues, adhering or not as desired) would also be advantageous.

**[0005]** Natural tendon ends, which are living tissue, have been connected to 'towel bar' fixtures on artificial bones, over which they are looped and sewn. Because of the shape of tendons—generally flattened in the plane of attachment, the axis of curvature is generally perpendicular to the surface to which they are to be attached. To avoid intolerable protrusion dimensions into surrounding tissue structures, the radius of curvature is very small. Since the compressive stress on a tension member surface, when that tension member is looped about any rod or pulley, is directly proportional to the tension applied and inversely proportional to both the radius of curvature and the projection of contact surface perpendicular to the transmitted tension, compressive forces intolerable by the tension member may be generated. An artificial force transmitting tension member, however, such as an artificial tendon, can be formed in any cross-sectional configuration. This allows the central stabilizing point to be relatively thin, flat, and oriented in the plane of the surface to which the tension member is to be attached.

[0006] In contrast to the 'towel bar' concept, the radius of curvature of the present invention may be made substantially larger with only minimal protrusion into surrounding tissue structures. In contrast to the 'knob loop' or 'tangential pulley' concept, the present invention does not require fibers to be organized into a circular cross-section, with imposition of a minimum thickness for a given number of fibers. The number of fibers still dictates the cross-sectional area of the bundle that passes through the matrix, but it can be very wide and quite thin, or any other combination of dimensions dictated by the device (e.g., a mechanical energy converter) or anatomic structure (e.g., a bone) to be joined.

#### **SUMMARY OF THE INVENTION**

[0007] The present invention provides for a prosthetic anchor including an implantable, flexible, force-transmitting fiber-based tissue coupler or central layer with fibers, and to non-limiting examples of methods of fabrication and of fixing the anchor to a relatively rigid structure, natural or prosthetic, in a human or animal body with improved stress distribution in a fixed tension member, such as fibers defining a tendon or ligament. The invention may be useful in addressing cardiac surgical, plastic and reconstructive surgical, or orthopedic surgical problems.

[0008] To this end, the prosthetic anchor defines a thin wafer-like device including a central layer that incorporates, or embeds, multiple bundles of fibers of a tension member, e.g. a natural or artificial tendon, to form a matrix. This central layer may include an elastomeric or other polymer material. The fibers are packed closely and concentric to each other, and generally in a horseshoe pattern, but permit permeation and interstitial distribution of the matrix. Opposing ends of each fiber exit generally on the same aspect or edge of the central layer and may be attached, such as to the muscle of a human or animal, by means commonly known in the art. Harder and thinner surface membranes such as carbon-fiber/epoxy or glass-fiber/epoxy or sheets of a biocompatible metal optionally cover both faces of the central layer, forming a 'sandwich' of variable flexibility. Flexibility is dependent on thickness of the overall structure and the materials chosen both for the surface membranes and the central matrix layer. Generally, regions near the center of the concentric path of fibers will not contain fibers and comprise either none of the layers (a central 'hole' or opening), or one, two, or all three layers.

[0009] The surface membranes may be variously configured as smooth or textured on the surface opposite the matrix layer, so as to purposefully encourage or discourage tissue

adherence. The side of the membranes interfacing the matrix layer may or may not be roughened or textured so as to achieve mechanical bonding with the matrix layer. Alternatively, various adhesives may secure the surface membranes to the matrix layer. Since the rigid structure, whether hard tissue or rigid prosthesis, to which the prosthetic anchor is to be connected, will generally be moving relative to surrounding soft tissues, the peripheral margins of the anchor are generally tapered to a thin edge. The anchor is also adapted for mechanical fixation to the natural (e.g., bone) or prosthetic (e.g., metal plate) rigid structure and, more specifically, may be outfitted, for example, with simple holes for screws or anchors, or integrated pegs or hooks.

**[0010]** The features and objectives of the present invention will become more readily apparent from the following Detailed Description taken in conjunction with the accompanying drawings.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0011]** The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with a general description of the invention given above, and the detailed description given below, serve to explain the invention.

**[0012]** **Figure 1** is a perspective view of a central layer of the prosthetic anchor in accordance with the present invention;

**[0013]** **Figure 2a** is a cross-sectional view of the central layer of Figure 1 with surface membranes taken along line a-a' to provide a prosthetic anchor in accordance with the present invention;

**[0014]** **Figure 2b** is a cross-sectional view of the central layer of Figure 1 with membranes taken along line b-b' to provide a prosthetic anchor in accordance with the present invention;

**[0015]** **Figure 2c** is a cross-sectional view of the central layer of Figure 1 with membranes taken along line c-c' to provide a prosthetic anchor in accordance with the present invention;

**[0016]** **Figure 2d** is another view of the central layer of Figure 1 illustrating approximately half way between the two surface membranes of Figures 2a-2c to provide a prosthetic anchor in accordance with the present invention;

**[0017]** **Figure 3** is an exploded view of a prosthetic anchor in accordance with the present invention including a central layer with thin semi-rigid surface membranes on either side;

[0018] **Figure 4** is an exploded view of another embodiment, similar to that of Figure 3, with surfaces that are altered wherein the surfaces facing a central layer are textured to adhere to the matrix material, the outer surface of the superficial membrane is polished and smooth (as would be chosen to face skin), and the outer surface of the deep membrane is spiked (as might be chosen to fix to bone);

[0019] **Figures 5 through 23** illustrate one or more non-limiting examples for fabricating a prosthetic anchor in accordance with the present invention;

[0020] **Figure 24** is a perspective view of a machined or molded bloc replica, or master, of a central layer illustrating another method of fabrication;

[0021] **Figure 25** is a perspective view of a silicone mold of the master of the central layer from Figure 24;

[0022] **Figure 26** is an exploded view of radial fibers (carbon, glass, or other), with two diagonal layers in space illustrating an alternate method of fabrication;

[0023] **Figure 27** illustrates curing of a portion of the anchor, in accordance with the present invention, in the mold of Figure 25;

[0024] **Figure 28** illustrates a demolded, trimmed, fiber-composite envelope alone (above) and held in clasp (below) for insertion of fibers;

[0025] **Figure 29** shows a prosthetic anchor in accordance with the present invention being affixed to bone with screws and metal stress-distributing plates;

[0026] **Figure 30** shows a prosthetic anchor in accordance with the present invention affixed to a hydraulic or other mechanical energy converter;

[0027] **Figure 31** shows a prosthetic anchor in accordance with the present invention being affixed to a frontal bone; and

[0028] **Figure 32** shows a prosthetic anchor in accordance with the present invention being affixed to an olecranon of an ulna.

#### **DETAILED DESCRIPTION OF THE INVENTION**

[0029] **Part numbers**

[0030] 1. central layer

[0031] 2. embedded fibers

[0032] 3. entering and exiting fiber bundles

- [0033] 4. concentric pathways of fibers in central layer
- [0034] 5. thickened edge of central layer into which fiber bundles enter
- [0035] 6. optional central opening in central layer
- [0036] 7. deep (semi-rigid) membrane
- [0037] 8. superficial (semi-rigid) membrane
- [0038] 9. face of deep membrane configured for adherence to central layer
- [0039] 10. face of superficial membrane configured for adherence to central layer
- [0040] 11. face of deep membrane configured for adherence to bone
- [0041] 12. face of superficial membrane configured for non-adherence to contiguous living tissue
- [0042] 13. surface, or surface replica
- [0043] 14. mold made to mate part 13, of a soft elastomeric material such as a polyurethane or silicone rubber. Part 14 is termed "fabrication part A" in the continuing description.
- [0044] 15. replica of the applicable surface of part 13, termed 'fabrication part B' in description
- [0045] 16. clay, or clay-like moldable material, wafer configured to geometry of the device termed 'fabrication part C' in description
- [0046] 17. hard outer cast formed to mate with the parts 15 and 16 (fabrication parts B/C assembly); that outer cast is "fabrication part D" in description
- [0047] 18. inner section of part 17, termed "fabrication part E" in description
- [0048] 19. outer section of part 17, termed "fabrication part F" in description
- [0049] 20. removable pin
- [0050] 21. smooth surface of a composite membrane
- [0051] 22. metal mesh insert in the deep surface of part 7, the deep membrane

- [0052] 23. textured metal plate insert (22) in part 7, incorporated into the deep surface of part 7, the deep membrane
- [0053] 24. short needle-like projections
- [0054] 25. peg-like central plateau
- [0055] 26. roughening and texturing of superficial surface (25) of the deep composite membrane
- [0056] 27. generally parabolic disc of fabric or other porous biocompatible material
- [0057] 28. tows or bundles of coupler fibers
- [0058] 29. individual coupler fibers
- [0059] 30. central regions of fiber tows saturated with uncured elastomer
- [0060] 31. hole in disc to accommodate stabilizing pegs
- [0061] 32. stabilizing peg extending from either deep (shown) or superficial membrane
- [0062] 33. ends of tows
- [0063] 34. strip of uncured elastomer
- [0064] 35. fiber-matrix composite layup
- [0065] 36. prosthetic anchor
- [0066] 37. geometric molded or machined master replicating geometry of central layer
- [0067] 38. flanges to guide fiber tows
- [0068] 39. radial carbon or glass fibers in composite layup
- [0069] 40. diagonal 'a' fibers in composite layup
- [0070] 41. diagonal 'b' fibers in composite layup
- [0071] 42. fiber composite envelope
- [0072] 43. clasp for holding envelope during fiber insertion
- [0073] 44. rim joining outer and inner laminae of envelope
- [0074] 45. flange to hold envelope laminae apart during fiber insertion

[0075] 46. bone

[0076] 47. fixation screws

[0077] 48. stress-distributing metal plate

[0078] 49. mechanical energy converter surface to be anchored to coupled fibers by the anchor of this invention

[0079] 50. frontal bone

[0080] 51. olecranon of an ulna

[0081] The prosthetic anchor (36) of the present invention is configured for anchoring to a hard structure such as a prosthetic device or a bone, for the goals of minimizing material stress concentration inherent to such anchoring and minimizing height of the profile of the structure beyond the surface of that hard structure.

[0082] As best shown in Figures 1-3, the prosthetic anchor (36) generally includes the following three layers:

[0083] (a) a central layer (1) of wafer-like structure through which embedded fibers (2), defining a matrix, pass in defined pathways (4). Examples of materials of the central layer (1) include polymers such as elastomeric material, e.g. silicone rubber and polyurethane. The fibers may include natural material (e.g. human and/or animal tendons or ligaments) and/or synthetic materials such as polyester defining a tendon or ligament.

[0084] (b) a 'deep' surface membrane (7) which interfaces with a hard structure, such as by being anchored to, for example, a prosthesis, a bone, or other hard tissue. Examples of materials of surface (7) are titanium alloy or other metal, fiber (e.g., carbon, glass)/epoxy composites, and combinations of metals and fiber composites.

[0085] (c) a 'superficial' surface membrane (8) which interfaces with adjacent tissue and may be configured to adhere or not to adhere to that tissue. Examples of materials of surface (8) are titanium alloy or other metal, fiber (e.g., carbon, glass)/epoxy composites, and combinations of metals and fiber composites.

[0086] The deep and/or the superficial surface membranes (7, 8) may have one or more projections such as posts or needles, as further described below, that extend through

openings in the elastomeric central layer (1) to provide counter force to fibers as fibers are tensed. In addition, it should be understood that the surface membranes (7, 8) are optional insofar as the central layer (1) may be adapted to function alone, or with one surface membrane (7 or 8), thereby defining the prosthetic anchor (36).

**[0087]** With further reference to Figures 1-3, embedded fibers (2) traverse the central layer (1). Fiber bundles (3) enter and exit the wafer-like layer (1) generally on the same aspect thereof, and within the central layer (1) the embedded fibers (2) traverse concentric substantially parabolic pathways (4). The elastomeric material near edge (5) of the central layer (1), at which fiber bundles (3) enter and exit, may be thicker than in other regions so as to lessen and distribute local stress concentration effected by tension on fiber bundles. Adjacent the concentric fiber pathways (4), there may be an opening (6) which may serve to accommodate either a post or projection (32) (See figure 13b) during fabrication, a compression member providing counter-force when tension is applied to the fibers, or both. As best shown in Figures 2a-2d and 3, the semi-rigid surface membranes (7, 8) envelop the elastomeric layer (1) and preferably are adherent to it.

**[0088]** Figure 4 shows another embodiment of the device (36) of the present invention (fibers not shown for simplicity) wherein surfaces (9, 10, 11, and 12) are altered. More specifically, those surfaces (9, 10) facing central layer (1) are textured to adhere to the matrix material. The outer surface (11) of the deep surface membrane (7) is spiked, which might be chosen on one non-limiting example of surface alteration to facilitate fixation to bone; other examples are incorporation of textured metal plates, barbs, or meshes in that surface (11). The outer surface (12) of the superficial surface membrane (8) is polished and smooth as may be chosen to face skin and generate a sliding, bursa-like interface.

**[0089]** Figures 5 through 23 illustrate non-limiting examples for fabricating the prosthetic anchor (36) in accordance with the present invention.

**[0090]** Figure 5 shows step (a) wherein a block surface (13) of polished steel, polished ceramic, glass-filled epoxy polyester resin or other material, is produced, e.g. machined, molded, or cast as appropriate, in the form of the surface to which the device (36) is to be attached. Alternatively, the actual target anchoring surface may be used such as the

mechanical interfacing part of a cardiac prosthesis, or an excised anatomically typical bone with appropriate lacquering, or other surface treatment.

**[0091]** Figure 6 shows step (b) wherein the surface, or surface replica (13), is used to form a mold (14) of a soft elastomeric material such as a polyurethane or silicone rubber. Mold or part (14) is termed "fabrication part A" in the continuing description. Figure 7 shows step (c) wherein a hard mating surface (15), such as a glass-filled epoxy polyester resin or other material, is cast. This mating surface (15) is a replica of the applicable surface of part 13. Hard mating surface (15) is termed "fabrication part B" in the continuing description.

**[0092]** Figure 8 shows step (d) wherein a clay wafer (16), or a wafer of curable clay-like modeling polymer, whose geometry mimics the desired geometry of the anchor (36) is formed on the surface of fabrication part B (15). The wafer (16) is cured or hardened to produce "fabrication part C." Figure 9 shows step (e) wherein, after applying liberal mold-release agent(s), a hard outer cast (17) is formed to mate with the fabrication parts B (15) and C (16) assembly. The outer cast (17) is termed "Fabrication part D" in which two parts, i.e. an inner and outer section, are made.

**[0093]** Figure 10 shows step (f) that includes using a scroll saw, a wire cutter, a laser beam, or other tool, so that Fabrication part D (17) is cut a short distance, generally 2-3 mm inside, and concentric to the margin of Fabrication part C (16) to form an inner section (18), "fabrication part E" and an outer section (19), "fabrication part F." Figure 11 shows step (g) wherein Fabrication part F (19) is positioned offset from its original position on Fabrication part E (18) by a short distance, approximately the thickness of a diameter of a fiber tow (28), to facilitate step (m) (See figure 17) described below, generally 1 to 3 mm, and held in place by a removable pin (20) or other means.

**[0094]** Figures 12a-12g illustrate step (h) wherein a multilayer fiber/polymer composite layup with carbon-fiber/epoxy and glass fiber/epoxy, either manually saturating or utilizing pre-impregnated sheets, is formed between the mating surfaces of Fabrication parts A and B (14, 15), and cured under compression to form the deep semi-rigid surface membrane (7). Part or all of either surface of the deep or superficial surface membranes (7, 8) may be a smooth surface (21). One or more strips or plates of textured or sintered metal plates (not shown), metal mesh (22) or other materials designed for adhering to the bony or other mounting surface

may be incorporated between the composite layup and Fabrication part A (14), underlying all or part of that surface. The degree of metallic or other material underlayment is dependent on design goals, particularly desired regional flexibility or rigidity.

**[0095]** Specifically, Figure 12a shows the process of forming the composite layer under pressure, while Figures 12b, 12c, and 12d show a non-limiting set of possible variations in the outer or deep surface of the deep layer surface membrane (7): smooth (21) in Figure 12b, incorporating metal mesh (22) in Figure 12c, and/or textured metal plate (23) in Figure 12d. Figures 12e, 12f and 12g show further variations in the superficial surface of the deep layer (7). Figure 12e shows a composite layer with short needle-like projections (24) in the superficial surface of the deep surface membrane (7), formed either by drilling appropriate holes in the mating surface of Fabrication Part B (15) or by adding metallic or other projections or 'tacks' to Fabrication Part A (14) prior to the layup. These are shown in an array chosen to support the fiber placement procedure described below in figure 17, step (m). Figure 12f illustrates a deep composite surface membrane (7) with a peg-like central plateau (25) that serves the same purposes of the needle-like projections (24) of Figure 12e. Finally, Figure 12g shows a roughened, textured (26) portion of superficial surface of the deep composite membrane such as may be effected, for example, by preliminary mechanical pitting of Fabrication part B (15). Features 22 through 26 may be used in any combination or used alone.

**[0096]** Figure 13a shows step (i) wherein a generally parabolic disc (27) of porous biocompatible material, such as a polyester fabric, in one or more layers is saturated in uncured silicone rubber or other elastomeric resin and positioned on deep surface membrane (7) aligned with projections (24) of the type illustrated in Figure 12e. Alternately, as shown in Figure 13b, a hole (31) in the fabric or other disc material (27) can be configured to fit about one or more broader peg-like plateaus or projections (32) from the superficial surface of the deep surface membrane (7). The fabric disc (27) is separated from the deep surface membrane (7) in the right of the two drawings for clarity, and in actual position on the left.

**[0097]** Figure 13c shows a series of projections (24), which may or may not be hook-like in configuration, extending superficially from the deep surface membrane (7) to stabilize and support various concentric groups of fibers during casting of the fiber/elastomeric-matrix composite wafer (1). These will be generally positioned in two or more concentric curved rows

of two or more projections. For example, figure 13c shows three concentric rows having six, eight, and twelve projections (24), respectively.

**[0098]** Figure 14 shows step (j) wherein the uncut Fabrication Part D (17) and Fabrication Part B (15) are held together in compression on opposite sides of the central layer (1) and cured to form the superficial surface membrane (8). Figure 15 shows step (k) wherein bundles or tows (28) of individual coupler fibers (29), generally of a polymer such as polyester, generally 6 to 20 microns in diameter, and generally in tows or bundles (28) of several dozen to several thousand each, are saturated with uncured elastomer resin in their central regions (30).

**[0099]** The next steps describe three general embodiments of non-limiting example of methods for stabilizing fibers and embedding them within the elastomer of the central wafer-like layer (1).

**[00100]** Accordingly, figures 16-20 (steps l through p), as further described below, illustrate a method of stabilizing fibers, pending elastomeric matrix curing, by opposed rigid restraining surfaces and, more specifically, illustrate one method of insinuating bundles (28) between two restraining surfaces and sequentially tensing each bundle against the bundle concentrically inside it wherein the separation distance of the two restraining surfaces determines how thick or thin (i.e., how concentrated or spread out) the fibers are at a particular location. In this method, the innermost fiber bundle is supported by a generally parabolic disc of porous material, one or more projections (peg or needle-like) from one of the surfaces, or both.

**[00101]** Figure 16 shows step (l) for fabricating device (36). More particularly, assembled fabrication parts E (18) and F (19) (as in step g) are placed on the surface of the fabric disc (27) and clamped rigidly so that a space is left approximately the thickness of a diameter of a fiber tow (28) between parts F (19) and B (15). Figure 17 shows step (m) wherein each of the one or more tows or bundles (28) of fibers, with tension on either end (33), are insinuated between the margins of fabrication parts F (19) and B (15). The tows or bundles (28) of fibers are maneuvered centrally by maintenance of that tension until each lies between fabrication parts E (18) and B (15), and are sequentially held securely against, first, the fabric disc (27), and then against prior bundles, progressing concentrically outward.

**[00102]** Figure 18 shows step (n) wherein the varying thickness of the space between fabrication parts E (18) and B (15), as determined by the varying thickness of Fabrication part C (the clay wafer 16 – See figure 9) used to mold part E (18), determines in turn the varying thickness of the fiber layer as it progresses radially away from the central disc (27). The fiber layer may progress differently in terms of distance covered per number of fibers (29), at different points around the central disc (27), dependent on this varying thickness profile. For the non-limiting example shown, the center of the irregular approximately 180° wrap is thinner and wider than are the sides.

**[00103]** Figure 19 shows step (o). When the desired number of fibers (29) have been placed, and either end (33) of each bundle (28) of fibers secured by tension, either of weight or elastic or other mechanism, a strip of uncured elastomer (34) is applied peripherally to form the central layer (1). Figure 20 shows step (p) wherein the temporarily securing pins (20) are removed to allow Fabrication Part F (19) to be advanced on Fabrication Part E (18) until it contacts Fabrication Part B (15), expressing excessive uncured elastomer, and compressed against Part B (15) while the elastomer is cured to form the central layer (1).

**[00104]** Figures 21 and 22 (steps q and r) show another nonlimiting example of a method of stabilizing fibers, pending elastomeric matrix curing, by needle-like projections (24) from one or both of the enveloping membranes (7, 8) and, more particularly, illustrate one method in which there are two or more concentric curved rows of needle-like projections (24), which may be hook-shaped, from one of the enveloping membranes (7) wherein the membrane may be of any of a range of metallic, fiber-matrix composite, or other materials.

**[00105]** Specifically, in step (q), Figure 21 illustrates each elastomer-saturated bundle, or group of one or more bundles (28), placed around one concentric row of hook-like extensions (24), one at a time, progressing outwardly, and placed under tension until all bundles are in place. Accordingly, it should be understood that the extensions (24) may be provided on one or both of the surface membranes (7, 8). Next, in step (r), figure 22 illustrates the uncut part (17) or "Fabrication part D" that is positioned on the surface of projections (24) and bundles (28), pressure is applied, and the central layer (1) cured similar to step (p) of figure 20. Figure 23 shows step (s), another variation of step (q) in which, rather than curved rows of hook-like projections extending from membrane (7) or membrane (8), one or more flanges (35) can support successive concentric bundles of fibers.

**[00106]** Dependent upon which method of making as above described has been employed, the appropriate surface membrane(s) (7, 8), such as a carbon-fiber composite or glass-fiber composite, may be applied, e.g. adhesively, to the elastomeric central layer (1) following curing, such as in multiple laminae, to the opposite surface(s) of the central layer (1) to form prosthetic anchor (36). It should be understood that the surface membranes (7, 8) may be optional insofar as the central layer (1) may be provided alone, i.e. without the surface membranes (7, 8), or with only one surface membrane (7 or 8), thereby defining the prosthetic anchor (36). Accordingly, it should be understood that the material of the central layer (1) may be modified to provide the desired flexibility or rigidity and can optionally, or in addition to a suitable polymer, include a carbon-fiber composite or glass-fiber composite with a matrix such as epoxy.

**[00107]** Figures 24 and 25 show yet another alternative method in which an envelope (42) of fiber-matrix composite, such as carbon-fiber/epoxy, can be preformed and fibers inserted with uncured elastomer through one open margin, as further described below, following which the assembly defining the prosthetic anchor (36) is fixed to bone or prosthesis with screws or other means, which also fix the margins of the envelope to each other.

**[00108]** More specifically, figure 24 shows step (aa) wherein a machined or molded bloc replica, or master (37), of envelope or wafer (42) is provided. Figure 25 shows step (bb) including providing a two-part silicone mold (38) of the master (37). Figure 26 illustrates optional step (cc) wherein similar layers or surface membranes could be 'laid up' (not shown) on the deep side of the master (37) as well. In particular, figure 26 shows radial fibers (39), such as carbon, glass, or other, with two diagonal layers (40, 41) in space.

**[00109]** Figure 27 illustrates step (dd) showing curing in mold (38) to form fiber-composite envelope (42). Figure 28 illustrates step (ee) showing a demolded, trimmed, fiber-composite envelope (42) (above) and held in clasp (43) (below) for insertion of fibers. The outer and inner membranes of the envelope are united only at the margin (44) of the parabolic shaped opening. The clasp (43) has a flange (45) to hold the envelope (42) apart during insertion of fiber tows. Figure 29 illustrates step (ff) wherein the envelope (42) with inserted fiber tows defining prosthetic anchor (36) is fixed to bone (46) with screws (47) and metal stress-distributing plates (48).

**[00110]** Figure 30 shows an embodiment of the prosthetic anchor (36) as might be applied to terminate and affix to a hydraulic or other mechanical energy converter (49). Figure 31 shows another embodiment of the invention as might be applied to terminate and fix the prosthetic anchor (36) to a frontal bone (50), as might be desired in the cosmetic surgical procedure of brow lift. Figure 32 is yet another embodiment of the invention as might be applied to terminate and fix the prosthetic anchor (36) to an olecranon (51) of an ulna, as reconstruction of a damaged triceps tendon.

**[00111]** While the present invention has been illustrated by the description of the various embodiments thereof, and while the embodiments have been described in considerable detail, it is not intended to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the scope or spirit of Applicant's general inventive concept.

**WHAT IS CLAIMED IS:**

1. A prosthetic anchor adapted for attachment to a natural or prosthetic structure of a human or animal, comprising:

a central layer including a plurality of embedded fiber bundles having a plurality of fibers, each of the plurality of fiber bundles being situated concentrically therein to substantially define a horseshoe pattern, the central layer further having opposing first and second surfaces and first and second spaced apart openings to allow opposing ends of the plurality of embedded fiber bundles to exit the central layer, the opposing first surface membrane adapted to interface with the natural or prosthetic structure and the opposing second surface membrane adapted to interface with tissue.

2. A prosthetic anchor adapted for attachment to a natural or prosthetic structure of a human or animal, comprising:

a central layer including a plurality of embedded fiber bundles having a plurality of fibers, each of the plurality of fiber bundles being situated concentrically therein to substantially define a horsehoe pattern, the central layer further having opposing first and second surfaces and first and second spaced apart openings to allow opposing ends of the plurality of embedded fiber bundles to exit the central layer; and

first and second surface membranes, each of the first and second surface membranes cooperating with one of the opposing first and second surfaces of the central layer, the first surface membrane adapted to interface with the natural or prosthetic structure and the second surface membrane adapted to interface with tissue.

3. The prosthetic anchor of claim 2 wherein the first or second surface membranes include a carbon-fiber/epoxy composite, glass-fiber/epoxy composite, or biocompatible metal.

4. The prosthetic anchor of claim 2 wherein the first and second surface membranes are bonded mechanically and/or adhesively to the central layer.

5. The prosthetic anchor of claim 2 wherein the central matrix layer includes an elastomeric material.

6. The prosthetic anchor of claim 2 wherein the plurality of fiber bundles define artificial tendons.

7. The prosthetic anchor of claim 2 wherein at least one surface of the first or second surface membranes are textured to permit mechanical bonding with the central layer or adjacent structures.

8. A method of making a prosthetic anchor, comprising:
- molding first and second surface membranes having desired contours to a surface to which the prosthetic anchor is to be attached;
  - molding a central layer having a desired contour to the surface to which the prosthetic anchor is to be attached, the central layer including a plurality of fiber bundles having a plurality of fibers embedded therein, each of the plurality of fiber bundles being situated concentrically in the central layer to substantially define a pattern, the central layer further having opposing first and second surfaces and first and second spaced apart openings to allow opposing ends of the plurality of embedded fiber bundles to exit the central layer; and
  - securing each of the first and second surface membranes to one of the opposing first and second surfaces of the central layer, the first surface membrane adapted to interface with the surface to which the prosthetic anchor is to be attached and the second surface membrane adapted to interface with tissue.

9. A method of securing a prosthetic anchor to a natural or prosthetic structure of a human or animal, comprising:

providing the natural or prosthetic structure of the human or animal;

providing the prosthetic anchor comprising:

a central layer including a plurality of embedded fiber bundles having a plurality of fibers, each of the plurality of fiber bundles being situated concentrically therein to substantially define a pattern, the central layer further having opposing first and second surfaces and first and second spaced apart openings to allow opposing ends of the plurality of embedded fiber bundles to exit the central layer;

first and second surface membranes, each of the first and second surface membranes cooperating with one of the opposing first and second surfaces of the central layer, the first surface membrane adapted to interface with the natural or prosthetic structure and the second surface membrane adapted to interface with tissue; and

securing the prosthetic anchor to the natural or prosthetic structure of the human or animal.

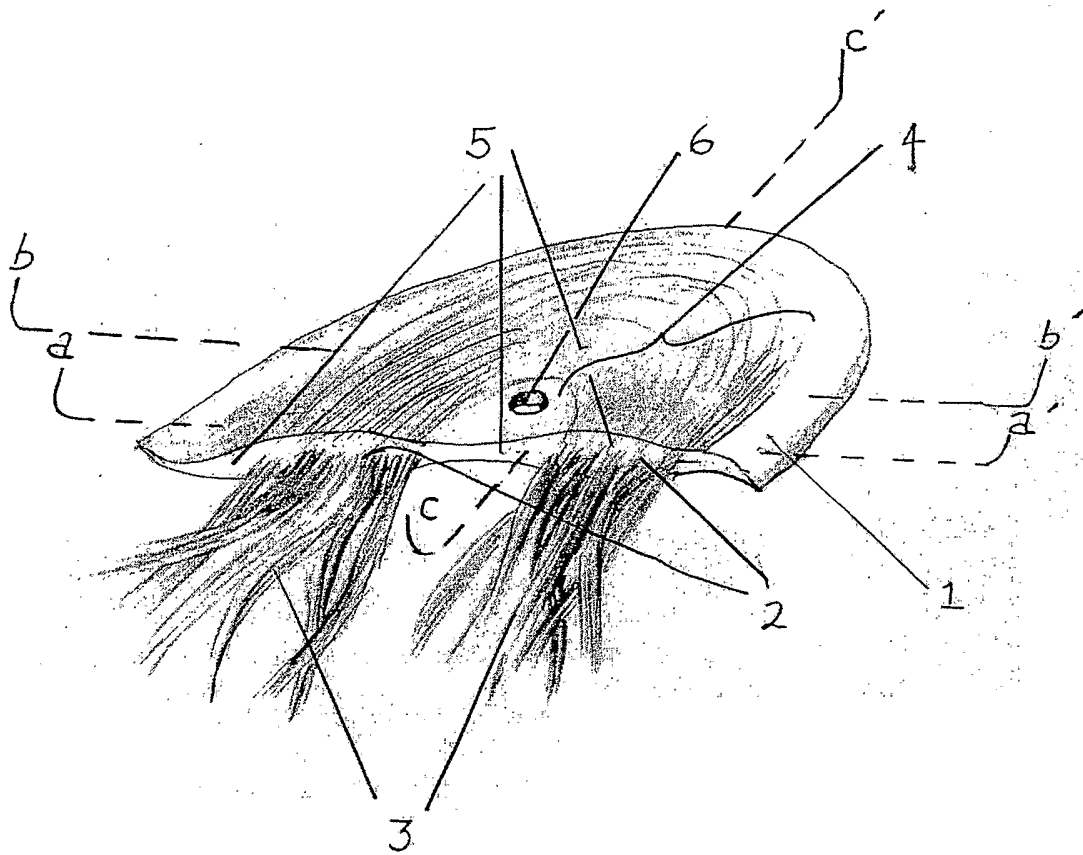


Figure 1

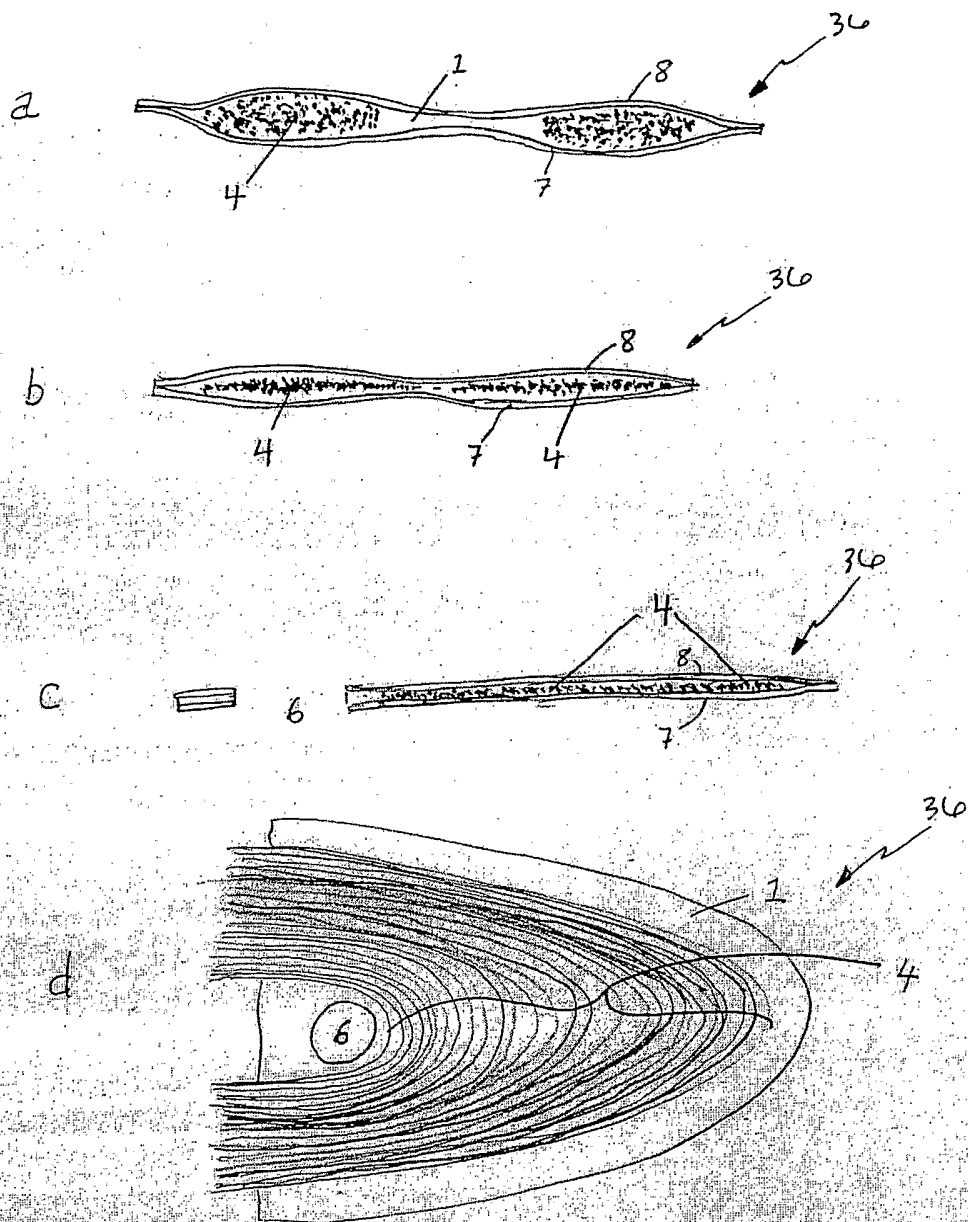


Figure 2

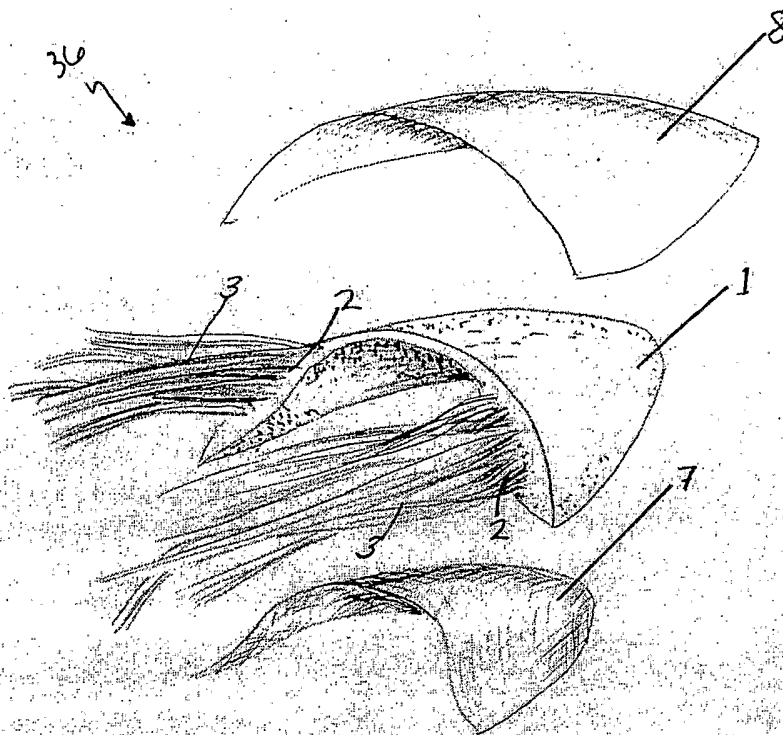


Figure 3

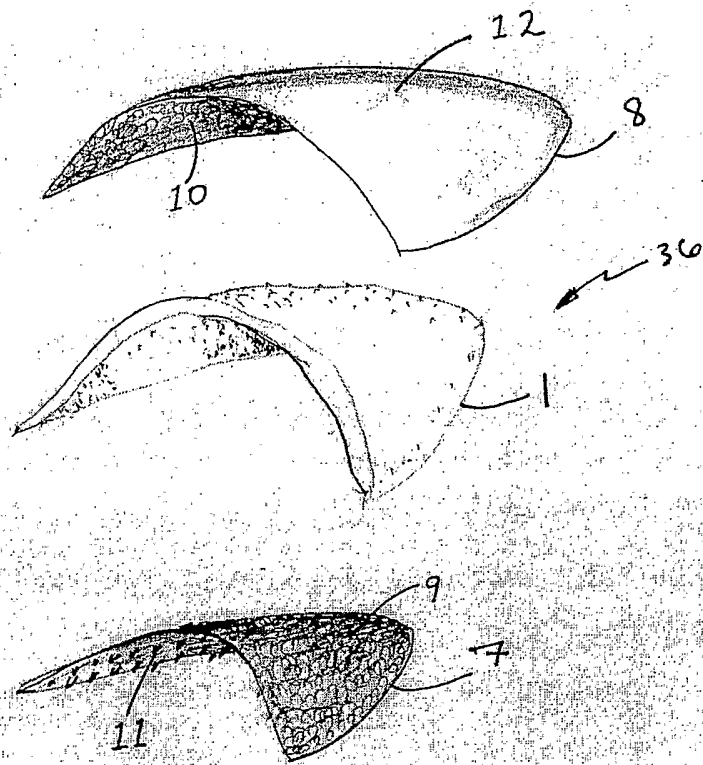


Figure 4

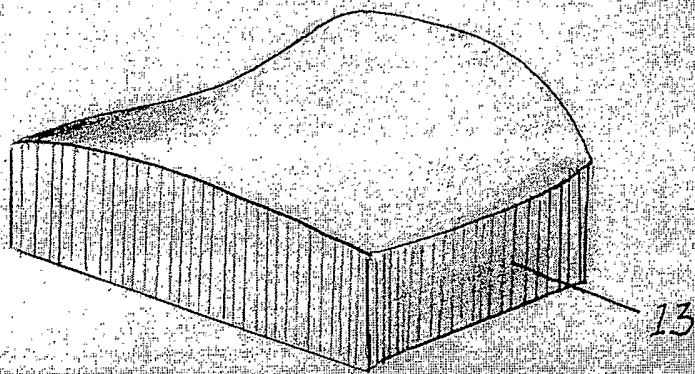


Figure 5

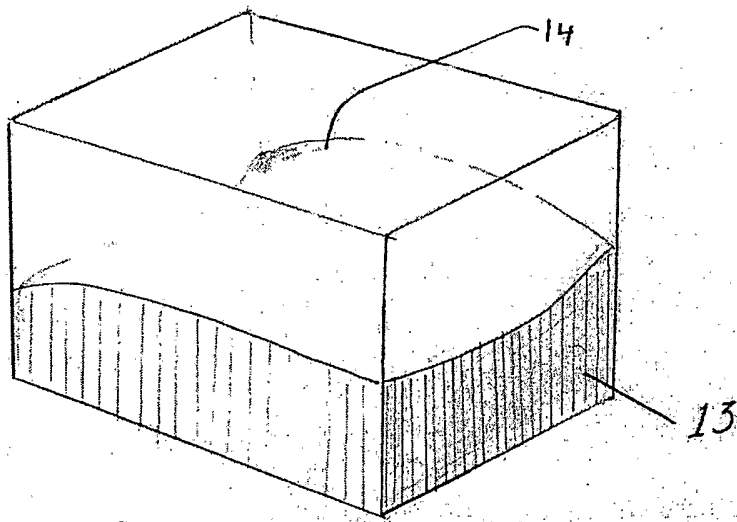


Figure 6

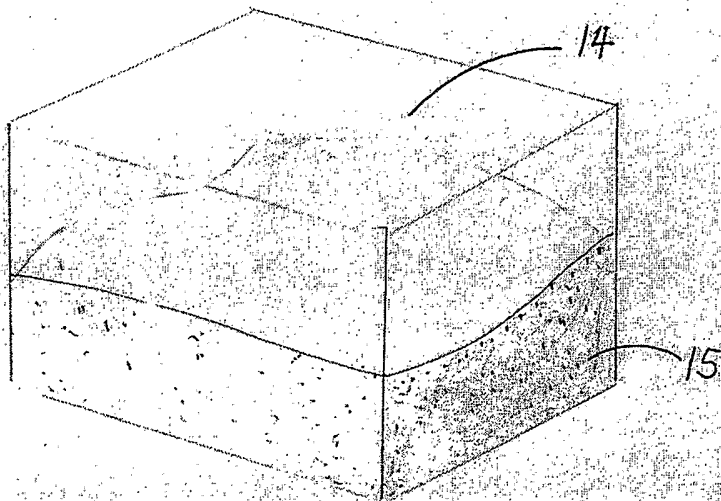


Figure 7

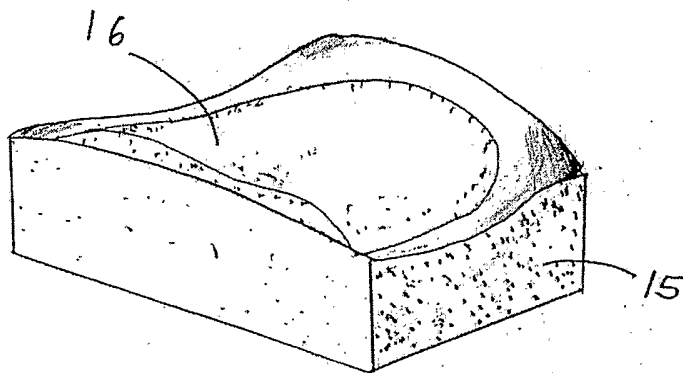


Figure 8

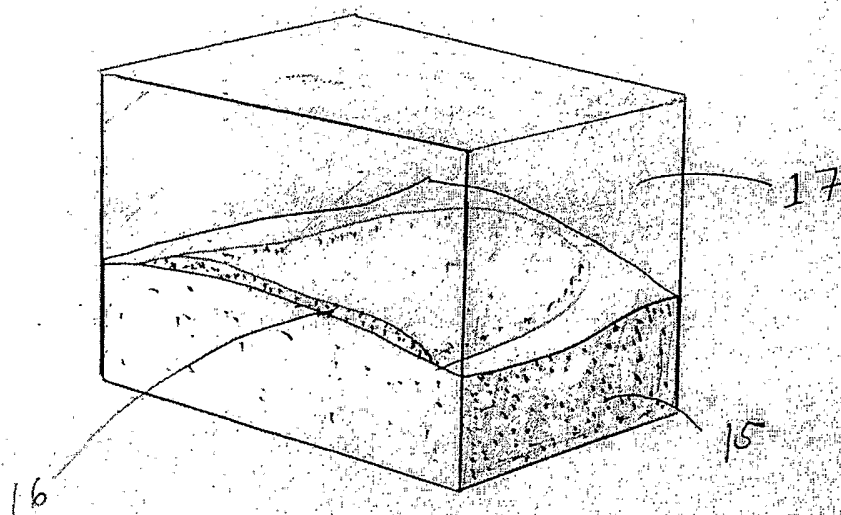


Figure 9

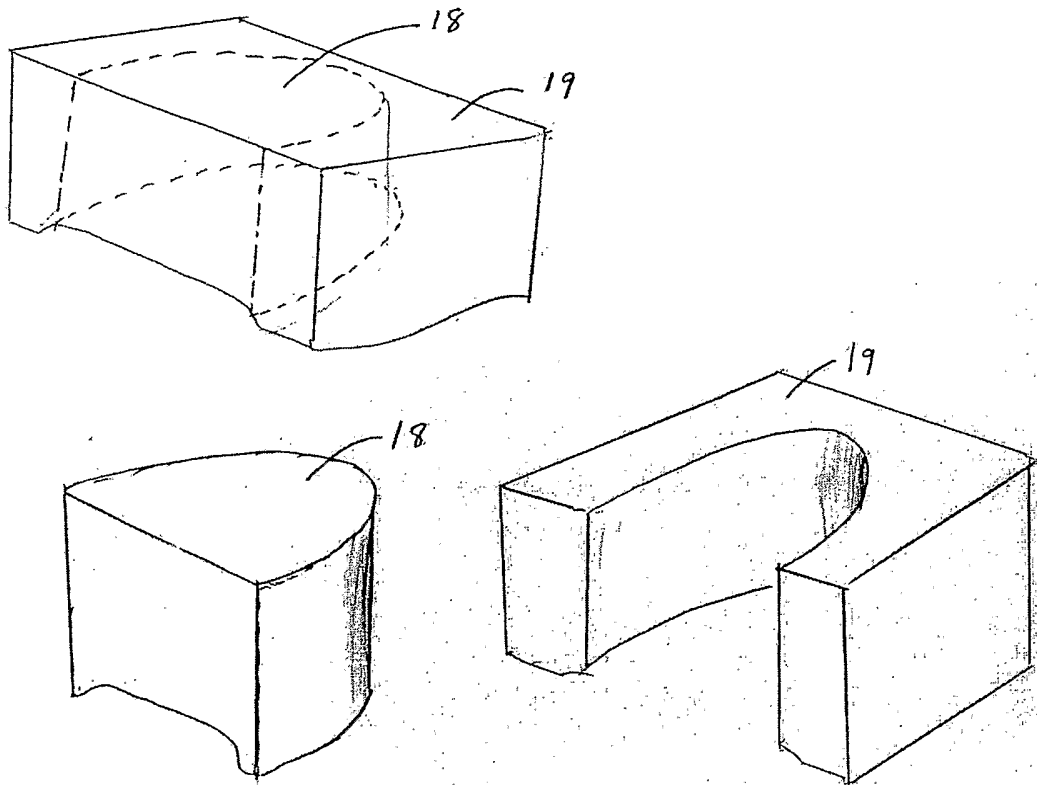


Figure 10

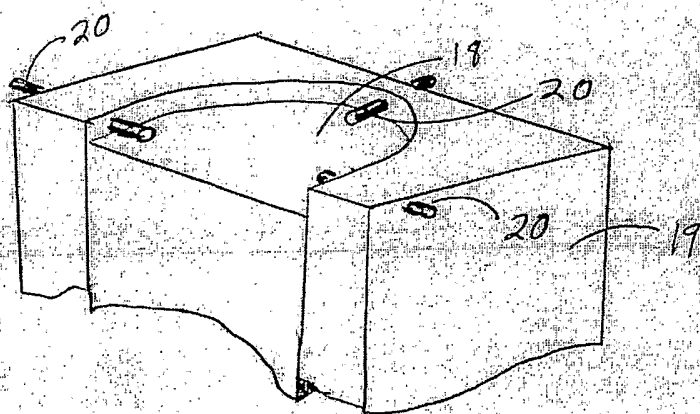
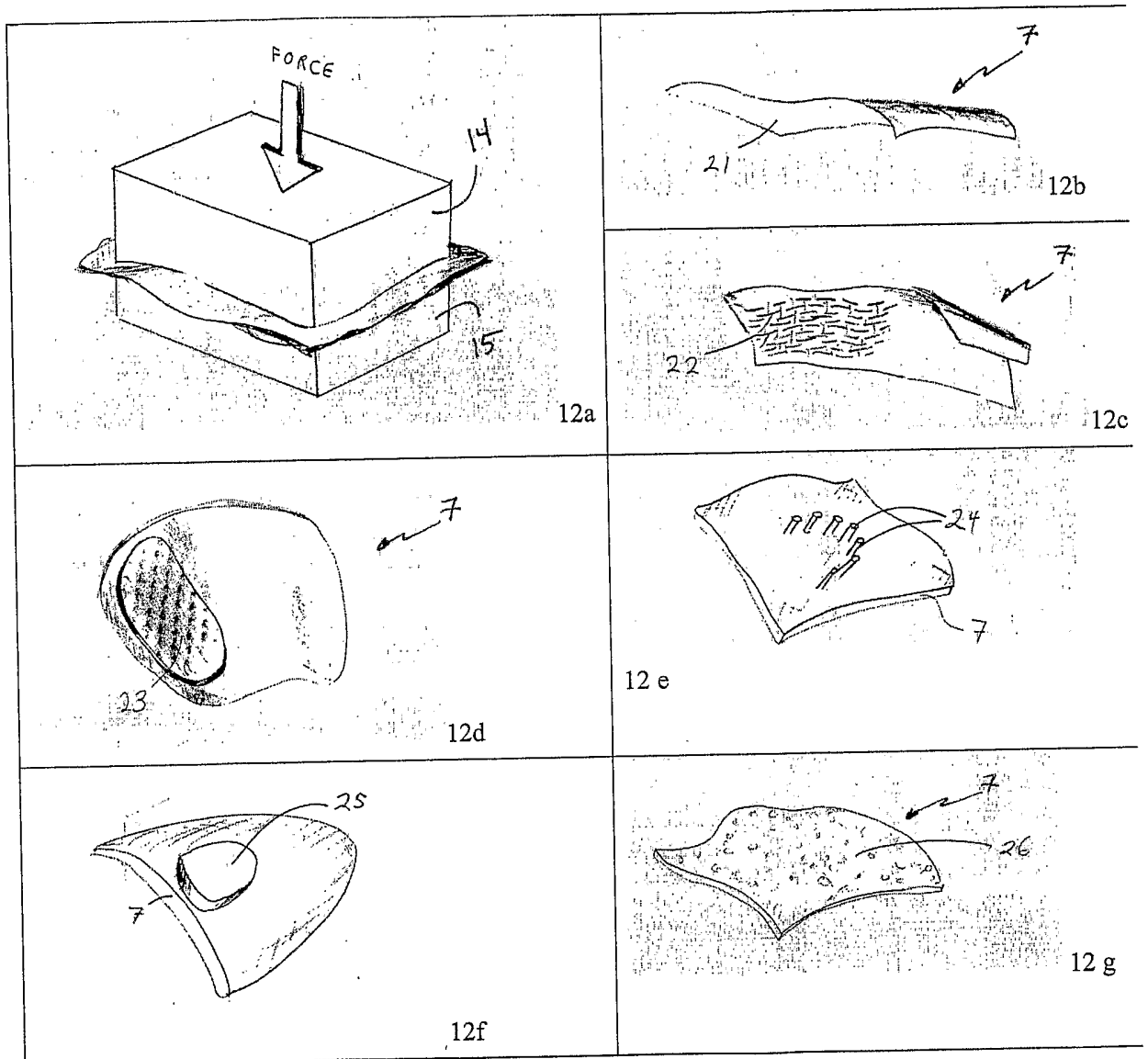


Figure 11



Figures 12a-12g

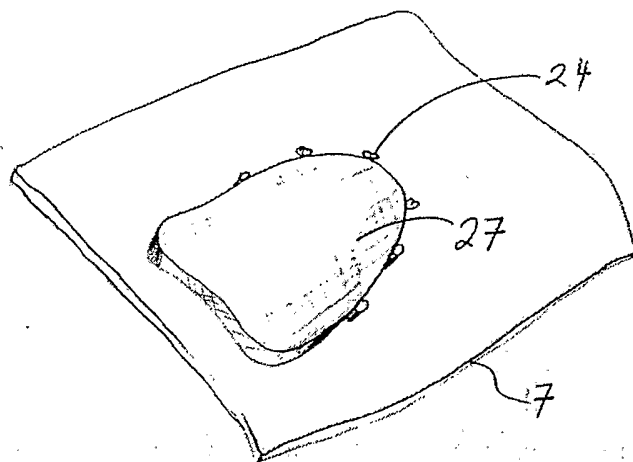


Figure 13a

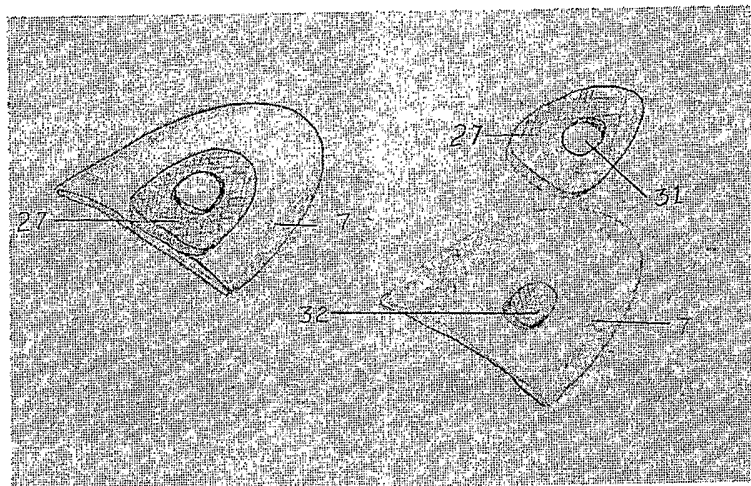


Figure 13b

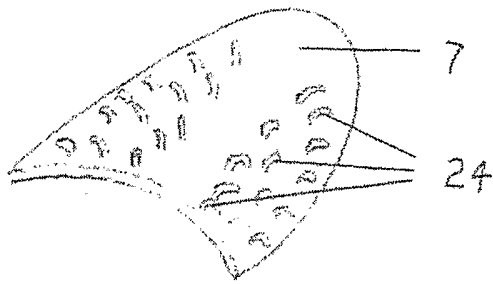


Figure 13c

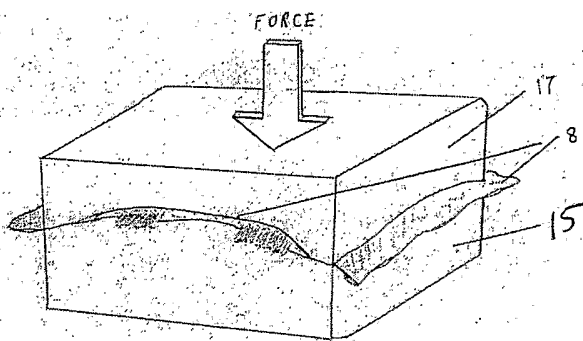


Figure 14

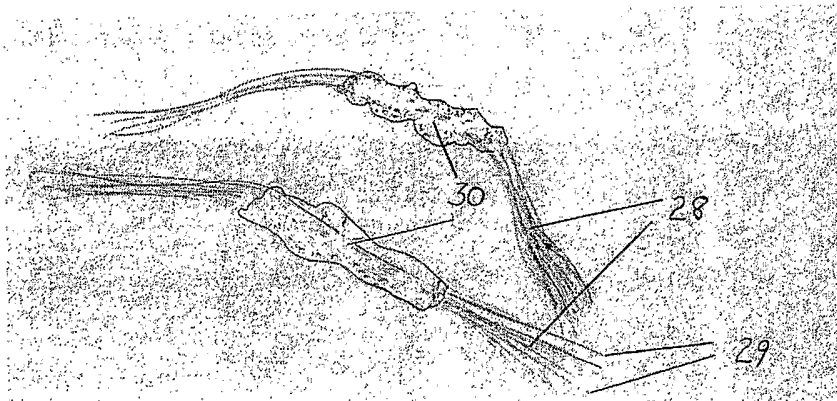


Figure 15

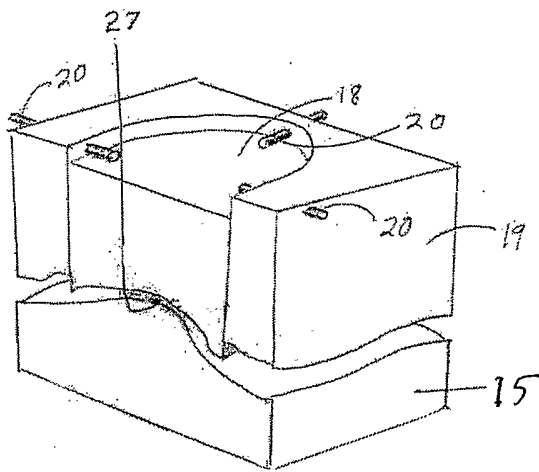


Figure 16

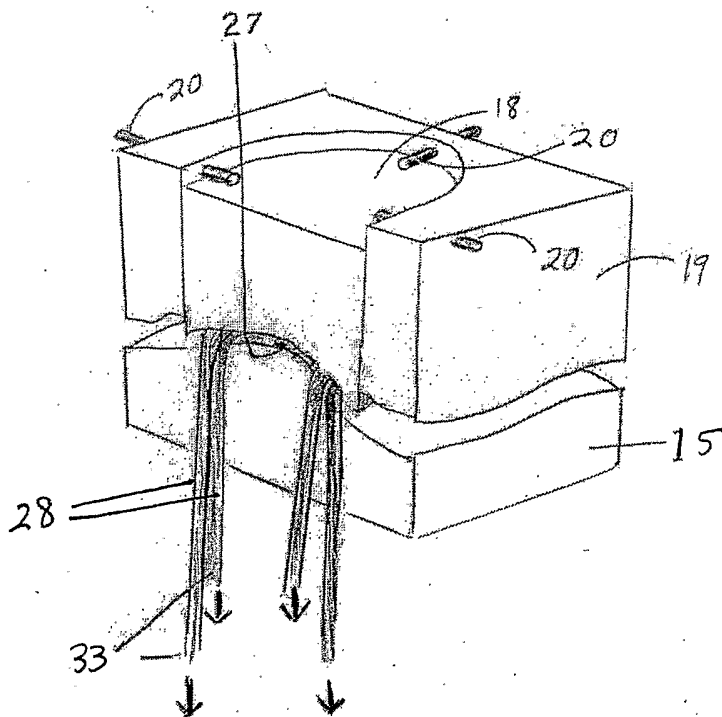
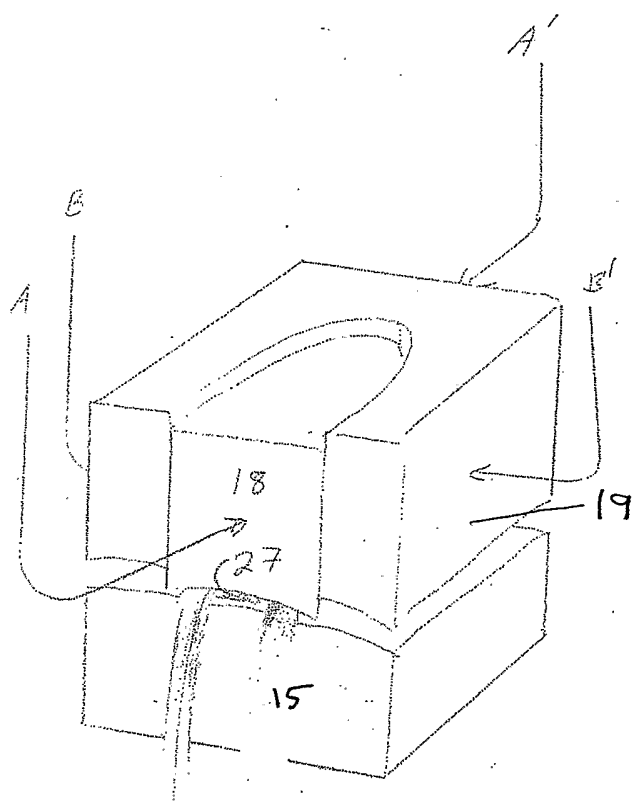
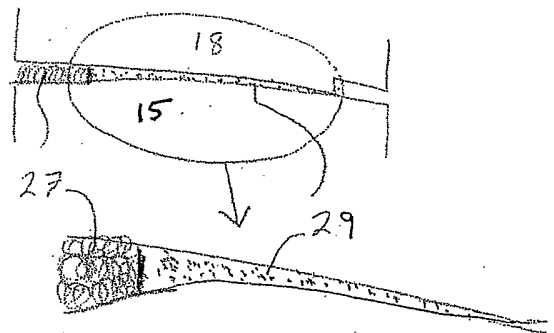


Figure 17

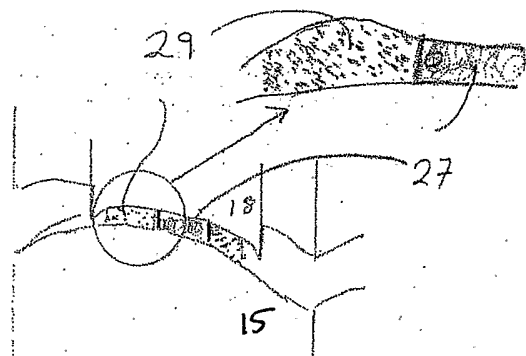
FIGURE 18



SECTION A/A'



SECTION B/B'



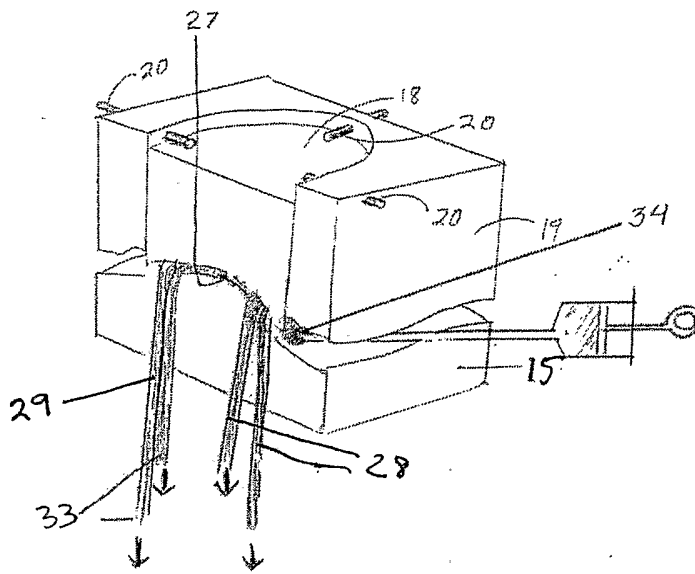


Figure 19

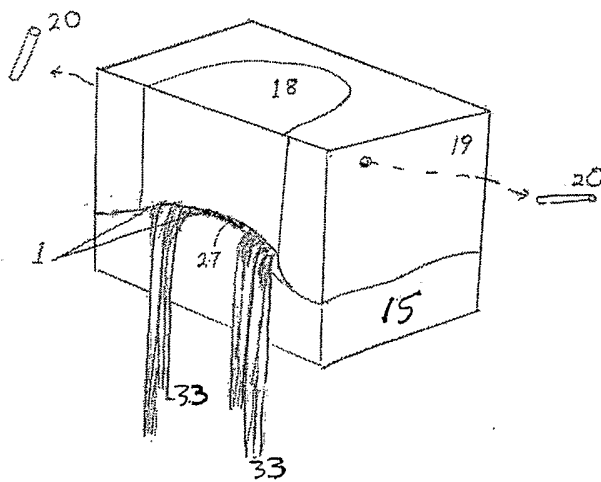


Figure 20

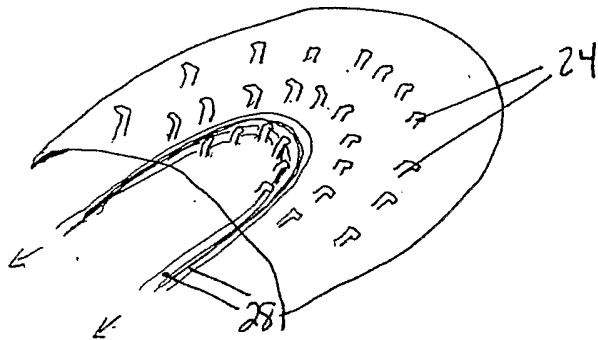


Figure 21

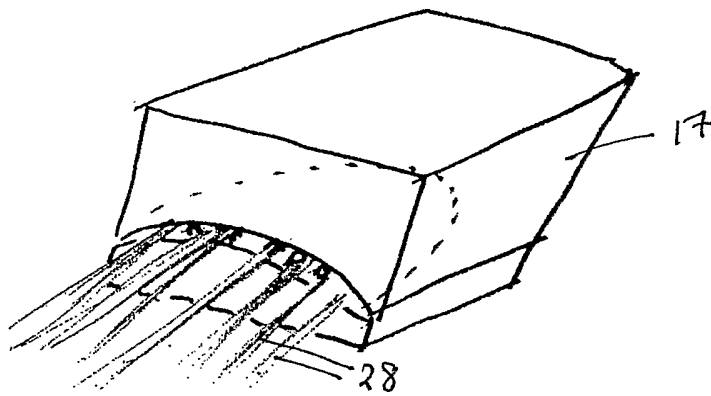


Figure 22

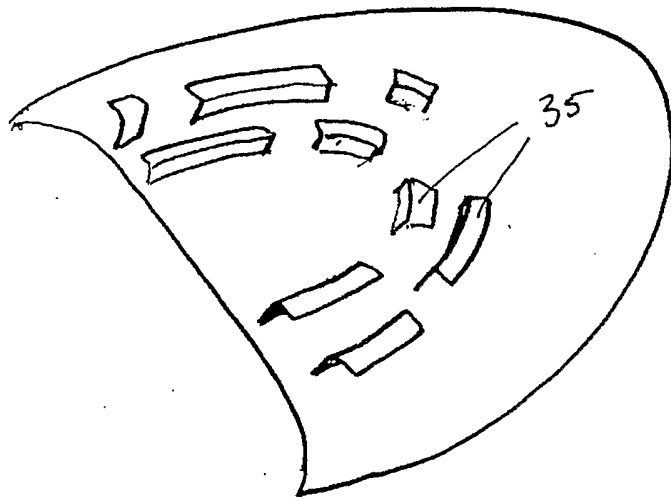


Figure 23

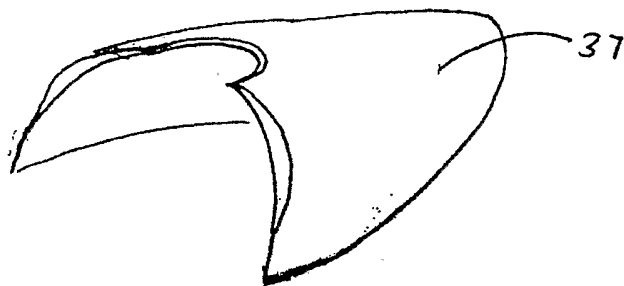


Figure 24

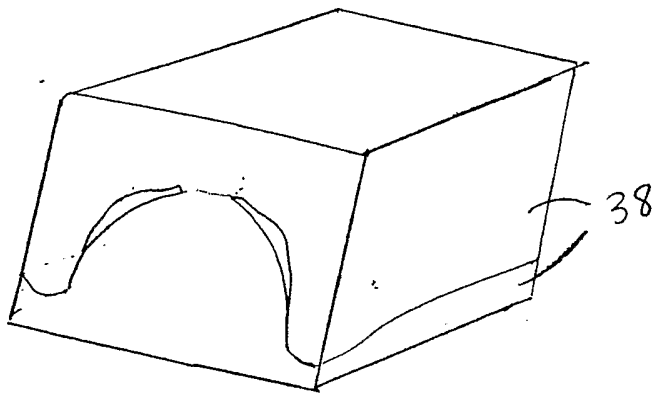


Figure 25

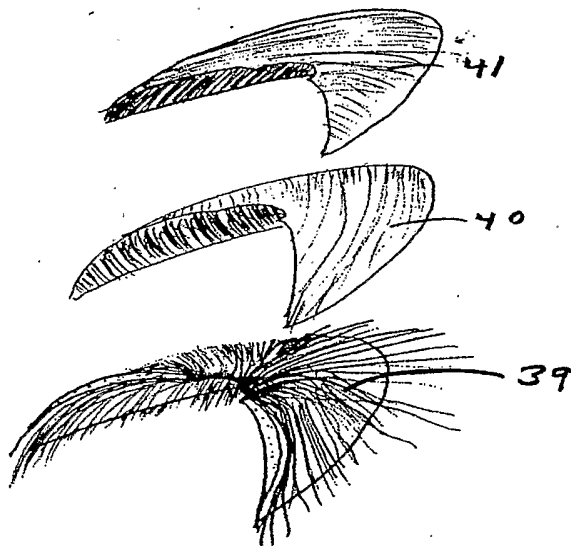


Figure 26

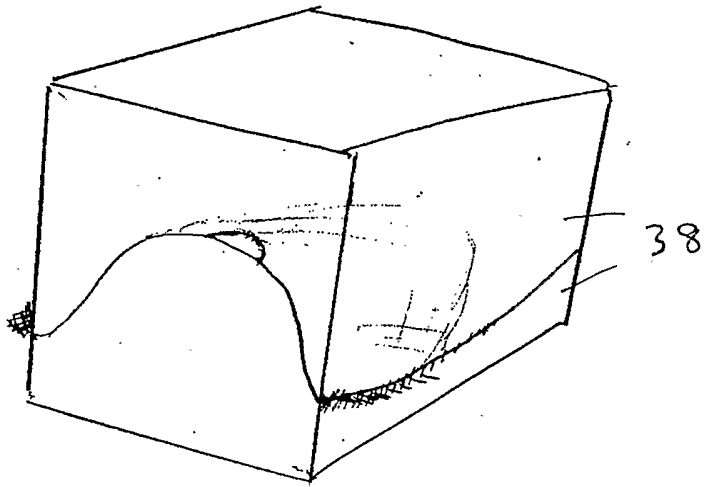


Figure 27

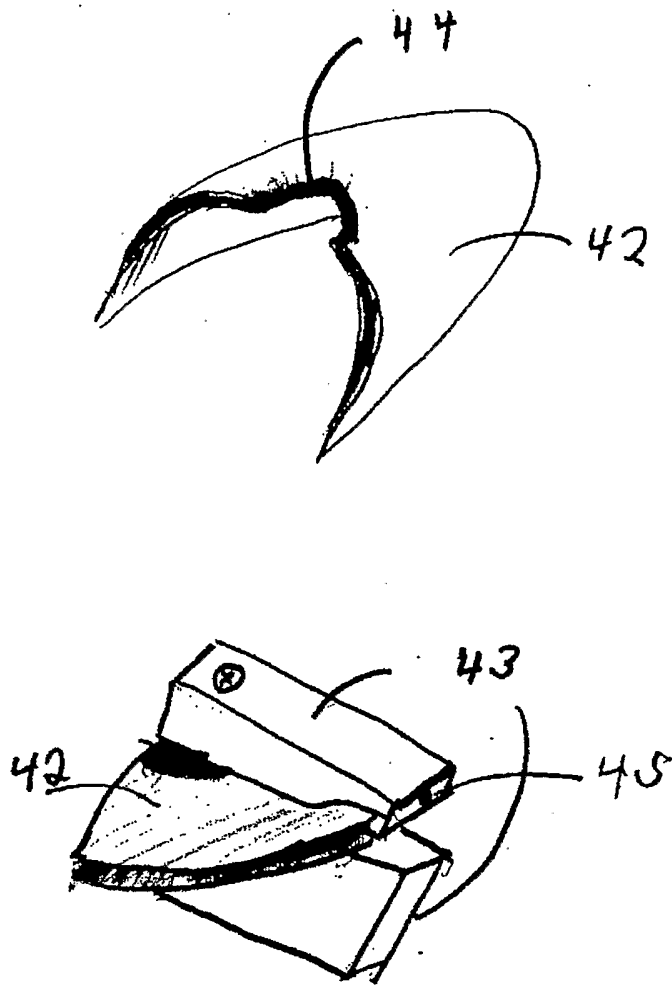


Figure 28

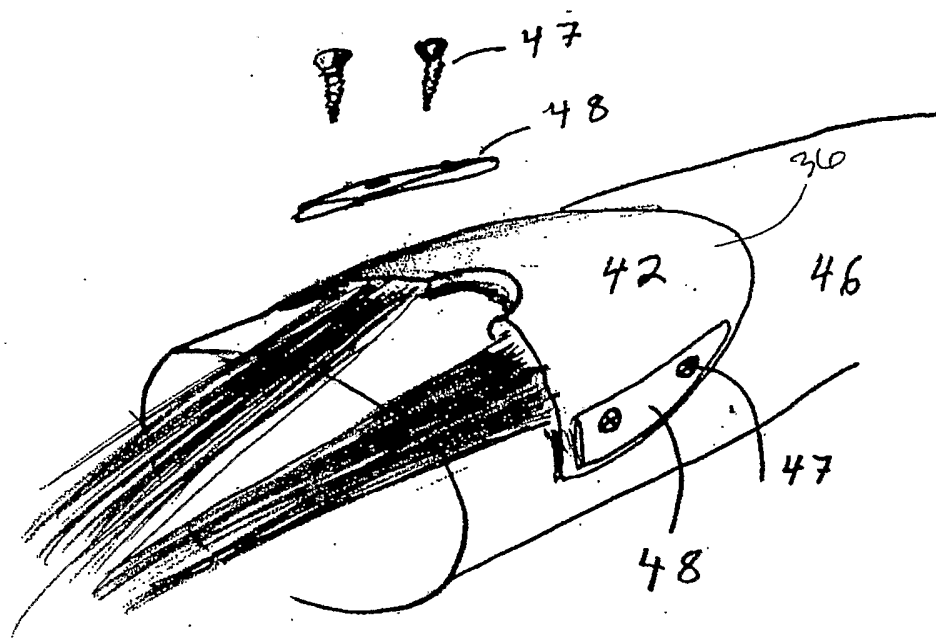


Figure 29

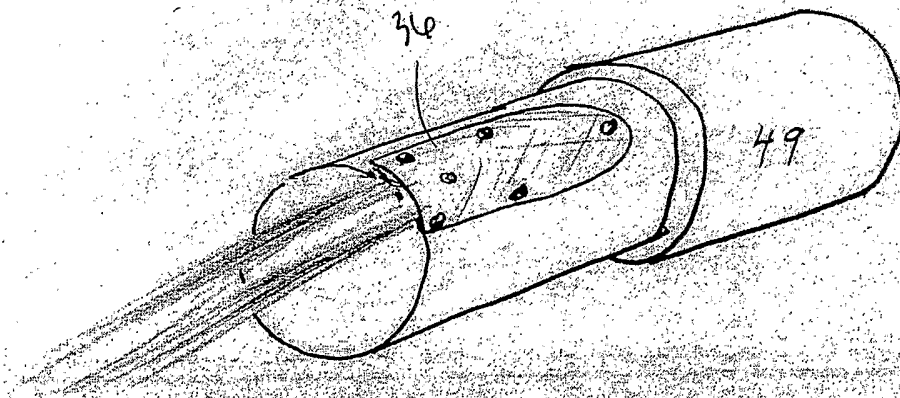


Figure 30

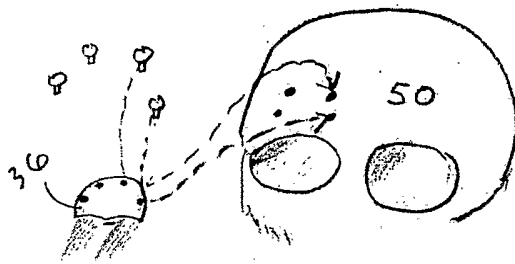


Figure 31

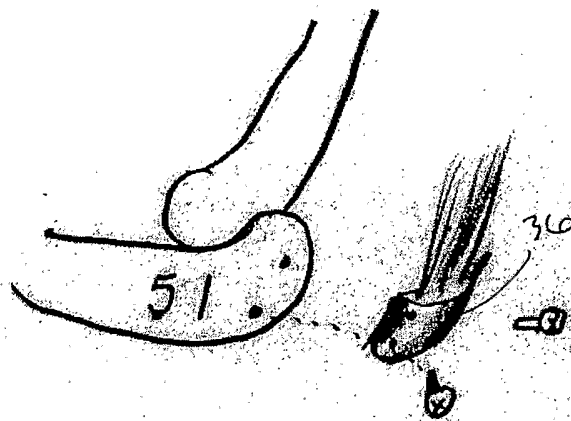


Figure 32