Mesh Selection for Open and Laparoscopic Hernia Repair

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Light? How light is too light?

- Density (mass) directly proportional to tensile strength, but not too porosity

- Lightweight mesh bulge, so for bridging laparoscopically, they may need to stick with heavier mesh and additional transfacial sutures.
Porosity

• Pore size < 100 microns $\Rightarrow$ tissue encapsulation
• Pore size 1000 microns $\Rightarrow$ better tissue ingrowth
Factors to consider
The “Ideal” Mesh

- Strong, yet Flexible
- Readily Available in Large Quantities
- Cost-Effective
- Good Handling Properties / Versatile
  - Cut, Fold, Mold, Hold Suture
- OR-Ready
- Biocompatible / Noncarcinogenic / Noninfectious
- Resistant to Infection
- Minimal Inflammatory Response
- Good Abdominal Wall Integration
- Minimal Visceral Adhesion Formation
- Avoidance of Significant Stretching or Contraction
- Appropriate Remodeling without Loss of Strength over time
- Lack of Pain or Discomfort to the Patient
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<table>
<thead>
<tr>
<th>Trade Name</th>
<th>Mesh Fiber</th>
<th>Barrier Coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mersilene</td>
<td>Multifilament Polyester</td>
<td>None</td>
</tr>
<tr>
<td>Dacron</td>
<td>Multifilament Polyester</td>
<td>None</td>
</tr>
<tr>
<td>Prolene</td>
<td>Polypropylene</td>
<td>None</td>
</tr>
<tr>
<td>ProLite Ultra</td>
<td>Lightweight Polypropylene</td>
<td>None</td>
</tr>
<tr>
<td>Composix</td>
<td>Polypropylene and ePTFE</td>
<td>None</td>
</tr>
<tr>
<td>DualMesh</td>
<td>Dual-surfaced ePTFE</td>
<td>None</td>
</tr>
<tr>
<td>Sepramesh</td>
<td>Macroporous Polypropylene</td>
<td>Sodium hyaluronate &amp; carboxymethylcellulose</td>
</tr>
<tr>
<td>Proceed</td>
<td>Prolene &amp; Laminated PDS</td>
<td>Oxidized Regen. cellulose</td>
</tr>
<tr>
<td>Parietex</td>
<td>Multifilament Polyester</td>
<td>Bovine collagen, glycerol, and polyethylene glycol</td>
</tr>
<tr>
<td>C-Qur</td>
<td>Lightweight Polypropylene</td>
<td>Ω-3 Fatty acid</td>
</tr>
</tbody>
</table>
## Strong, Yet Flexible

<table>
<thead>
<tr>
<th>Material</th>
<th>Marlex</th>
<th>Prolene Soft</th>
<th>Ultrapro</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>Polypropylene</td>
<td>Polypropylene</td>
<td>Polypropylene, poliglecaprone</td>
</tr>
<tr>
<td><strong>Weight (g/m²)</strong></td>
<td>95</td>
<td>45</td>
<td>28</td>
</tr>
<tr>
<td><strong>Pore size (mm)</strong></td>
<td>0.6</td>
<td>2.4</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Micrograph (20X)**

![Micrograph of Marlex](image1)

![Micrograph of Prolene Soft](image2)

![Micrograph of Ultrapro](image3)
ProLite™ & ProLite Ultra™

Atrium Medical Corp., Hudson, NH

ProLite™
“Intermediate” Weight Mesh

ProLite Ultra™
Lightweight Mesh

2nd Generation Lightweight Mesh
ProLite™ & ProLite Ultra™

**ProLite™ MESH**
Polypropylene Monofilament Mesh

Avg. pore size: 800 microns
Avg. filament weight: 6 mil
Avg. gm/m²: 85 gm/m²

**ProLite ULTRA**
Polypropylene Monofilament Mesh

Avg. pore size: 750 microns
Avg. filament weight: 4.5 mil
Avg. gm/m²: 50 gm/m²
Vypro™

Ethicon, Inc., Somerville, NJ
polypropylene/polyglactin 910
Vypro™

Weight = 26.8 gm/m²

Polypropylene/polyglactin 910

Polyglactin 910
70% initial strength – 10 days
30% initial strength – 20 days
Complete absorption – 60-90 days
Ultrapro™

Ethicon, Inc., Somerville, NJ

Weight = 28 gm/m²
polypropylene / polyglecaprone (monocryl)

Monocryl - 75% glycolide
25% caprolactone
50% initial strength – 7 days
20% initial strength – 14 days
complete absorption – 90-120 days
Lightweight Mesh - TiMESH®

• PFM Medical, Inc., Oceanside, CA
  lightweight polypropylene mesh
  30 nm layer titanium coating

TiMESH® Light
  area weight - 35 g/m²; 0.3 mm thickness, 86.3% porous

TiMESH® Extralight
  area weight - 16 g/m²; 0.2 mm thickness, 94.3% porous

In vivo studies comparing the biocompatibility of various polypropylene meshes and their handling properties during endoscopic total extraperitoneal (TEP) patchplasty: an experimental study in pigs. 
Lightweight Mesh - TiMESH®
Lightweight Meshes

VYPRO®

Prolene – non-absorbable polypropylene
Vicryl – absorbable polyglactin 910

ULTRAPRO®

Prolene - non-absorbable polypropylene
Monocryl - absorbable poliglecaprone

<table>
<thead>
<tr>
<th></th>
<th>area wt (g/m²)</th>
<th>Thickness</th>
<th>Pore size</th>
<th>P_{max}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolene</td>
<td>80-95</td>
<td>0.6 mm</td>
<td>1-2 mm</td>
<td>1650 mmHg</td>
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<tr>
<td>Vypro</td>
<td>26.8</td>
<td>0.5 mm</td>
<td>3-4 mm</td>
<td>525 mmHg</td>
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<tr>
<td>Ultrapro</td>
<td>28</td>
<td>0.39 mm</td>
<td>3-4 mm</td>
<td>375 mmHg</td>
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</table>

# Range of Intraabdominal Pressures
Generated for each Maneuver

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>Minimum (mmHg)</th>
<th>Maximum (mmHg)</th>
<th>Mean (mmHg)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>15</td>
<td>27</td>
<td>20.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Sitting</td>
<td>10</td>
<td>21</td>
<td>16.7</td>
<td>2.9</td>
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<tr>
<td>Stairs</td>
<td>40</td>
<td>110</td>
<td>68.9</td>
<td>17.4</td>
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<tr>
<td>Abdominal crunch</td>
<td>7</td>
<td>47</td>
<td>26.7</td>
<td>10.7</td>
</tr>
<tr>
<td>Bend at waist</td>
<td>6</td>
<td>30</td>
<td>14.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Bend at knees</td>
<td>14</td>
<td>30</td>
<td>20.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Cough</td>
<td>40</td>
<td>127</td>
<td>81.4</td>
<td>25.6</td>
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<tr>
<td>Standing cough</td>
<td>64</td>
<td>141</td>
<td>107.6</td>
<td>23.0</td>
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<tr>
<td>Valsalva</td>
<td>20</td>
<td>64</td>
<td>39.7</td>
<td>11.0</td>
</tr>
<tr>
<td>Standing Valsalva</td>
<td>32</td>
<td>116</td>
<td>64.9</td>
<td>22.0</td>
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<tr>
<td>Jumping</td>
<td>43</td>
<td>252</td>
<td>171</td>
<td>48.4</td>
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<tr>
<td>Bench press</td>
<td>2</td>
<td>34</td>
<td>7.4</td>
<td>7.3</td>
</tr>
<tr>
<td>Arm curl</td>
<td>17</td>
<td>37</td>
<td>25.5</td>
<td>6.0</td>
</tr>
</tbody>
</table>
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Proceed™

Ethicon Inc., Somerville, NJ
oxidized, regenerated cellulose / polypropylene
Barrier = oxidized, regenerated cellulose

- protection against adhesion formation during the critical period of re-mesothelialization
- anti-adhesive barrier forms physical barrier on damaged surfaces to impede adherence
- physical barrier allows injured tissue to heal separately from other injured or healing tissue

polydioxanone (PDS) polymer film bonded to lightweight polypropylene
Sepramesh™

Genzyme Corp., Cambridge, MA

hyaluronic acid – carboxymethylcellulose / polypropylene

disaccharide N-acetylglucosamine glucoronic acid
inhibits collagen deposition extracellular matrix
  cell / cell – cell / tissue interaction
regulates matrix-degrading enzymes
  mesothelial cell fibrinolytic response
  ↑ peritoneal hydroxyprolene
promotes phagocytosis

carboxymethylated cellulose
anionic polysaccharide
resorbable membrane - ↓ viscosity
Parietex® Composite™

Covidien, Norwalk, CT

polyethylene glycol - glycerol / collagen coated polyester

polyester coating - oxidized bovine atelocollagen Type I
  ↑ hydrophilicity / ingrowth – abdominal wall

polyethylene glycol
  hydrogel – ↓ tissue adherence

glycerol
  hydrophobic lipid; osmotic effect

Parietene® Composite™

polypropylene
Parietex™ ProGrip™ Mesh

Covidien, Norwalk, CT

- Monofilament Polyester Mesh
- Resorbable PLA (Polylactic Acid) Gripping system
  - “Velcro-like”
- Used for open inguinal hernia repair
C-Qur™ Atrium Coated Mesh

- FDA-approved for human use
- Tissue-separating, anti-adhesion layer derived from Omega-3 fatty acids
- Thin coating on side contacting abdominal wall, thicker coating on visceral side
- Coating remains intact for at least 90 days
C-Qur EDGE™
Dual Mesh®

W.L. Gore & Assoc., Inc., Flagstaff, AZ

polytetrafluoroethylene

microporous ~ 3 µm
“barrier to adhesions”
Dual Mesh Plus®

Impregnated - silver carbonate / chlorhexidine diacetate

Dent et al., Surg Forum 18:72, 1992
↓ infectability - Staph Aureus

Malaisrie et al., Laryngoscope 108:1733, 1998
resistance to bacterial biofilm

↓ infectability - Staph Aureus ; MRSA?
Composix™
C.R. Bard, Inc., Murray Hill, NJ
polytetrafluoroethylene / polypropylene

polytetrafluoroethylene: hydrophobic microporous fluoropolymer
Dulex™

C.R. Bard, Inc., Murray Hill, NJ

Dual-sided Polytetrafluoroethylene

- Micro-porous structure on one side minimizes visceral attachment to prosthesis
- Other side is a macro-porous structure designed to promote tissue ingrowth
- 35x more tissue ingrowth capacity than Gore-Tex® DualMesh* Corduroy Biomaterial
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Lack of Pain or Discomfort to the Patient
Complicated Ventral Hernias
Complicated Ventral Hernias
Bioprosthetic “Meshes”

• Currently obtained from Human, Porcine, and Bovine Sources

• Naturally-derived Extracellular Dermal Matrix
  – Comprised primarily of Collagen and Elastin
  – All cellular and genetic material is removed

• May be chemically Crosslinked or Noncrosslinked (stability)

• Provide a “scaffolding” for the host’s cells to move along and repopulate

• Remodel to various extents - Nonpermanent
<table>
<thead>
<tr>
<th>Name</th>
<th>Manufacturer</th>
<th>Source</th>
<th>Tissue</th>
<th>Cross Link?</th>
<th>Cost (US$/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgisis</td>
<td>Cook (IN, USA)</td>
<td>Pig</td>
<td>Sm. Intestine</td>
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<tr>
<td>Permacol</td>
<td>TSL (Hampshire, UK)</td>
<td>Pig</td>
<td>Dermis</td>
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<td>8.33</td>
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<tr>
<td>CollaMend</td>
<td>Davol Inc. (RI, USA)</td>
<td>Pig</td>
<td>Dermis</td>
<td>Yes</td>
<td>16.00</td>
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<tr>
<td>SurgiMend</td>
<td>TEI Biosci. (MA, USA)</td>
<td>Cow</td>
<td>Dermis</td>
<td>No</td>
<td>22.00</td>
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<tr>
<td>Alloderm</td>
<td>LifeCell (NJ, USA)</td>
<td>Human</td>
<td>Dermis</td>
<td>No</td>
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<tr>
<td>Allomax</td>
<td>Davol Inc. (RI, USA)</td>
<td>Human</td>
<td>Dermis</td>
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<tr>
<td>FlexHD</td>
<td>MTF (NJ, USA)</td>
<td>Human</td>
<td>Dermis</td>
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<td>ND</td>
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<tr>
<td>Tutopatch</td>
<td>Tutogen (FL, USA)</td>
<td>Cow</td>
<td>Pericardium</td>
<td>No</td>
<td>ND</td>
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<tr>
<td>Veritas</td>
<td>Synovis (MN, USA)</td>
<td>Cow</td>
<td>Pericardium</td>
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<td>8.60</td>
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<tr>
<td>Periguard</td>
<td>Synovis (MN, USA)</td>
<td>Cow</td>
<td>Pericardium</td>
<td>Yes</td>
<td>1.90</td>
</tr>
</tbody>
</table>
Alloderm®

LifeCell Corp, Branchburg, NJ

• NON-crosslinked product derived from deceased donor human dermis
• All cells, DNA, and MHC antigens removed via Na+ deoxycholate treatment
• Final product composed of vascular basement membrane, elastin and Collagen types I, III, IV, and VII
• Shelf Life = 2 years
• Rehydrate = 20-30 minutes
Alloderm®

- Blood vessel growth seen by 28 days in rabbits, 3 months in pigs, 8 months in humans
- Initial Tensile Strength = 144 N
  - At 1 month, similar strength to Gore-Tex graft material, but less than primary fascial closure
- Animal study showed persistence of matrix @ 9 months. Numan - biopsy @ 2 years showed no sign of residual graft.
Alloderm®

• Disadvantages
• Often requires “quilting” together of several small sheets in order to cover large defect
• Tends to stretch and thin out over time, leading to prominent bulging and possible hernia re-formation.
Acellular Dermis (Flex HD)

- **Application:** Hernia repair, pelvic floor reconstruction, urological incontinence, rotator cuff repair
- **Study:** Develop a process to remove epidermal and dermal cells from donated skin producing acellular dermis matrix
- **Result:** Matrix supports cellular repopulation and vascularization at the surgical site. Supplied pre-hydrated & stored at room temperature
Surgisis™

Cook Biotech, Inc., West Lafayette, IN

• Derived from porcine small intestinal submucosa
• First developed in 1987 @ Purdue Univ.
• Available in 1-, 2-, 4-, or 8-layer (Surgisis Gold®) formats
• Composed primarily of Types I, III, and IV collagen with some glycoprotein, proteoglycan, and lipid as well
Surgisis™

- remove: mucosa / muscularis externa
- extract antigenic cells

**Acellular Dermal Matrix**

- Collagen (90% Type I),
- Proteoglycans, GAG,
- Glycoproteins (fibronectin)

preserved: freeze-dried phase
no cross-linking
sterilized – ethylene oxide
Surgisis™

- Also claims to contain numerous growth factors such as fibroblast growth factor (FGF) and vascular endothelial growth factor (VEGF)
- Shelf life = 18 months
- Rehydrate = 10 minutes
- Relative strength (animal studies)
  - Abd Wall = 146 N  - 8-Layer = 434 N
  - 4-Layer = 130  - 2-Layer = 42 N
Canine Ventral Hernia Model

- ~45% decrease in strength after 10 days, but return to original strength after 1 month
- Approximately 25% reabsorption by 1 month, 75% by 2 months and 100% by 4 months
- NO inherent antimicrobial properties despite some early claims of this
Surgisis™

Disadvantages

“Single-layer device should not be used in applications requiring high strength. SURGISIS ES may not have sufficient strength to support stresses encountered in some ventral hernias or large-area, body-wall repairs”.
Surgisis™

Disadvantages

“Device performance has not been evaluated with suture spacing greater than 2 mm. Ensure that all layers of SURGISIS ES are secured when suturing or stapling”

delamination (↓ fixation strength)
In contrast to the GRAFTJACKET® Scaffold, Porcine SIS® is a collagen matrix that has been distorted by compaction of the collagen fibers within collagen bundles and separation of adjacent collagen bundles (see Figure 2). In the sample of Porcine SIS® obtained for this report (COOK® Surgisis) the processed tissue contained numerous cell remnants evidenced by H&E staining (see Figure 2). In addition, due to the anatomical nature of small intestine (a formed tube), the tensile characteristics differ based on the directional orientation of the graft (Dejardin, 1999).

**FIGURE 2** | Porcine SIS® Material, (left H&E stain, right Verhoeff’s stain)
Note presence of cells in the processed Porcine SIS® and disrupted appearance of the collagen matrix. Elastin appears as black threads in Verhoeff’s stain.

**Conclusions**

Porcine SIS® is extensively processed, contains abundant cell remnants and minimal amounts of elastin.
Permacol™
Tissue Science Laboratories, Covington, GA

- Scaffolding composed of porcine dermal collagen
- Developed at Dundee University in 1980s and approved for use in Europe in 1995
- USA - 510(k) clearance in 2000 for repair of soft tissue defects (hernia)
- Product IS cross-linked
- Finished product is primarily collagen with significant amount of elastin (skin)
Permacol™

- Shelf life = at least 24 months
- Rehydrate = none required
- Relative tensile strength: 21,000 kPa
  - Intra-abdominal standing = 2.7 kPa
  - Intra-abdominal coughing = 14.3 kPa
- Animal studies showed tensile strength to be < polypropylene @ 15 days, but comparable @ 90 days postimplantation
<table>
<thead>
<tr>
<th>Size (cm)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 x 5</td>
<td>0.5, 1.0, 1.5</td>
</tr>
<tr>
<td>5 x 10</td>
<td>0.5, 1.0, 1.5</td>
</tr>
<tr>
<td>3 x 3</td>
<td>0.5</td>
</tr>
<tr>
<td>2 x 20</td>
<td>1.0</td>
</tr>
<tr>
<td>4 x 18</td>
<td>1.0</td>
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<tr>
<td>10 x 10</td>
<td>1.5</td>
</tr>
<tr>
<td>10 x 15</td>
<td>1.5</td>
</tr>
<tr>
<td>18 x 28</td>
<td>1.5</td>
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</tbody>
</table>
Permacol™

Disadvantages (?)

Cross-linking ≠ Re-absorption

"Retains its strength over time, thus providing support and natural contours".

Permacol™ is a proven biomaterial with unique features. Combining strength and permanence with biocompatibility results in a product that displays the best features of both synthetic and natural biomaterials. Permacol™ is a very versatile product and its use in many applications across some of the major surgical disciplines is discussed.
CollaMend™

Davol Inc., Cranston, RI

- Also composed of cross-linked porcine dermal collagen
- Approved for use in US in 2006
- Shelf life = ND
CollaMend™

- Rehydrate = 3 - 7 minutes
- Relative tensile strength = 186 N
- Found to be 80% intact @ 13 weeks in rodent study. Estimated to be completely reabsorbed after 1 year.
SurgiMend™

TEI Biosciences Inc., Boston, MA

• Composed of NON-cross-linked bovine dermal collagen (fetal, primarily Type III)
• FDA approval for use in US in 2002
• Shelf life = 3 years
• Rehydrate = 1 minute
• Average tensile strength = 20,000 kPa
• Vascular ingrowth seen as early as 3 weeks. Reportedly 100% replaced by host tissue by 9 month time point.
SurgiMend™

SurgiMend is available in large sizes including 13 x 25 cm and 16 x 20 cm.
Veritas®

Synovis Surgical Innovations, St. Paul, MN

- NON-crosslinked product derived from bovine pericardium
- FDA Approval in 2003
- Proprietary treatment process of NaOH, propylene oxide, ethanol
- Shelf Life = 3 years
- Rehydrate = Not necessary – ready to use
- Tensile Strength = to, and Suture Retention Strength > cadaveric fascia lata products
Veritas®

- Substantial blood vessel ingrowth by 28 days
- Appears to have significantly less residual cellular/DNA material than competitors
- Peri-Guard® is essentially identical to Veritas, except that it is purposely crosslinked with glutaraldehyde
  - Requires a 2 minute rinse before OR use
  - Should remodel/degrade more slowly
Veritas Collagen Matrix explant exhibits a pronounced angiogenic response resulting in the seamless integration of the Veritas implant into the surrounding tissue. 28 days post implant in rabbit abdominal wall model.

Host fibroblasts have repopulated the Veritas implant and have begun to deposit new collagen. In addition, the development of blood vessels through the implant (angiogenesis) is clearly seen. 29 days post-implantation. Original magnification: 400x.
Veritas®

Veritas displays minimal tissue attachment characteristics in rat abdominal wall model at 28 days.

3-months post implant
Perforation of small bowel

Implantation of Veritas
Wicker Paper

Veritas®

Application of Wound V.A.C.

Six-month wound follow-up
• Rat model with mesh implants (Peri-Guard, Veritas, Permacol, Alloderm) in midline or on either side of midline

• Animals survived for 3 and 6 months, then sacrificed, with graft evaluation for adhesions, size, thickness, tensile strength, histology

• Saw low adhesion formation, and similar vascular ingrowth and abdominal wall burst strength in all samples

• Crosslinked products showed greater tensile strength than non-crosslinked

• Alloderm tended to stretch and bulge (re-herniate)
Key Points

• Use of Lightweight Meshes to minimize stiffness and pain due to the presence of a foreign body

• Development of Barrier Coated Meshes for intraperitoneal placement to prevent the development of chronic, nonhealing wounds above, or adhesions and/or erosion into the viscera below

• Use of Biologic Meshes in infected fields
“A surgeon can do more for the community by operating on hernia cases and seeing that his recurrence rate is low than he can by operating on cases of malignant disease.”

Sir Cecil Wakely - 1948
President, Royal College of Surgeons