Geometric and Mechanical Stress Focusing in Model Heineke-Mikulicz Strictureplasties

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Chronic Manifestations of Crohn’s

Crohn’s disease: devastating inflammatory condition capable of afflicting the entire GI track mouth to anus

Key aspects of Crohn’s pathology:
1. multi-focal - especially in aggressive diffuse Crohn’s jejunoileitis
2. luminal stricturing
3. recurrence despite optimal medical management

clinical presentation:
chronic and persistent SBO and malnutrition

Surgical Challenges of Chronic Crohn’s

- multiple narrow strictures causing obstruction separated by healthy tissue

- high rate of recurrence with 30%-60% of patients requiring re-operation at 5 years

**En-block resection**, often done for Crohn’s confined to the terminal ileum, places patients with chronic multi-focal Crohn’s at high risk of developing *short gut syndrome*.

**bowel-sparing procedures** developed to locally alleviate the obstruction without any tissue resection: *strictureplasties*


Strictureplasties

- late 1800’s: Heineke-Mikulicz pyloroplasty
- 1977: Katariya performed multiple small bowel strictureplasties for diffuse TB in India
- 1982: Lee and Papaioannou first performed the Heineke-Mikulicz strictureplasty for small bowel Crohn’s

**Initial concerns about strictureplasties: active disease being left behind**

1. Fazio et al. *Ann Surg* 1996, 227:563 - randomized controlled study, showed that in ileal resection positive margins did not increase risk of recurrence

2. Strictureplasty - multiple studies have shown that strictureplasty has the same rates of recurrence as en-block resection.
Strictureplasties vs. Resection

Strictureplasty for Crohn's Disease: Techniques and Long-term Results

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Surgical recurrence rate 40% at 72mo with strictureplasty

Reoperative Rates for Crohn's Disease Following Strictureplasty

Long-Term Analysis

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Conclusion: Strictureplasty is a safe and effective procedure for Crohn's disease.
Surgical Technique - **Heineke-Mikulicz**

- *short suture line with very local effect*
- anastomotic failure leads to only local resection of failed strictureplasty
- poorly understood parameters for placing multiple strictureplasties - what is optimal spacing? optimal length for a single plasty?
Surgical Technique - **Finney**

- essentially folded Heineke-Mikulicz
Surgical Technique - *Michelassi Strictureplasty*

- **long suture line:**
  Michelassi = 2 x HM

- anastomotic failure leads to the need for a significant resection
Open questions with strictureplasty

- in multiple strictures what parameters would allow the surgeon to decide whether to perform multiple HM strictureplasties versus the Michelassi with more than anecdotal evidence?

- Michelassi and Milsom note in their *Operative Strategies in Inflammatory Bowel Disease*:

  “At the time of repeat operation for recurrent stricturing, nearly all reporting centers have noted that the majority of new strictures occur at new sites, with recurrent stricturing at the previous strictureplasty sites occurring at a rate of about 3 or 4%. This is an interesting observation and one that does not have a clear explanation. Alexander-Williams has suggested that Crohn’s disease at strictureplasty sites heal due to the relief of the obstruction, breaking a vicious cycle of bacterial overgrowth, ulceration, and more scarring.”
The goals of the present study are to elucidate the geometric character and regional effects of the HM strictureplasty; second, to provide a model experimental system in which to study the intrinsic geometry of one or multiple strictureplasties.

- latex models of the HM strictureplasties were made to precisely define and study its geometry
- the latex models were cast with cold-setting epoxy to prevent heat induced deformation of the thing tube geometry
- CT was used to scan the casts and extract geometric properties, especially luminal cross-sectional area and surface reconstructions
Geometric Preliminaries

What is *intrinsic geometry*?

Carl Friedrich Gauss and Bernhard Riemann showed that surfaces can be classified into groups via an internal parameter:

\[
K_g = \kappa_1 \times \kappa_2 = \frac{1}{r_1} \times \frac{1}{r_2}
\]

**Gaussian Curvature**

\[
K_g > 0 \quad K_g = 0 \quad K_g < 0
\]

*spherical geometry*  
*Euclidean geometry*  
*hyperbolic geometry*

**Shape** is the manifestation of a surface in \(R^3\) driven by energy minimization:

**Gauss’ Theorema Egregium**  
(‘Remarkable Theorem’)

Surfaces with equal Gaussian curvature are isometric to one another, meaning they can easily be shaped into one another, simply by bending (e.g. plane into a cylinder).

\[
E \propto (K_{1g} - K_{2g})^2
\]
Single HM strictureplasty

**Regime I:**

\[ \pm d \leq \ell \text{ and } -d \geq \ell \]

\[ A = A_0 \]

**Regime II:**

\[ -d \leq \ell \leq +d \]

\[ A(\ell = 0) \approx (1.5 - 3) \cdot A_0 \]

\[ A(\ell = \pm d/2) \approx 1/2 \cdot A_0 \]
Hyperbolic Saddle Intrinsic Geometry of the Single HM

The area contracture seen in the model HM casts is a direct product of the Gaussian curvature condensation and hyperbolic saddle geometry that develops from the HM surgery.

\[
\int \int K \, dA = 2\pi - 2\pi - 2\pi = -2\pi
\]

Gaussian Curvature

\[
K = \kappa_1 \cdot \kappa_2
\]

\[
\int \int K \, dA = 2\pi - \int_{\partial \Omega} k_g \, dS
\]

\[
\int \int K \, dA = 2\pi - \alpha - \beta
\]
**Weak interaction regime:** HMs separated by at least one tube diameter, the area between HMs returns to baseline.

**Strong interaction regime:** HMs closer than one tube diameter, the area between HMs collapses to nearly zero.
Conclusions

1. the existence of both dilated and contracted regions within the strictureplasty is consistent with its saddle-like geometry. The dilation (50-150% increase in cross-sectional area) is simply driven by the transverse closure of the enterotomy; however, the strong condensation of negative Gaussian curvature that occurs during this closure induces regions of area contracture (~25-50% decrease relative to undeformed tubing).

The proximal and distal areas of contracture might provide an explanation to the puzzle mentioned by Michelassi and Milsom concerning re-current disease occurring at site proximal and distal to the prior strictureplasty.

2. When two strictureplasties are created in series and in close proximity to each other, the compromising affect on the lumen is dramatically increased. This additive effect becomes prominent when the strictureplasties are positioned within a distance equal to or less than the diameter of the normal un-distorted lumen.
It is important to note that the distance between strictureplasties is different from the distance between the strictures themselves. The distance between strictureplasties is a function of the distance between the strictures and the length of the enterotomy that is utilized to create the strictureplasty. For example, if two focal strictures located 7 cm apart in a segment of intestine with a baseline diameter of 3 cm are managed with HM strictureplasties each performed with a 4 cm enterotomy, the resultant strictureplasties would be 3 cm apart and thus within the range where significant luminal compromise of the segment between the strictureplasties may occur.
Michelassi Isoperastaltic a possible alternative

A. isoperastaltic strictureplasty model

B. [Image of anatomical structure]

[Graph showing relative change in cross-sectional area (%) versus arc length (mm)]
Changing the geometry of the HM
Appendix Slides
Fazio et al.

- Randomized Controlled Study
- 152 Ileal Resections
- 2cm vs 12 cm Gross Margins
Question of leaving diseased bowel behind

Fazio et al.
*Ann Surg* 1996, **227**:563

- Mean Follow-up of 56 Months
- No Difference In Recurrence Rates
  - 23% vs 20%

- Microscopic Positive Margins Did Not Increase Risk of Recurrence