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Durability of Sutures Used in Partial Nephrectomy: Tested Across Commonly Used Diameters and Materials Stopped with LAPRA-TY® Suture Clips and Hem-o-Lok® Ligation Systems under a Given Tension

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Durability of Sutures Used in Partial Nephrectomy: Tested Across Commonly Used Diameters

and Materials Stopped with LAPRA-TY® Suture Clips and Hem-o-Lok® Ligation Systems under

a Given Tension

Nadia Sunny

A Thesis Submitted to the Graduate Faculty of

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Biomedical Engineering
Seymour and Esther Padnos College of Engineering and Computing

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Dedication

This work is dedicated to Engr. H. C. M. A. Reza and Mrs. Marjia Arefin, my parents, for their relentless dedications to my pursuit of higher studies and well-being.

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The text of this dissertation thesis includes information from previously published researches mentioned in the References section.

Abstract

The primary healing of soft tissue incision advances in the first fourteen days after surgery. Sutures used to close the incision are terminated with knots to last over this period under tension inside the tissue. However, knots significantly reduce the tensile strength of the sutures, and make the surgery closing time longer and tedious. Suture clips are used to overcome these limitations. It was found in prior researches that sutures slip out of the suture clips, although the manufacturer of the LAPRA-TY® suture clips claims endurance of this product under tension for at least fourteen days. Use of suture clips and ligation systems together to terminate sutures was found to endure more tension than using only knot or only clip. This calls for an investigation on the durability of different types and sizes of sutures stopped with suture clips and ligation systems under a tension used to control bleeding and urine leakage following partial nephrectomy. This research examined the tension durability of synthetic absorbable sutures (smooth and barbed) commonly used in partial nephrectomy, for four weeks under four Newton tension, when stopped with surgeon placed LAPRA-TY® suture clip and Hem-o-Lok® ligation system.

The suture samples were prepared with knots and a Hem-o-Lok® at one end, and a Hem-o-Lok® and a LAPRA-TY® at the other end. They were hung vertically (with LAPRA-TY® at the top) in a simulated in vitro environment. Slippage from LAPRA-TY® and Hem-o-Lok® combination at the top was found to be the major mode of failure. Vicryl^{TM} 0 and Vicryl^{TM} 2-0 had 100% survival rate over fourteen days, followed by Vicryl^{TM} 3-0 which had 50% failure before seven days. Vicryl^{TM} 4-0 and Vicryl^{TM} 5-0 failed 100% before fourteen days, though manufacturer's recommendation for the use of LAPRA-TY® includes Vicryl^{TM} 4-0. Use of more than one LAPRA-TY® or more than one Hem-o-Lok®, tissue closure and suture performance under other tension levels, and durability of other types and sizes of sutures in the same set-up are necessary to be explored.

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1. Introduction

Dumville, et al. investigated the effects of conventional and novel techniques for surgical wound closure from records of 2793 participants studied by 33 researches by March 2014. They concluded that use of sutures are significantly better than tissue adhesives in terms of minimizing dehiscence (rupture of wound along the approximated incision line due to reasons like age, diabetes, obesity, poor knotting or grabbing of stitches, and trauma to the wound). Probably, because of this security of closed incision, sutures remain the common choice for post-surgery wound closure although the alternatives were in the market since long (Greenberg & Clark, 2009). This security is primarily attributed by the higher tensile strength delivered by sutures where alternatives like tissue adhesives, for instance, first synthesized in 1949 (cyanoacrylate), did not receive widespread acceptance because of their low tensile strength and brittleness (Coover HN, 1959). Dumville's study explored the closure techniques for skin closure only. Although suture is the choice over the other available techniques, a comprehensive study on tension durability of sutures used to close tissue inside the body, closure of kidney tissue for example, is not yet available in the current literature. Sutures typically need to be knotted to keep them from sliding out of the closed incision. The tensile strength of the sutures is minimum near the knot (Tera & Aberg, 1976). Manufacturers worked to improve suture characteristics over the decades to keep the tensile strength as required, while minimizing the induction of infection by sutures, and to optimize their lasting and handling properties.

The oldest information on surgical sutures is found in 3000 B.C. (Bishop, 1960). The earliest known suture is available in a mummy from 1100 B.C. (Grammaticos PC, 2008). As the scope of

surgery broadened over the years following advancements in technology, need for soft tissue closure increased, and in turn, the use and scope of sutures also increased. Consequently, manufacturers of sutures produced varieties of these devices to cater to the surgery needs. Removal of sutures remained a difficult and sometimes impossible (in cases of internal organ surgeries like endourologic, obstetrics and gynecologic procedures etc.) process. Burying sutures inside the tissue creates a possible source of infection, stone formation and other medical consequences. Absorbable sutures were eventually synthesized to overcome these challenges in order to ensure surgery success (although absorbable collagen sutures made from animal intestines were in use since ancient age with unpredictable post-implantation reactions). However, the tensile strength of sutures diminishes over time as well. Hence, demand from surgeons and the challenge for the manufacturers became optimization of tensile strength and absorbability. For an ideal suture, tensile strength should last until the tissue strength of the approximated soft tissue is recovered enough to take the process of healing forward and complete absorption should take place immediately after that (Ethicon, Inc., 2009). However, these two characteristics of suture are mutually independent properties, and come from the constituent material. Higher absorbability can exist with weak tensile strength, whereas poor absorbability does not guarantee more tensile strength (Ethicon, Inc., 2009). Manufacturers also developed surgical clips that are, in effect, suture support devices to overcome the tedious and time consuming step of tying knots. Physiology and duration of wound healing varies over tissue types and location. While biology of the wound being closed dictates the selection of suture based on their tensile strength requiring appropriate absorbability (LaMorte, 2014), suture sizes and types place limitation on use of surgical clips.

For kidney tissue healing after partial nephrectomy, it takes about 7 to 10 days for enough tissue health to be restored (Stadelmann, Digenis, & Tobin, 1998), while tensile strength support is needed for longer as the tissues are only at their 20% of original strength in 2 (two) weeks (Stroncek & Reichert, 2008). As such, whether the absorbable synthetic sutures can endure required tension for 14 days or more when terminated by the surgical clips instead of knots is an important information for surgeons in suture selection and surgery success.

From searches primarily in PubMed and Google Scholar, 23 research papers were found that relate to tensile strength of sutures used in surgery areas such as skin closure, obstetrics and gynecology, renorrhaphy (discussed in the Literature Review section). Only one study was found with a focus on partial nephrectomy and reported the range of tension that sutures undergo when surgeons tie knots to close tissue incision (Endres II, Bossemeyer Jr., Tobert, Baer, & Lane, 2014). Length of time the sutures could last under a constant tension was not investigated by them. One study reported durability of different types and sizes of sutures over time under a given tension where the sutures were terminated using a surgical clip (Hem-o-Lok®) and knots to backstop the Hem-o-Lok® (Gupta, et al., 2015). Their initial attempt was to study durability of sutures under tension when used with LAPRA-TY®. However, they found many of the samples were slipping to fail immediately while hanging, and hence they decided to study the durability with knots and Hem-o-Lok®. The research of this thesis is done as a revisit to their initial attempt to address the question: how long the sutures of different types and sizes, used in partial nephrectomy, can endure a given tension when stopped with surgical clips (LAPRA-TY® and Hem-o-Lok® in this context).

1.1   Research Objective

Being inspired to investigate the challenge faced in Gupta, et al.'s (2015) initial attempt, this research explored the whether different types and sizes of sutures, used in surgeries like partial nephrectomy, can last for the length of time required for wound healing, under a relevant tension, as needed in incision closures, when stopped with surgical clips. The sutures to be tested were chosen by an experienced surgeon from the pool commonly used in partial nephrectomies for kidney tissue approximation. LAPRA-TY® suture clip manufactured by Ethicon, Inc. ("Ethicon™") and Hem-o-Lok® ligation system produced by Weck® (distributed by Teleflex®) were used to terminate the sutures and test the sutures' length of enduring a specific tension of four Newtons, determined by Endres II et al. (2014) to be adequate for hemostasis and primary wound healing following partial nephrectomy. The experiment was done in an in vitro set-up explained in the Methodology section. A Total of 88 samples of 11 groups of sutures (described in the Methodology section) were examined in two batches for slippage from the anchoring point of the clips or breakage within the tensed length for 28 days.

1.2   Reporting

Results of the experiments are reported as durability under tension over time (detailed in the Results section) based on the number of samples that were able to maintain the given tension without breakage or significant slippage of the suture over the observation period. Various failure modes and their weightage are noted to compare suture groups. Comparison is also made between the finding of this study and that of Gupta, et al.'s (2015) as appropriate. Based on these outcomes, recommendations are framed as discussed in the Conclusion and Recommendations section.

The purpose of this literature review is to assess the current state of art relating to research on sutures as tissue closure devices in partial nephrectomy. Because significant number of papers are not available focusing the sutures used only in partial nephrectomy, information from other related research, like studies on sutures used in gastrointestinal, obstetric, gynecologic, skin and tendon surgery – both laparoscopic and open, are also included (Greenberg & Clark, 2009; Tanaka, et al., 2012). The review is aimed to discover the information on tension durability of synthetic absorbable sutures stopped with suture clips and ligation systems for soft tissue closure. It is also focused to gain methodological insights from relevant studies done, identify recommendations of the preceding researchers, and seek support from grounded theory for the planned course of action.

2.1 Wound Healing

A wound needs to pass through a complex series of molecular and cellular events until a provisional matrix is formed that is capable of resisting the disruptive forces on the wound (Greenberg & Clark, 2009). Based on the location and severity of the wound, healing may take from 4 days to 21 days to heal (Bishop, 1960). At 1 week the wound has 3%, at 3 weeks it has 30%, and at 3 months and beyond, based on the type and location of the tissue, it has approximately 60% to 80% of its bursting strength of the unwounded state (Stadelmann, Digenis, & Tobin, 1998). Rath & Chevrel, 1998 drew the wound healing curve of the abdominal wall on the basis of strength recovery as shown in Figure 2.1 on page 17. This process reaches a plateau at 12 to 18 months. Wound closure biomaterials are used to provide the supplemental

support for the tissues in the healing period. However, different types of tissue closure devices,

i.e. sutures, for the purpose of this review, have tensile strengths that last for different durations based on the material and mechanical properties they are manufactured with. Because all materials induce some degree of an unwanted inflammatory reaction, optimizing the
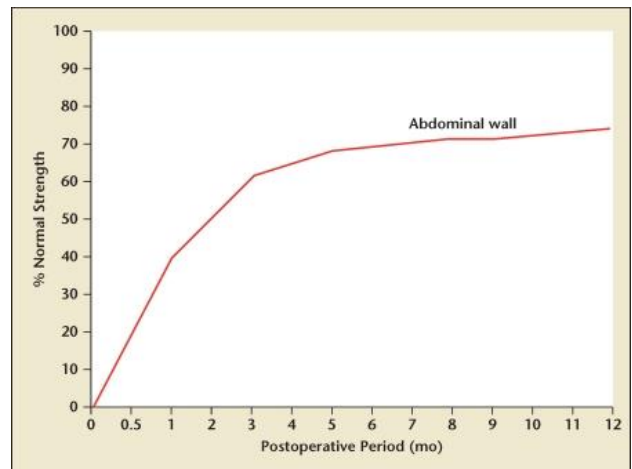
Figure 2.1. Strength recovery during wound healing

duration of strength (including rapid absorbability) and inflammation is the key to selecting a

particular suture for a particular tissue closure. For this review, only certain tissues and

conditions as they pertain to partial nephrectomy are considered; suture support period

required for wound healing is considered as minimum 14 days and preferred as 28 days.

In addition to the physiological healing process, surgical principles also has effect on wound

healing. These principles that can help faster wound healing are based on the followings (Mayo

Clinic, 2015):

1. Direction of the incision matched with that of tissue fibers and short length to help quicker

   healing.

2. Dissection technique to incise with one clear stroke of evenly applied pressure on the

   scalpel that would preserve the integrity of the underlying nerves, blood vessels, and

   muscles.

3. Gentle tissue handling to avoid altering of the local physiological state at the incision area, and predisposition to microbial colonization.

4. Application of mechanical, thermal, or chemical methods to decrease the flow of excess blood and fluid to the incision area which would allow the surgeon to work in a clear field with greater accuracy.

5. Maintaining moisture in tissues by irrigation or cover to help the wound be in natural state.

6. Removal of necrotic tissue and foreign materials to reduce probability of undue reactions.

7. Choice of closure materials fully customized to the specific patient and tissue. This step calls for knowledge of necessary suture characteristics and choice of sutures from the available brands in the market.

8. Cellular response to closure materials to avoid infection, allergy, or trauma.

9. Elimination of dead space in the wound to remove collected serum or blood that offer a medium to the growth of microorganism.

10. Closing tension that can cause ischemia and tissue necrosis if more than necessary, or inappropriate approximation and delayed healing if less than necessary.

11. Postoperative distraction forces to minimize undue stress upon a healing incision.

12. Adequate immobilization of the approximated wound after surgery for efficient healing and minimal scar formation.

2.2   Tensile Strength

In these discussions, the phrases "tension durability" and "strength" of sutures are used interchangeably. Both of these phrases means the length of time a suture can last without breakage in its effective length or slippage from its terminating support (e.g. suture clips).

Tensile strength of any material is the load per cross-sectional area unit at the point of rupture. It relates to the nature of the material rather than thickness (Ethicon, Inc., 2009).

There are two tensile strengths that may be referred to in the discussions. One is the tensile strength of a tissue. Tensile strength affects the tissue's ability to withstand injury, but is not related to the length of time it takes the tissue to heal (Ethicon, Inc., 2009). On the other hand, tensile strength of the tissue affects the suture's ability to hold the closed tissues together, while the suture manages other tensions applied by the suture terminating supports (e.g. knots, suture clips, ligations systems etc.), the tissue itself and the physiological movements of the tissue (due to perfusion, pumping etc.).

It can be logically inferred that sutures should have at least as much tensile strength as does the tissue through which they are being placed in its unwounded state. As collagen accumulates during the reparative phase of tissue healing, strength increases rapidly, but it is many months before a plateau is reached (as mentioned before). Tissue closure devices are utilized, as such, to provide the wound with extrinsic support to have enough strength until the natural strength is regained that can lead the tissue to the plateau. Characteristics of the tissue closure devices (may be a single device, or a combination) and its components (sutures, clips etc.) thus become a key to surgery success in addition to the patient's physiological factors, tissue characteristics and surgical care.

It is relevant to mention that the load required to break a wound regardless of its dimension is called the breaking strength (Ethicon, Inc., 2009). Another related parameter is burst strength, which is the amount of pressure needed to rupture a viscous, or large interior organ like kidney,

for instance (Ethicon, Inc., 2009). These parameters are often used to report compatibility of sutures in terms of strength. These are measurements with more clinical significance.

2.3 Characteristics of Absorbable Sutures

The purpose of a tissue closing device is to hold the tissues together with enough strength until primary stability is regained in the tissues without causing adverse reactions or needing to be withdrawn after serving its purpose. Sutures are the most commonly used tissue closing device for surgeries like partial nephrectomy. A suture that undergoes rapid degradation in tissues and the strand is eventually completely dissolved, leaving no detectable traces, is an absorbable suture. These sutures lose their tensile strength within 60 days. Sutures that are never hydrolyzed by the body, or generally maintain their tensile strength for longer than 60 days are non-absorbable sutures (Ethicon, Inc., 2009). However, loss of tensile strength and the rate of absorption of a suture are separate phenomena. A suture can lose tensile strength rapidly and yet be absorbed slowly, or it can maintain adequate tensile strength through wound healing, followed by rapid absorption (Figure 2.2).
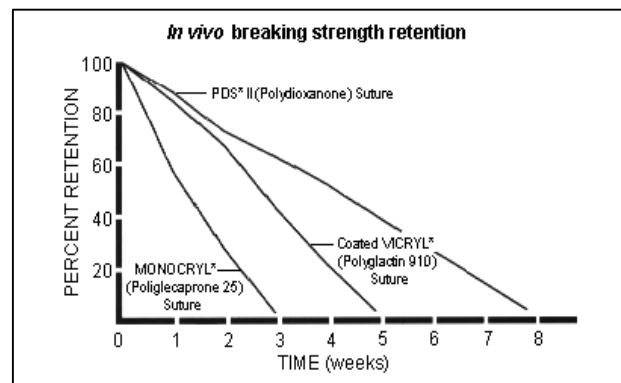
Figure 2.2. Breaking strength reduction in example sutures (LaMorte, 2014)

Non-absorbable sutures are made from non-biodegradable materials and are ultimately encapsulated or walled off by the body's fibroblasts. These sutures ordinarily remain where they are buried within the tissues. When used for skin closure, they must be removed postoperatively. Non-absorbable sutures are generally used in applications like exterior skin

closure, within the body cavity where they remain permanently encapsulated in the tissue, for patients having history of reaction to absorbable sutures (e.g. keloidal tendency, tissue hypertrophy), and in prosthesis attachment (e.g. defibrillators, pacemakers, drug delivery mechanisms). This research investigated on absorbable sutures only, and so non-absorbable sutures are discussed in no more detail.

Absorbable sutures can be categorized in the following ways:

1. Collagen versus synthetic

2. Coated versus uncoated

3. Dyed versus un-dyed

4. Monofilament versus multifilament

5. Smooth versus barbed.

2.3.1   Synthetic Absorbable Sutures

Synthetic absorbable sutures are tested in this study. These sutures are made from synthetic polymers (given in Table 2.1, page 25) and offer the strength needed for a wide range of applications, from abdominal and chest wound closure to ophthalmic and plastic surgery (Ethicon, Inc., 2009). Collagen sutures are collagen of healthy mammals. These sutures are digested by body enzymes which attack and break down the suture strand. For this characteristic, these sutures are also reasons for some unwanted reactions and infections at the wound.

Synthetic absorbable sutures are hydrolyzed in a process by which water gradually penetrates the suture filaments, causing the breakdown of the suture's polymer chain. Compared to the

enzymatic action of natural (collagen) absorbable sutures, hydrolysis of synthetic absorbable

sutures results in a lesser degree of tissue reaction following implantation (Ethicon, Inc., 2009).

2.3.2   Coated and Uncoated Sutures

Sutures that are impregnated or coated with agents are called coated sutures. Coating is added

to improve the handling properties of the sutures, such as easy sliding through the tissues and

tying knots. Uncoated sutures are better in knot security. Both coated and uncoated sutures are

tested in this study.

2.3.3   Dyed and Undyed Sutures

Sutures are dyed to increase their visibility in the tissues which helps the surgeon to track them

as needed. They can be naturally colored or dyed with agents approved by United States Food

and Drug Administration ("FDA"). Undyed sutures look white or clear. There is no infection or

unwanted reaction observed from use of dyed or undyed sutures. Both types are used in

surgery and tested in this research for their durability under tension with surgical clips.

2.3.4   Monofilament and Multifilament

Monofilament sutures are soft and pliable, and made of a single strand. An advantage of the

absence of interstices, for which they do not facilitate harboring bacteria. When thicker sizes

are needed, handling and knot-tying with these sutures become more difficult. A disadvantage

is that nicking or damaging the sutures with forceps or needle holder weakens them and

predispose them to breakage.

Multifilament sutures are made of more than one strand that are twisted or braided together.

They have better knot security and tensile strength than the monofilament of same size.

Rougher surface make these sutures difficult to slide through tissues and hence are generally coated (e.g. Vicryl^TM sutures in the test pool of this study) that makes the irregular surface smoother and facilitates sliding through tissue. Their coating also reduces capillarity that prevents bacterial growth (Sarajevo Joint European Project II, 2015). Sutures tested in this research were both monofilament and multifilament based on their brands.

2.3.5   Smooth and Barbed Sutures

Smooth sutures are the most common type of sutures with uniform smooth strand. These are easy to slide through tissue, but need knot or clips to be stopped. Knot and clips effectively weaken the tensile strength of sutures at and near the points of application (Tera & Aberg, 1976). On the other hand, barbed sutures have self-anchors to pin themselves with the tissues (Figure 2.3). As such, according to the manufacturer's claim, they do not need to be knotted or clipped at the end. The elimination of a knot effectively reduces the overall foreign

Figure 2.3. Smooth and barbed sutures from the experiment

body load and thereby reduces the total wound tissue reactions. Moreover, in minimally invasive laparoscopic procedures where knot-tying is difficult, the use of knotless bidirectional barbed suture can securely re-approximate tissues with less time, cost, and aggravation (Dumville, et al., 2014).

Frequent self-anchoring of barbed sutures help to have a uniform distribution of wound tension across the suture line than with conventional smooth suture. It results in stronger wounds by

eliminating the high tension spots that are more prone to disrupt healing (Weld, Arzola, Montigilo, Bush, & Cespedes, 2008). A barbed suture is generally rated equivalent to 1 USP (United States Pharmacopeia) size greater than its smooth equivalent, because of its decreased effective diameter as a result of the process of creating barbs. USP has standards prescribed for different sizes (diameter) of sutures. In their advised method, diameter of 10 strands of a suture size are measured at three evenly distant points on each strand and averaged. The average diameter of the strands being measured must be within the tolerances given in the following table for the respective size. None of the measurements should be less than the midpoint of the range for the next smaller size or more than the midpoint of the range for the next larger size (U. S. Pharmacopeia, 2015). According to USP, a 2-0 barbed suture equals a 3-0 smooth suture. Barbed suture are often referred as "knotless" sutures (e.g., PGA-PCL knotless suture as labeled on the packet). The samples investigated in this research include both smooth and barbed types of sutures.

2.4   Materials of Tested Sutures

History of suture materials dates back to 2,000 B.C. when Egyptian and Syrian surgeons used to close wounds using strands of silk, linen, cotton, horsehair, animal tendons and intestines, and wire made of precious metals in their operative procedures (Ethicon, Inc., 2009). Those sutures were either plain processed collagen that would be enzymatically broken by the body after 7 days, or chromic, i.e., collagen treated with chromium salts to delay the absorption, typically losing their strength after 2 to 3 weeks and completely being digested after about 3 months (LaMorte, 2014). As discussed before, the natural absorbable sutures showed reactivity to the tissues, and hence synthetic absorbable materials made from polymers are now being used to

produce sutures. When water penetrates the filaments of these synthetic absorbable sutures, the polymer chains are broken down (non-enzymatic hydrolysis). These sutures evoked less tissue reaction than sutures made from plain or chromic natural material. Table 2.1 on page 25 shows the materials of sutures investigated in this study. Materials mentioned in the table are used to provide the suture with intended tensile strength, absorbability and reactivity with tissue along with other properties like smoothness.

Table 2.1. Sutures and their constituent materials (Source: suture packets and manufacturer's website)

Sl. No.	Trade Name of Sutures Tested	Materials from Which the Sutures Are Made
1	Coated Vicryl™	Polyglactin 910 (90% glycolide and 10% L-lactide)
2	Monocryl™	Poliglecaprone 25 (copolymer of glycolide and epsilon-caprolacton)
3	PDS*II	Polydioxanone (from polyester, poly (p-dioxanone))
4	Stratafix™ PGA-PCL	Polyglycolic Acid (combination of glycolide and e-carpolactone)
5	Stratafix™ PDO	Polydioxanone

2.5   Suture Selection

The selection of sutures vary depending on the location and nature of the related tissues. Closing a simple laceration on the foot, a complex laceration on the face, a gastrointestinal anastomosis, or closing kidney tissues after partial nephrectomy would lead the choices for sutures (LaMorte, 2014). The surgeon's training, familiarity, professional experience and contemporary practices in the specialty area are also guide suture choices. Patient factors like

age, weight, overall health status, and the presence of infection are important determinants of sutures (Ethicon, Inc., 2009). For tissue closing after surgeries like partial nephrectomy, the following characteristics are mostly considered for suture selection:

1. Smoothness: For easy sliding through the tissue and tying knots by surgeons.

2. Infection resistance: To be safe to use, not to be predisposed to bacterial growth.

3. Uniform diameter: To deliver same properties over its length used to close the incision, conforming to the USP.

4. Smaller diameter: To affect the tissue as little as possible and still have enough of required properties like the following two.

5. Tensile strength: To hold the wound securely until primary tissue health is restored.

6. Variable rate of absorption: To last until restoration of primary tissue health (slow absorption) and to disappear as soon as restoration is done (rapid absorption).

2.6   Tested Sutures, Their Tensile Strength and Absorption profile

Sutures tested in these studies are all absorbable synthetic sutures, as mentioned before. Out of the five types of sutures tested, one (Vicryl^{TM}) had multifilament and was coated (as mentioned before, multifilament sutures are coated to add smoothness of handling). There were two barbed suture types (Stratafix PGA-PCL and Stratafix PDO) and three smooth ones. Two types were colored (Stratafix PDO and PDS*II), while the other three types were undyed. The pool was chosen to cover the common types used in partial nephrectomy. Victryl^{TM} sizes 0, 2-0, 3-0, 4-0 and 5-0, Stratafix^{TM} PGA-PCL sizes 2-0 and 3-0, Stratafix^{TM} PDO size 2 and 3-0 and PDS*II size 1 were selected to have more information on those as compared to the preceding

researched by Gupta, et al. (2015) and Endres II, et al. (2014). Table 2.2 on page 27 summarizes

the types of sutures tested and their tensile strength and absorption profile as given by the

manufacturer (Ethicon, a Johnson & Johnson company, OH, USA).

Table 2.2. Tensile strength and absorption profile of tested sutures (Source: manufacturer's website)

Sl. No.	Types of Sutures (Brand Name)	Sizes Tested	Strength Retention Profile	Absorption Profile
1	Vicryl^{TM}	0, 2-0, 3-0, 4-0, 5-0	75% @ 14 days 50% @ 21 days 25% @ 28 days	56 - 70 days
2	Monocryl^{TM}	4-0	50 - 60% @ 7 days 20 - 30% @ 14 days	91 - 119 days
3	PDS*II	1	60 - 80% @ 14 days 40 - 70% @ 28 days 35 - 60% @ 42 days	183 - 238 days
4	Stratafix^{TM} PDO	1, 4-0	80% at 14 days* 80% at 28 days 40% at 42 days	90 - 120 days
5	Stratafix^{TM} PGA-PCL	3-0, 4-0	62% at 7 days* 27% at 14 days	120 – 180 days

*Information specific to these two types of sutures are not available at Ethicon^{TM}'s suture catalogue; given information are quoted from Quill^{TM}'s catalog assuming equivalency since the constituent materials are same across Ethicon^{TM} and Quill^{TM}

2.7 Surgical Clips

To ease the termination of sutures during wound closure after a surgery, surgical clips, like

suture clips and ligation systems, are used to stop the sutures against the tissues. These are

support devices that reduce the time required for incision

closure and release surgeons from the tedious knot tying job

by removing the need for tying knots (Figure 2.4). Suture

clips used in this experiment are absorbable, while ligation

systems are non-absorbable.
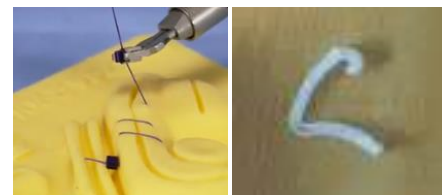
Figure 2.4. LAPRA-TY® (left) and Hem-o-Lok® (right)

Suture clip tested in this study is LAPRA-TY® and ligation system

tested is Hem-o-Lok®. Combination of these two were used to stop

one end of the suture (Figure 2.5). LAPRA-TY® is absorbable, violet in

color and Hem-o-Lok® is non-absorbable, colorless. The

manufacturer suggests that an experienced surgeon must apply the

surgical clips to get proper functionality. They also suggest using the

LAPRA-TY®s where strength requirement is not more than 14 days
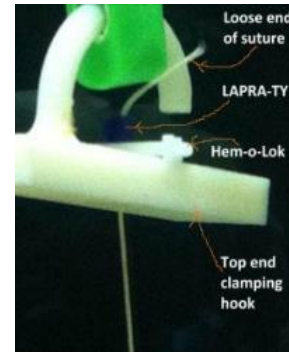
Figure 2.5. LAPRA-TY® and Hem-o-Lok® combination in the test

(Ethicon, Inc., 2015). Recommended sutures to be clipped with LAPRA-TY® are coated Vicryl™

of sizes 2-0, 3-0, 4-0 (Ethicon, Inc., 2015), although various suture brands and sizes are tested in

this study. Hem-o-Lok® is primarily used to distribute the force applied to the tissue and as a

physical barrier to the LAPRA-TY® sliding through the hole of the clamp; it also worked to hold

the suture in addition to LAPRA-TY®. This combination is standard practice for some surgeons

during partial nephrectomy closure.

2.8   *Previous Research*

The topics of interest to explore the literature for studies similar to this research were: tension

durability of sutures, characteristics of absorbable sutures, suture clips, and ligation systems,

tensile strength of surgical sutures, comparison of surgical suture materials, "LAPRA-TY" and

holding strength of "LAPRA-TY". Out of the prior researches, 23 publications (journal articles)

matched the broader criteria with at least 1 of the topics of interest. These publications

covered comparison or determination of slippage characteristics of different types of sutures,

tensile strength of straight sutures, tensile strength of suture materials with knots, tensile

strength of different types of knots, strength of barbed sutures with respect to smooth sutures

(and also other barbed sutures), strength of collagen and synthetic sutures, strength of

different types of sutures in different surgeries, holding strength of suture clips across suture

types and sizes and holding strength of various suture clips. Experiments in these research

covered both in vivo and in vitro methods ranging from saline tank, porcine kidney, and human

cadaver kidney. Tensile tests using tensor machine as well as observations of applied sutures

over time for failure were the techniques in these studies.

Significant studies were done on strength of sutures to hold tissues together for restoration of

primary healing. Benway, et al. (2010) experimented with in vivo porcine model to compare a

sliding-clip technique for suture termination against an LAPRA-TY®-only closure, and a surgeon-

placed knot closure. A force gage was used in their experiment to record the maximum tension

that could be applied during each closure method before the suture ripped through the renal

parenchyma. They found that the knotted closures ripped at a mean force of 11.3 N, while the

LAPRA-TY®-only closures a mean force of 16.7 N, and the sliding Hem-o-Lok with a LAPRA-TY®

bolster provided the strongest closure, allowing for a mean force of 32.7 N before ripping

through parenchyma. They inferred that the larger footprint of the Hem-o-Lock® allows for the

tension to be distributed over a greater surface area and the LAPRA-TY® ensures the security of

the closure by holding the Hem-o-Lock® in place.

Endres II et al. (2014) reported the tensile forces under which holding capability of sutures

stopped with Hem-o-Lok® and either LAPRA-TY® or knot were tested (Figure 2.6). They

concluded that more than 2 N tension was always required to achieve hemostasis in the

perfused porcine kidney and not more than 5 N. The conclusion was based on the specific

combinations of knot and clips. This information of tension range (2 N to 5 N) was used to choose a tension at which sutures were tested for their
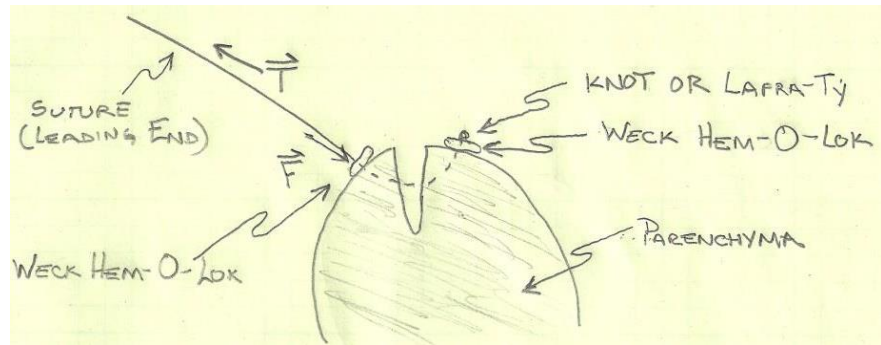
Figure 2.6. Endres II's (2014) set up for tensile test

durability in the follow on studies (e.g. Gupta et.al, 2014, as discussed in the next paragraph).

Gupta, et al. (2015) suggested that not only the tensile strength of suture, but also the suture support devices can cause suture failure. In their initial attempt, sutures were found to fail because of slipping from the LAPRA-TY® and Hem-o-Lok® clips, and not because of sutures' breakage to endure tension over time. This challenge inspired the research of this thesis to investigate suture durability using LAPRA-TY® and Hem-o-Lock® in combination with different suture materials of different dimensions. Gupta, et al. (2015) finally tested durability of sutures using knots and Hem-o-Lok® on both sides of the suture sample. They developed the tank and support devices (Figure 3.5, page 39) that are used in the same way for the experiments of this thesis. Their results are compared to the results of this research in subsection 4.3.1 on page 52.

Weld, et al., 2008 investigated the holding strength of LAPRA-TY® where the sutures were passed through saline solution immediately before being tested using a tensor machine (tension increased until failure). Testing was performed on 0, 2-0, 3-0, and 4-0 sizes of Vicryl™, Monocryl™, and PDS sutures. Three trials were performed with each suture size and type. This method is very close to ours with the difference of uninterrrupted observation to failure

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(tension applied using spring balance and suture was kept hanging until failure). They

concluded that the optimal suture type and size to maximize LAPRA-TY® holding strength and

minimize slippage were Vicryl[TM] 2-0 and 3-0, Monocryl[TM] 2-0, and PDS 2-0 (Figure 2.7-a). They
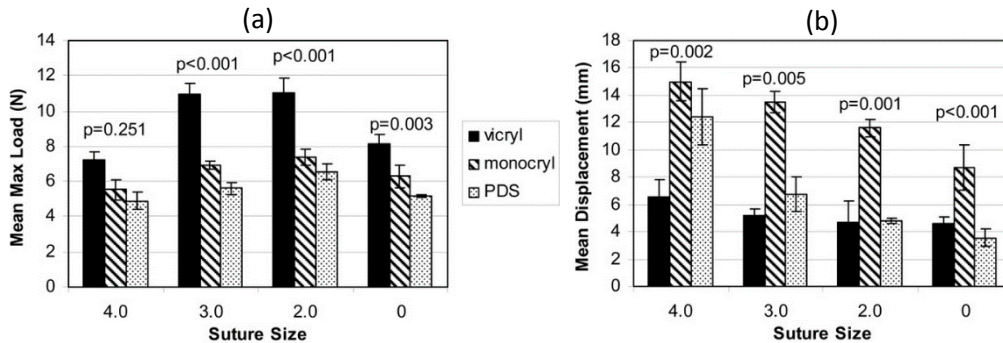
Figure 2.7. Mean holding strength of LAPRA-TY® (a) and displacement for the sutures with the LAPRA-TY®
fixed in position (b) found by Weld, et al., 2008

found that Monocryl[TM] sutures stretched more than Vicryl[TM] and PDS at higher loads. They also

reported difference in displacement (defined as a direct measure of suture stretch under

increasing loads) among the suture types for the mentioned sizes (Figure 2.7-b). Displacement

for Monocryl[TM] 0 was significantly greater than for Vicryl[TM] 0 and PDS 0, for Monocryl[TM] 2-0

was greater than for Vicryl[TM] and PDS of the same gauge, for Monocryl[TM] and PDS 3-0 was

greater than for Vicryl[TM] of the same gauge, and for Monocryl[TM] and PDS 4-0 was greater than

for Vicryl[TM] of the same gauge. In all cases their LAPRA-TY® slipped off the suture, and no suture

breakage was observed.

Gliding resistance of LAPRA-TY® (defined as the tension at which the clip either slipped off the

suture or the suture broke) was explored by Orvieto, et al., 2007 for Polysorb (absorbable) and

Prolene (non-absorbable) sutures. They found that the gliding strength of one LAPRA-TY® was

significantly lower than the breaking strength of all, except one, tested suture sizes. With two

LAPRA-TY®s placed sequentially, the gliding strength increased significantly and was found equal to or greater than the breaking strength for Polysorb 3-0 to 5-0 and Prolene 3-0 to 6-0. This study shows that using two LAPRA-TY®s can also be an alternative to knots in order to save time and also gain better holding strength by LAPRA-TY®s.

In a research on the suture anchors, it was found that one LAPRA-TY® clip dislodged from the suture at a tension of 9 N (standard deviation 2.91), one Hem-o-Lok® at 3.4 N (standard deviation 1.30), and two Hem-o-Lok®s at 10.6 N (standard deviation 3.20). Six trials was done for each set up using human cadaveric kidney (Tarin, et al., 2010).

Greenberg, et al., 2004, evaluated the tensile strength, elongation, and degradation of polydioxanone, poliglecaprone 25, polyglyconate, and glycomer 631 suture materials in specimens of canine urine having different pH level. Ten strands of each suture material were tested for 0 to 28 days in their experiment. A texture analyzer was used to evaluate tensile strength and elongation of each suture material on days 0, 1, 3, 7, 10, 14, 21, and 28. They detected reduction in tensile strength for all materials in all urine specimens over time. Polyglyconate and polydioxanone were found to have superior tensile strengths in sterile neutral and E coli-inoculated urine, and polydioxanone retained the greatest tensile strength throughout the study period. All suture materials disintegrated before day 7 in P mirabilis-inoculated urine. They concluded that polydioxanone, polyglyconate, and glycomer 631 may be acceptable for urinary bladder closure in the presence of sterile neutral and E coli-contaminated urine, but tensile strength of poliglecaprone 25 in urine may be unacceptable by the critical healing time for bladder tissue (14 to 21 days).

The Washington manual of surgery, 2012, advised the surgical principles that can help wound healing effectively, one of which is suture selection.

Greenberg & Clark, 2009 summarized the wound healing process and the biomechanical properties of available suture materials to better understand how to choose suture material in obstetrics and gynecology. They detailed the wound healing steps and inflammatory responses in three phases, namely - inflammation at the onset of injury in days 4–6, proliferation of epithelial cells in days 4–14, and maturation and remodeling in week 1 to year 1. Effects of foreign bodies and excess inflammation on wound healing was also detailed. Based on these information on wound healing stages, they suggested to choose synthetic absorbable sutures over the non-absorbable and collagen ones subject to their size, tensile strength, structure, flexibility, and surface texture as needed per the scientific principles for the specific wounds and tissues.

Tera & Aberg, 1976 derived from their research that the knot (12 types of knots) is the weakest point in suture being tested under tension. The tensile strength of 12 different knots using twelve different suture materials with the USP dimension 3-0 was examined in their study. They found that the efficiency of the knots (ratio of tensile strength of a knotted suture to an un-knotted one) varied depending upon the tensile strength of the material, 5% for the weakest and 99% for the strongest knot-material combination. They also observed that the knot is stronger with more turns and throws.

Ethicon™'s Wound Closure Manual worked as a comprehensive reference for this research. They discussed the stages of wound healing to an extent that helps to relate durability

(absorbability and tension endurance) of sutures with the healing process, and understand how the features of suture materials can affect the process. They compiled the rate of absorption and decay of tensile strength of the sutures so that a user can choose appropriate sutures from their product pool. These information are utilized in this research to think about possible reasons of premature and outlying failures of the suture samples tested (discussed in the Results section).

LaMorte, 2014, on the website of Boston University School of Medicine, summarized the suturing basics and related wound closure healing information. Tensile strength curve presented in this article clearly depicts the comparative tensile strength reduction of different types of sutures given in Figure 2.2, page 20. This article referred to Ethicon, Inc., 2009 and re-emphasized on suture selection strategies based on the characteristics of the wound and tissue.

2.9   Statistical Inferences

For results of an experiment on product performance to be statistically significant, the number of samples has to be a representative of the population. If the number of sutures of a specific type used in surgery, or specifically partial nephrectomy, in a year in United States is taken as the population, and the variance and distribution of that data is known, then probably an ideal sample size can be determined (NIST, 2003). Because these information on the population are not available, and limitations like tank size, time, and budget exist, 8 samples of each suture are being tested in this research. Upon discussion with a statistician (Zeitler, 2014, 2015) at length, it appears that to predict a proper sample size variance within the group of sutures, effect size,

and distribution of the expected data should be known and principles of Design of Experiments should be applied thereon. To know these information, there should be pilot studies and the results of these pilot studies should be coherent, explainable and reproducible. In the absence of such information, sample size is generally the optimum number that covers the limitations mentioned above.

In the study of Gupta, et al., 2015 and Endres II, et al., 2014 sample size was determined based on a statistician's advice. Other articles referenced here also show that they used data as was available to them and passed their filtering criterion (Greenberg & Clark, 2009; Dumville, et al., 2014). Repeatability of the experimental set-up is not also known. As such, selecting a sample size of 8 (eight) for each suture is reasonable with a focus that the experiment itself does not carry innate weaknesses (like – proper suspension of the sutures, stable temperature and saline concentration etc.).

This methodology is designed to determine the length of time a suture lasts under 4 N tension without failing, when terminated with of LAPRA-TY® and Hem-o-Lok® surgical clips. For this research, suture failure means either breakage of suture in its effective length (shown in Figure 3.1), or slipping out of suture from the point of application of clip and/ or ligation system (A – B in Figure 3.1). Slipping means the suture is no longer held by the LAPRA-TY® and Hem-o-Lok®
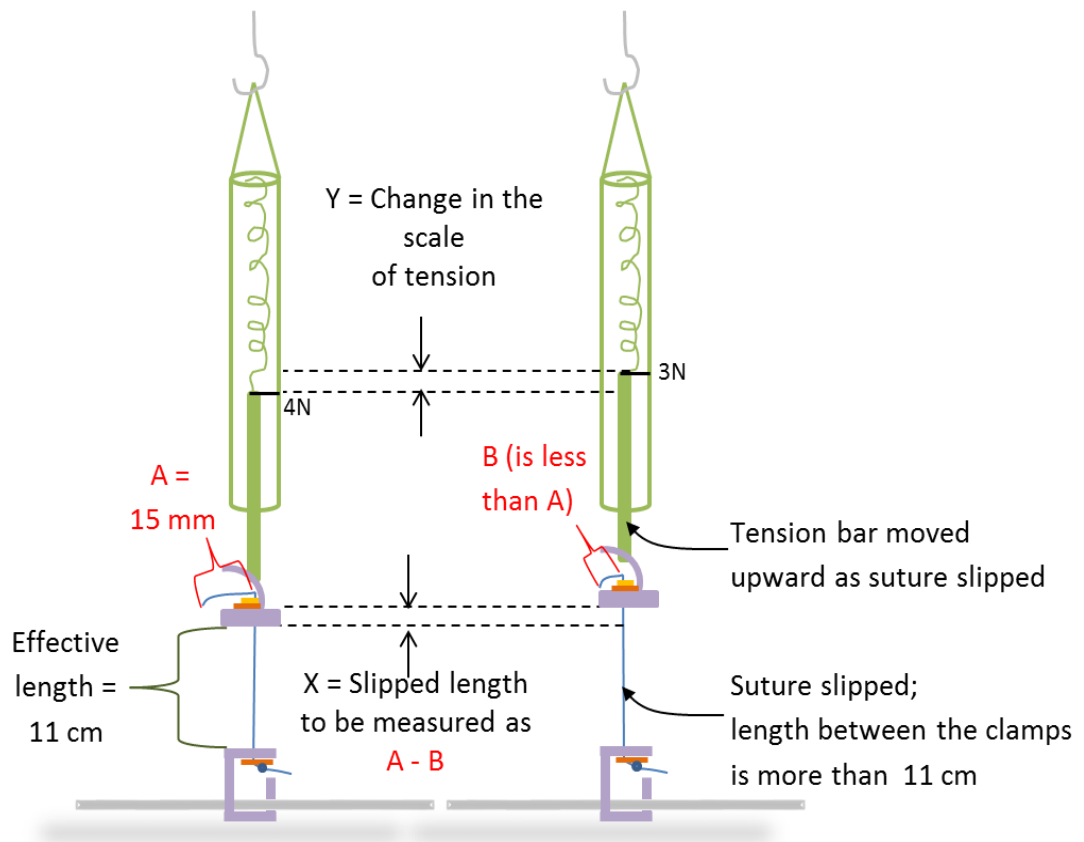
Figure 3.1. Schematic diagram of hanged suture (left) and slipped suture (right); Hem-o-Lok® and knot are used at the bottom, and Hem-o-Lok® and LAPRA-TY® are used at the top; item sizes are exaggerated for clarity

combination at their original site of application. More than 5 mm (X in Figure 3.1) slippage from the point of application will be required for it to be considered as slippage and measured as the difference between A and B. Reduction of tension in the scale of the spring balance (Y in Figure

3.1) may be observed for some samples when they slip. However, compared to initial observations, this reduction was not linear to slippage. This non-linearity can be because of the initial stretch that the sample goes through when tension is first applied, after which the stretch might not have been significant enough to cause further change in tension. This is a possibility; what actually happened can only be determined from the stretch and tension relationship of constituent material specific to the sample suture.

3.1 Materials

Types of sutures tested are in this experiment are: Coated Vicryl™, Monocryl™, PDS*II (PDS™), Stratafix™ PGA-PCL and Stratafix™ PDO (Figure 3.2). Table 3.1 summarizes diameters of the tested sutures. As mentioned before, surgical clips used are LAPRA-TY® of Ethicon™ brand, made of absorbable polymer, and Hem-o-Lok® of Weck® brand, made of non-absorbable polymer.

Figure 3.2. Types of sutures tested

Table 3.1. Suture types and sizes being tested

	Sl. No.	Trade Name of Sutures Being Tested	Sizes
Batch 1	1	Coated Vicryl™	0, 2-0, 3-0, 4-0, 5-0
	2	Monocryl™	4-0
Batch 2	3	PDS*II	1
	4	Stratafix™ PGA-PCL	2-0, 3-0
	5	Stratafix™ PDO	2, 3-0

Suture samples were taken from their sealed sterile packets in the project room, and prepared with clips and clamps by an experienced surgeon (Figure 3.3). The prepared samples were
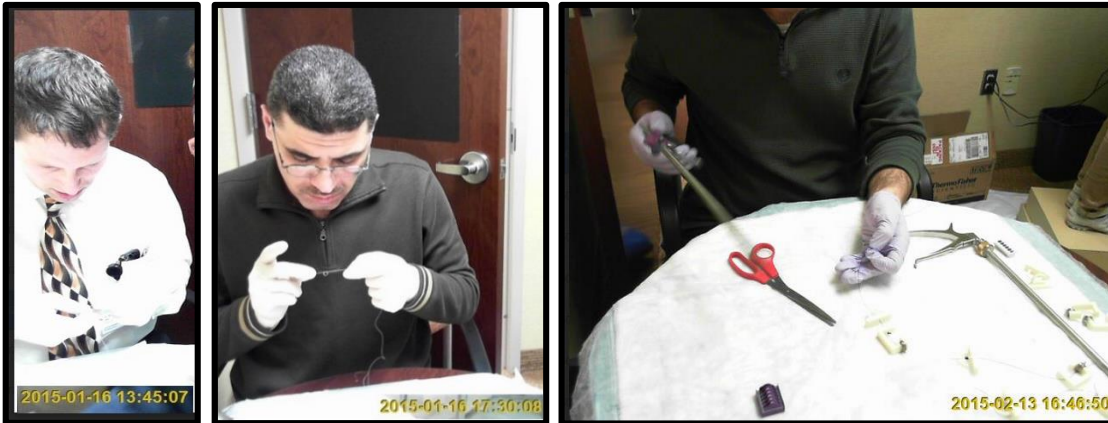
Figure 3.3. Suture preparation by experienced surgeons

loaded almost immediately (within 2 to 3 minutes of unpacking) in the test tank. This is done to retain the packed quality of sutures; it was observed previously that leaving the sutures out of their packet harden them, possibly because of dehydration.

3.2   Experimental Set-up

The investigation is being done on an in-vitro experiment of the mentioned sutures loaded in a tank. The rectangular test tank is kept on a hard horizontal surface. Removable PVC (polyvinylchloride) pipes are installed inside the tank as structures to hold spring balances in a tensed and vertical position (Gupta, et al., 2015). Holes were drilled on the PVC pipes to hold screw hooks (Figure 3.4) which are adjusted by butterfly bolts to change the tightness of the hanged sutures in order to apply desired tension on them. In total, the tank has 40 hooks to hang 40 suture samples. Screw hooks and

Figure 3.4. Screw hook and butterfly bolts

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butterfly bolts are made of stainless still to avoid rusting and smooth operation. At the bottom

of the PVC structure, there are two stainless steel ("SS") rods, placed horizontally parallel to the

bottom surface of the tank. These rod works as an anchor for the bottom clamps used to

position the prepared sutures. Figure 3.5 shows the items described here.
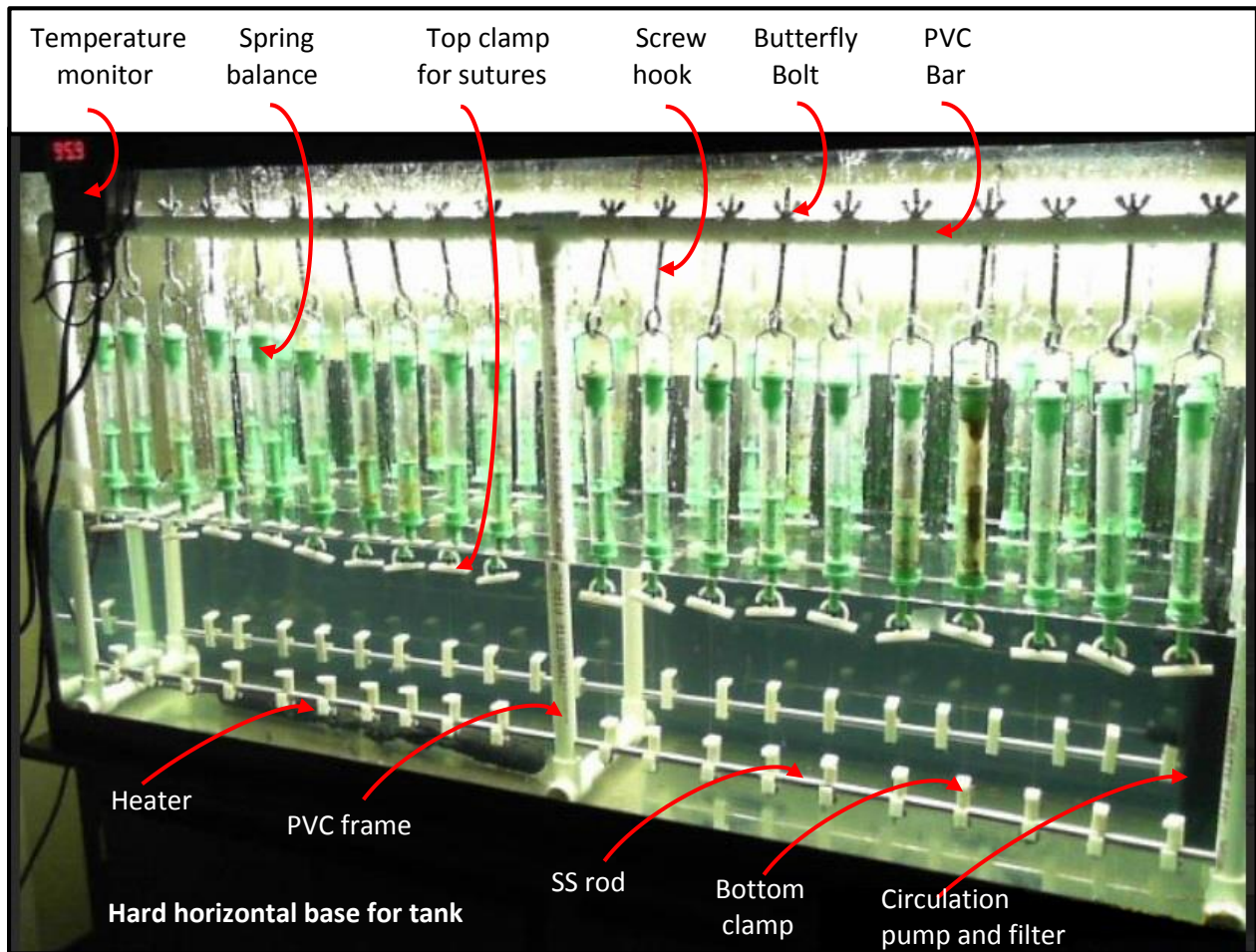
Figure 3.5. Test tank and its components

To simulate the in-vivo environment, 0.9% saline water is poured in the tank before loading the

sutures. Temperature of the saline is maintained closed to human body temperature (94°F to

98°F). A digital heating system (TRUE TEMP brand, Figure 3.6) is used that has an indestructible

titanium heating element with thermal shut off, safety guard, remote temperature probe to

measure the effective temperature, smart memory chip, calibration setting, LED heating

indicator, and LED display of the current temperature (Premium Aquatics, 2015). A circulation

Figure 3.6. Digital thermostat (left) and circulation pump including filter (right)

pump is kept inside the tank that draw the saline into it and pass the saline through the filter

cartridge (consisting of layers of rock, carbon and polymeric fiber) and release the clean saline

back to the tank. It filters out the debris and organic growth from the liquid. Although it causes

a small amount of turbulence in the water that may affect the nearby sutures in the tank, the

impact is negligible.

A suture sample is prepared with a knot at the bottom and then a Hem-o-Lok®. The suture is

then slid through the hole of the bottom clamp and afterward, through that of the top clamp

(shown in, Figure 3.7-a). Effective length of the sample that is being kept under tension is the
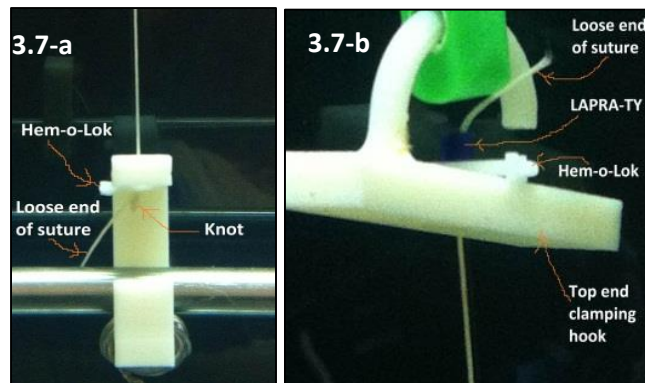
Figure 3.7. Application of clips and knots on a suture strand. Left photo (3.7-a) shows the knot and Hem-o-Lok® beneath the bottom clamp; right photo (3.7-b) shows the Hem-o-Lok® and LAPRA-TY® above the top clamp.

part between the top and bottom clamp, which is kept eleven centimeter (11 cm) long

(exceptions are discussed in the Results section). A Hem-o-Lok® is applied on the cut end of the

sample strand immediately outside the top clamp; a LAPRA-TY® is then clipped as close as

possible to the Hem-o-Lok® (Figure 3.7-b). The loose end of the sample (part A in Figure 3.1) is

kept 15 mm.

Tubular spring balances are used in this experiment to apply and adjust force of the sutures.

The effective part of these balances are about 8 inches long. These are graduated from 0 (zero)

to 5 (five) N with a precision graduation of 0.1 N. According

to the supplier, these balances work best 50°F to 104°F. As

mentioned before, the spring of the balance can be adjusted

to change the tension by turning the butterfly bolts tight or

loose. The prepared sample is attached to the balance using

the top clamp and the balance is hung on the screw hook

held by the PVC bar (Figure 3.8). The bottom was clinched

Figure 3.8. Suture loaded with spring balance

with the SS rod near the floor of the tank which kept the

balance and the suture sample in a vertical position so that the tension can work through the

center of gravity of the sample. A 4 N tension is applied on each suture by adjusting the

butterfly bolts; this tension also kept the bottom clamp tightly attached to the SS rod. The knot,

Hem-o-Lok® and LAPRA-TY® are applied to the sutures by an experienced surgeon.

The tensed sutures are kept submerged inside the saline in the tank. Two batches of sutures are

administered; each batch is kept for 28 days. In the first batch ("batch 1"), five sizes of coated

Vicryl^{TM} (given in Table 3.1, page 37) are loaded having 8 (eight) samples of each size (40

samples for all the Vicryl^{TM}). Since the Vicryl^{TM} 5-0s failed immediately during loading, Monocryl^{TM} 4-0 was loaded in their place. As such, a total of 48 samples were tested in batch 1. In the second batch ("batch 2"), PDS*II size 1, Stratafix^{TM} PDO sizes 2 and 3-0, and Stratafix^{TM} PGA-PCL sizes 2-0 and 3-0 are tested having 8 (eight) samples of each (40 samples for batch 2).

3.3 Measurements

Apart from breakage of the sutures within their effective length (as shown in Figure 3.1, page 36), if a suture displaced (slips) more than 5 mm from the point of application of the LAPRA-TY® at the top, it is considered as a fail. Since, Hem-o-Lok® is used at the bottom with a knot, slipping is not expected or observed from the bottom end. In this way the holding capability of LAPRA-TY®s is kept in focus.

As a consequence of suture slippage, tension on the scale of the spring balances reduced from the initial 4 N. However, this change in tension was not found linearly increasing with further slippage. Hence, the reduction in tension is not used to predict probable fails. Suture ends hanging out of LAPRA-TY®s were measured using a slide caliper immediately before (part A in Figure 3.1) hanging the sutures and after the end of 28 days (B in Figure 3.1). Displacement of clipping point (i.e. slippage) is the difference between A and B of Figure 3.1. If this difference is more than 5 mm, the samples are taken as failed. The samples that slip out fully from LAPRA-TY®s before 28 days are fails anyway.

3.4 Monitoring

Continual status monitoring of the hanged sutures is done using a webcam (Figure 3.9). The webcam is positioned in a way that it can take picture of the whole tank in the project room in every shot. It was set to capture images of the experimental setup at every 15

Figure 3.9. Webcam focused to the tank (photo taken before loading the sutures)

minutes and streams the photos to a Google drive designated for this project. The photos were viewed from any location by logging in to the designated drive. This set-up helped determine the time within the closest 15 minute interval when sutures failed. In parallel to the Google drive, photos are backed up in the computer provide for this project by Spectrum Health. In person visits were done regularly and whenever needed.

If any suture is seen failed in the photos, it was noted; however, no attempt was taken to remove the broken or slipped out suture so that there was no agitation in the tank from removal activities. Generally, the failure mode (breakage or slippage) was not clearly understandable from the photos (because the sutures are too thin when the whole tank is focused). Regular in person visits helped identify the mode appropriately from parts hanging with the left over clamps.

3.5 Statistical Design of Experiment

Eight samples from each suture group (type plus size) were tested. The tank capacity is 40 samples at a time. Since all samples of one suture group (Vicryl[TM] 5-0) failed during loading, eight samples of another group (Monocryl[TM] 4-0, 8 samples) were hung in the empty hangers of the failed ones. In total, 88 samples were tested in two batches (48 in batch 1, 8 samples for each of the 6 groups, and 40 in batch 2, 8 samples for each of the 5 groups).

The following table (Table 3.2) was compiled based on primary rules of statistics (Rouzer, Goos, & Jones, 2011; NIST, 2003; SAS Institute, 2013). Statistical analysis was done based on the characteristics of acquired data (discussed in the Results & Discussions section).

Table 3.2. Relationship of data quality to statistical analysis methods

Data Quality	Parametric	Non-parametric
Assumed distribution	Normal	Any
Assumed variance	Homogeneous	Any
Typical data	Ratio or Interval	Ordinal or Nominal
Data set relationships	Independent	Any
Usual central measure	Mean	Median
Tests		
Correlation test	Pearson	Spearman
Independent measures, 2 groups	Independent-measures t-test	Mann-Whitney test
Independent measures, >2 groups	One-way, independent-measures ANOVA	Kruskal-Wallis test
Repeated measures, 2 conditions	Matched-pair t-test	Wilcoxon test
Repeated measures, >2 conditions	One-way, repeated measures ANOVA	Friedman's test

This table was used to select appropriate tests for the analysis based on data quality. For instance, as the data was not normally distributed and variance was not homogeneous, non-

parametric tests were considered for analysis. Furthermore, the non-parametric tests

mentioned in the table require the distributions to have equal variances and same shape, as

discussed in sub-section Summary of Statistical Analysis 4.3.8 on page 60, the non-parametric

tests also did not qualify. As such, bar charts of significant numbers were reported (to be

comparable to one another) and percentages are tabulated where relevant.

JMP Pro 11.2 software licensed for Grand Valley State University from SAS Institute was used

for processing the data.

4. Results & Discussions

Objective of this research was to find out whether the tested suture samples last for 28 days under four Newton (4 N) tension and are able to maintain this tension while secured with a combination of Hem-o-Lok® and LAPRA-TY®. The research aimed at the following goals:

1. Count the number of sutures of a given material and size that failed by breaking without slipping from the stops (where breaking means the breakage of suture anywhere in its effective length, Figure 4.1-a).

2. Note the length of time until a suture sample failed by breakage without slipping.

3. Count the number of sutures of a given material and size that slipped from the stops at the top (where slipping is measured as 5 mm or more slippage of the loose end of the suture beyond the LAPRA-TY®, Figure 4.1-b). Sutures were not expected to slip from the bottom clamp because they were secured with a Hem-o-Lok® and a knot.

4. Observe the length of time until a suture sample slipped from the LAPRA-TY® and Hem-o-Lok® combination at the top.
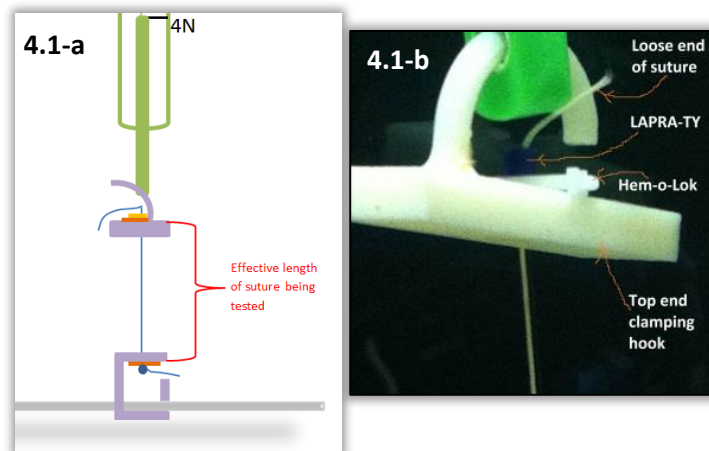
Figure 4.1. Effective length (4.1-a, excerpt from Figure 3.1) and the top loose end (4.1-b) of suture being tested

The aim of statistical analysis of the results was to find out whether there is a difference in the sutures tested in their ability to retain tension and not fail in the observation period (under the given combination of sutures, LAPRA-TY® and Hem-o-Lok®), based on the number of sutures of each type that failed in 28 days. However, 14 days is the period recommended by the manufacturer for use of LAPRA-TY® under tension (Ethicon, Inc., 2015). Hence, analysis based on sutures failing before and after 14 days are also presented in the next section.

4.1   Summary of Results

Eleven (11) groups of suture samples were tested (given in Table 4.1). Each type and size combination had 8 samples. The groups were tested in two batches.

Table 4.1. Sutures types and sizes tested

Batch 1	Vicryl™ 0	Vicryl™ 2-0	Vicryl™ 3-0	Vicryl™ 4-0	Vicryl™ 5-0	Monocryl™ 4-0
Batch 2	PGA-PCL 3-0	PGA-PCL 4-0	PDO 1	PDO 4-0	PDS*II 1	-

It was observed that none of the samples maintained 4 N tension until the 28th day. Almost all of the applied tensions reduced from 4 N at 1 (one) hour of loading the sutures. However, tension reduction rate until failure was not linear. Table 4.2 shows the range of tensions on the eight samples of each suture type and size read from the spring balances at 1 hour of loading:

Table 4.2. Tension on samples at 1 hour of loading the sutures

Suture Samples	V 0	V 2-0	V 3-0	V 4-0	V 5-0	M 4-0	PGA-PCL 3-0	PGA-PCL 4-0	PDO 1	PDO 4-0	PDS*II 1
Tension after 1 hr (N)	3.9 - 4.0	3.8 - 4.0	3.6 - 3.8	3.6	0	2.0	3.0 – 3.5	3.4 – 3.8	3.6 - 3.8	3.5 - 3.9	3.9 - 4.0

*V refers to Vicryl™, M refers to Monocryl™. There is no range for V 5-0 because all failed within an hour; no range for M 4-0 because all samples were at 2.0 N at 1 hour of loading.

The following figure (Figure 4.2) summarizes the number of samples remaining at the end of 4, 3, and 2 weeks, and 1 week.
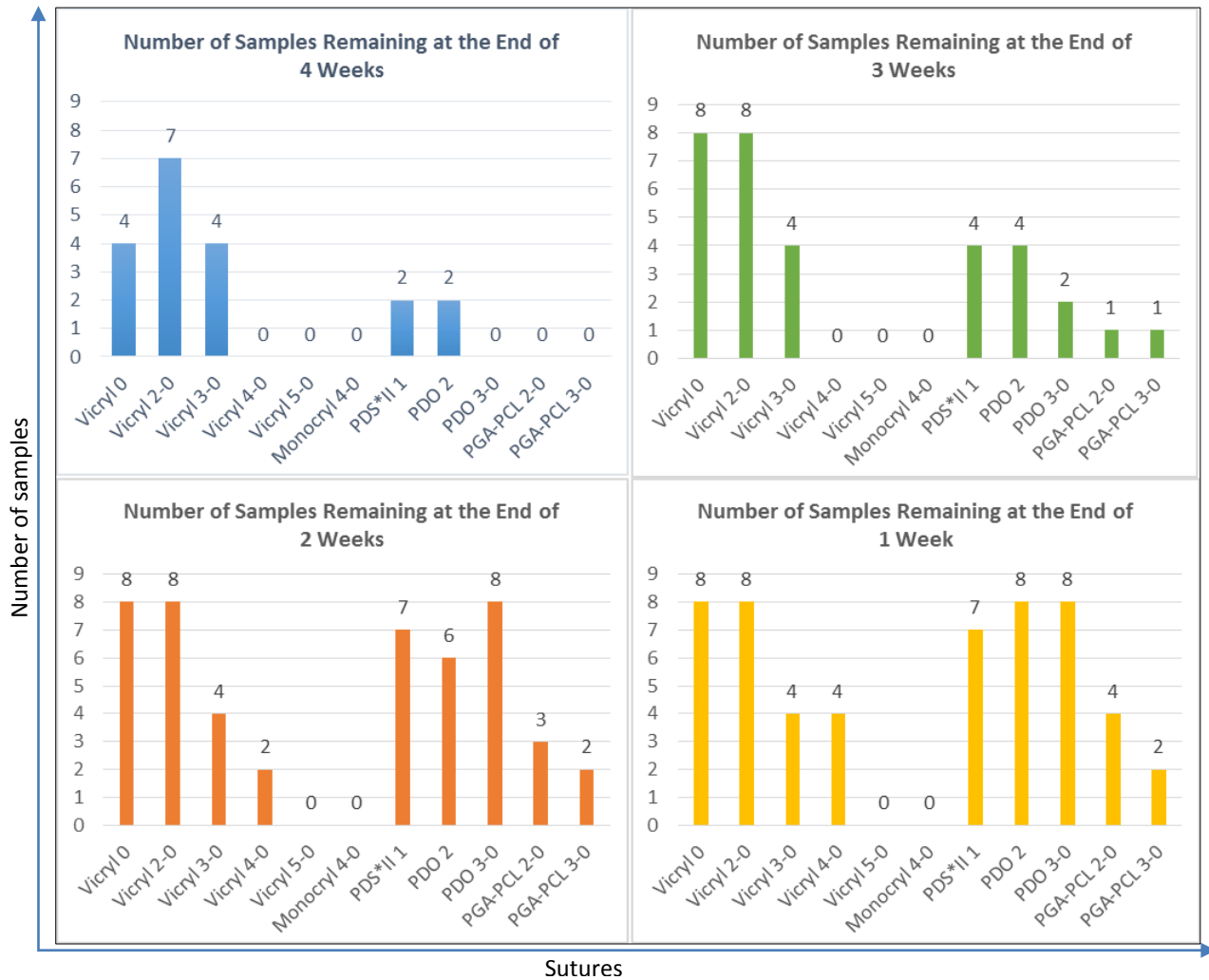
Figure 4.2. Samples remaining after different time periods

Except Vicryl™ 5-0, all samples were loaded with 4 N tension. Vicryl™ 5-0's slipped out of the top clips before reaching 4 N. The loose ends (part A in Figure 3.1, page 36) of the suture samples were carefully measured and trimmed to 15 mm for most of the samples; a few were trimmed to less than15 mm because of short length of the sutures in the pack (loose end length can be seen from Table 6.4, page 70).

in the Appendix section, page 70). The loose end was measured carefully so that the amount of slippage could be identified by measuring this end again (as B in Figure 3.1, page 36) after the observation period is complete.

Figure 4.2 on the last page shows that Vicryl[TM] 2-0, in combination with Hem-o-Lok® and knot at the bottom and Hem-o-Lok® and LAPRA-TY® at the top, is the most successful group in terms of the number of samples (7 of 8, 87.5%) remaining for the longest duration (at the end of the 4th week, blue bars in the figure). It is followed by Vicryl[TM] 3-0 and Vicryl[TM] 3-0 (both 4 of 8, 50%). Between Vicryl[TM] 0 and 3-0, Vicryl[TM] 0 is the better choice, because the 4 samples that did not failed before the end of the 4th week, lasted more than 3 weeks (please see Table 6.2 on page 68 for raw data). No sample of this group failed in the first week, whereas Vicryl[TM] 3-0 lost 4 samples in the first week (orange bars in Figure 4.2).

It is important to highlight that, the quick failures (for instance, within an hour) would be visible to the surgeons during the surgery. Hence, they will be able to take alternative actions like re-suturing as applicable, but the ones failing at one (1) to four (4) hours may happen immediately after the surgery is done when the sutures are not directly observable. Primary mechanical stability cannot be restored within that time (at least 14 days are needed, as discussed in the Literature Review section regarding wound healing). As such, sutures losing any sample in the 1 week and 2 weeks quadrants (orange and purple bars in Figure 4.2) should be considered as a risky choice. According to manufacturer's recommendation, optimum LAPRA-TY® performance under tension is available within 14 days (Ethicon, Inc., 2015). Figure 4.3 shows the number of suture samples failing before 14 days and lasting after this time mark (14 days). Two halves of
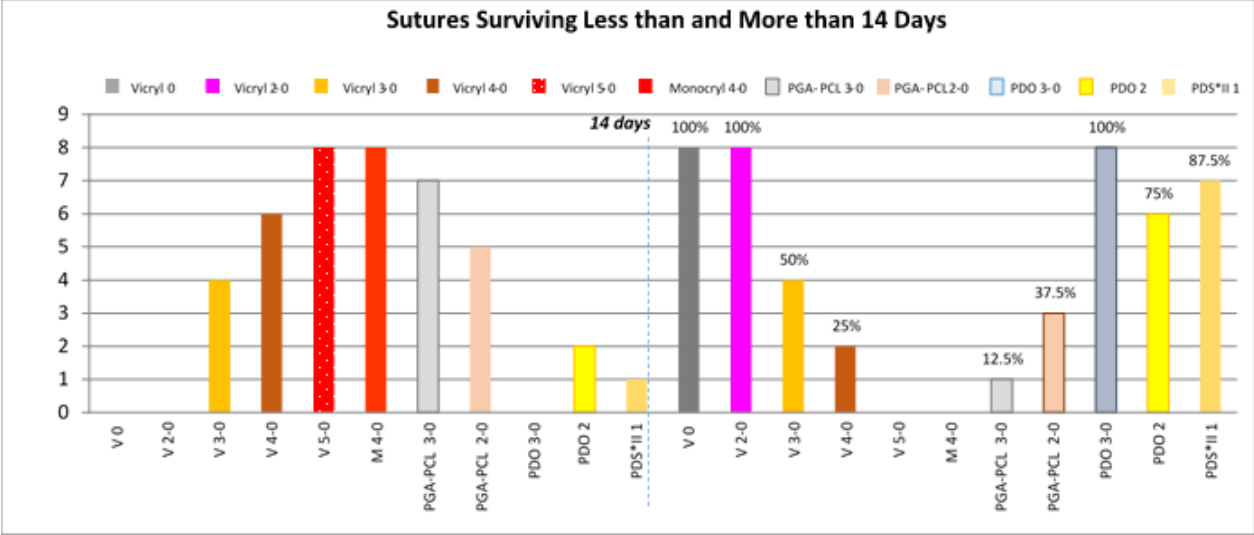
Figure 4.3. Summary of length of time the sutures were hanging

this figure report the same result from two opposite sides (failing and passing); it is just two

different ways of looking at the data. Based on this recommendation of the manufacturer,

Vicryl^{TM} 0, Vicryl^{TM} 2-0, and PDO size 3-0 are equally good choices (100% survival), followed by

PDS*II 1 (87.5%), PDO size 2 and Vicryl^{TM} 3-0 (75% and 50% respectively).

4.2   Summary of Observations

Having discussed the scenarios above, if it is considered that any breakage before 28 days and

any slippage of the top loose end more the 5 mm (manufacturer recommends 3 to 5 mm suture

to be left beyond the knot or clip point (Ethicon, Inc., 2015) is a fail, only the following number

of samples can be considered as a pass.

Table 4.3. Sutures surviving slippage until the end of 28 days duration

Sutures	V 0	V 2-0	V 3-0	V 4-0	V 5-0	M 4-0	PGA-PCL 4-0	PGA-PCL 3-0	PDO 4-0	PDO 1	PDS*II 1
Samples having 5 mm or less slippage	3	5	1	0	0	0	0	0	0	2	2
Percentage	37.5	62.5	12.5	0	0	0	0	0	0	25	25

50

Taking this information in account the ultimate surviving samples can be plotted as Figure 4.4

which summarizes the observations on sutures that were able to maintain tension without

significant slippage (more than 5 mm) for the entire 28 day observation period. This figure adds

the slippage information to Figure 4.2, page 48. It is observed that, all samples of Stratafix™

PDO size 2 and PDS*II size 1 that survived (2 samples of both) the whole duration, also survived

slippage as well. On the other hand, 2 of the 7 of Vicryl™ 2-0 and 1 of the 4 of Vicryl™ 0 did not
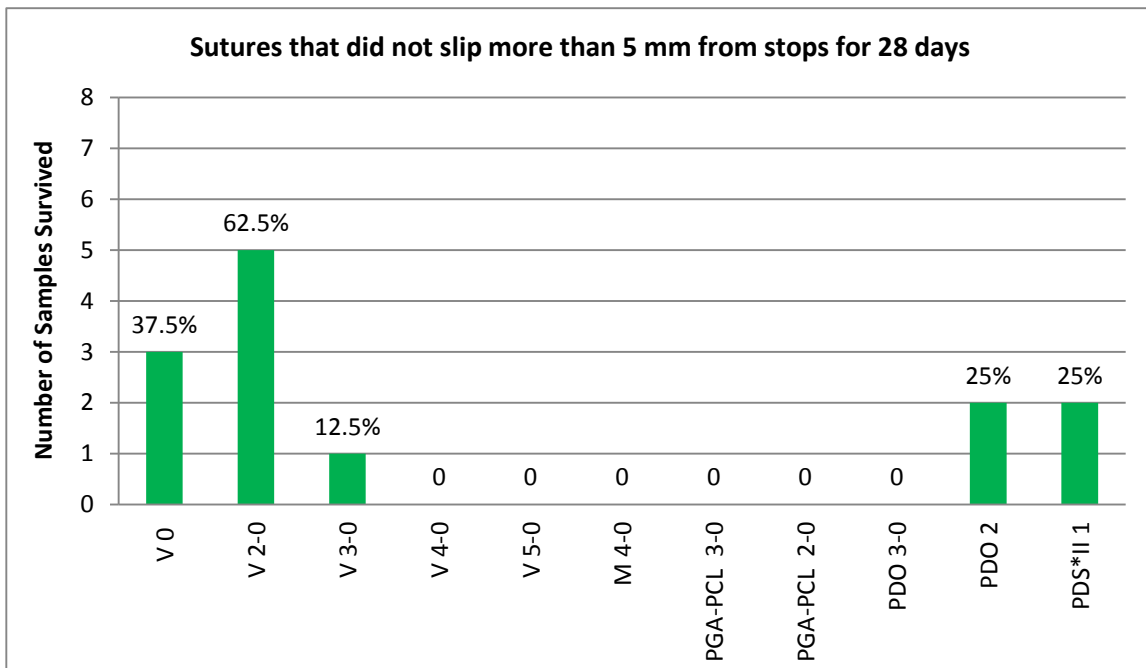
Figure 4.4. Suture samples surviving slippage and the whole observation period

survive the designated slippage (5 mm), although they lasted for 28 days. The highest survival is

62.5% (Vicryl™ 2-0). The next few paragraphs discuss these results based on manufacturer's

recommendations.

4.3   Discussion

4.3.1   Comparative Analysis

As mentioned in the Introduction section, Gupta et al. (2015) found in their initial observations

that many of their sutures were slipping immediately from the LAPRA-TY® and Hem-o-Lok®

combination; consequently, they decided to test the durability using knot and Hem-o-Lok® on

both ends of the suture samples. Figure 4.5 gives a comparative picture of the durability of

sutures (that are common in the two studies) and the suture supports (knot, Hem-o-Lok®, and
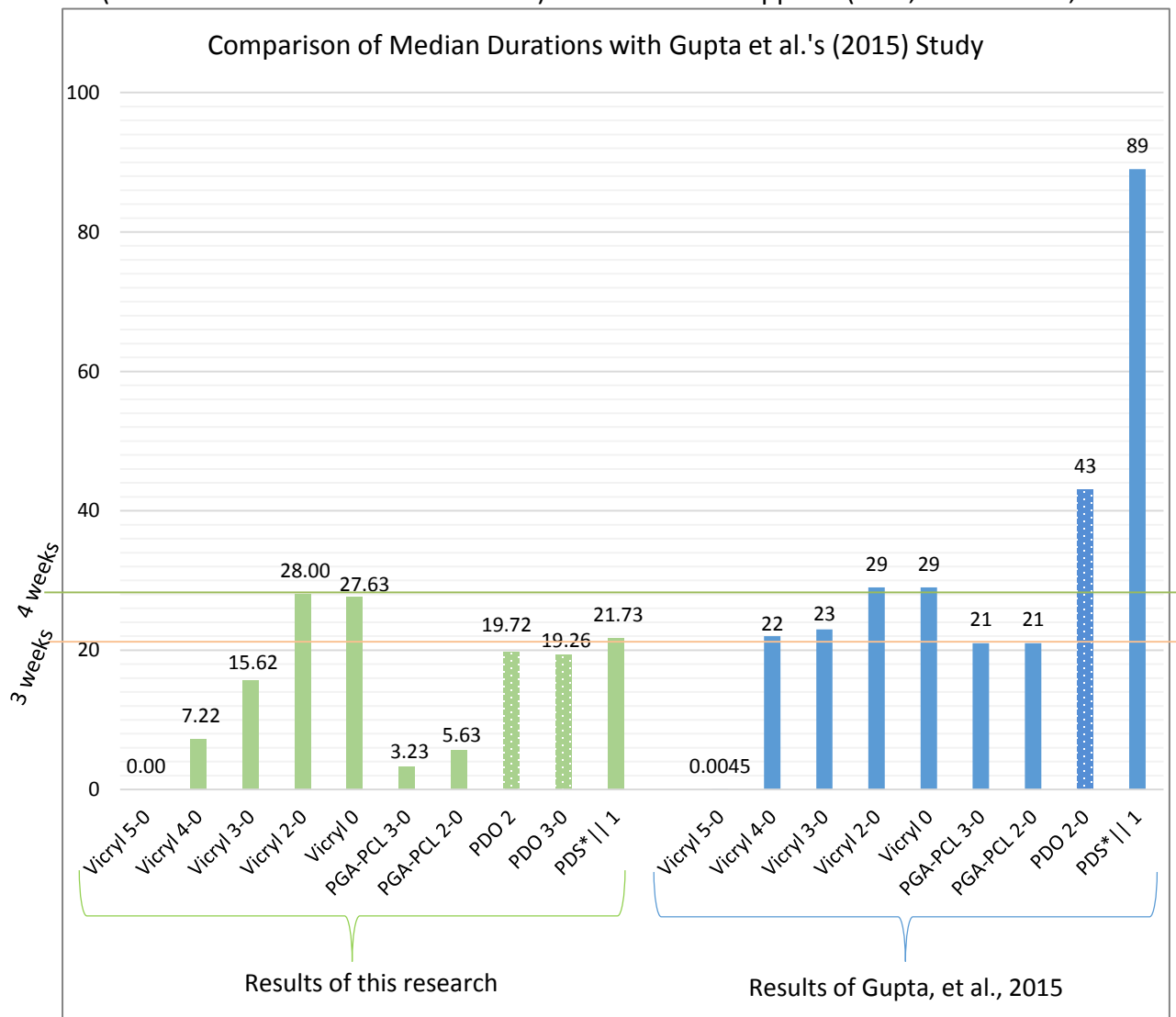
Figure 4.5. Comparison between the results of this study (green bars) and Gupta, et al., 2015 (blue bars). Bars for PDO sutures are made patterned to highlight that the tested sizes in the two studies are different.

LAPRA-TY®) based on the results of this thesis and their study. This figure of median durability shows:

1. The use of knots and Hem-o-Lok® combination gave longer median durability to both Vicryl^{TM} 4-0 and Vicryl^{TM} 3-0 (22 and 23 days) than LAPRA-TY® and Hem-o-Lok® combination (7.22 and 15.62 days); with knots, the mode of failure was breakage, not slippage.

2. The Hem-o-Lok® and LAPRA-TY® combination was able to hold Stratafix^{TM} PGA-PCL size 3-0 and 2-0 for significantly less duration (3.23 and 5.63 days) than the knot and Hem-o-Lok® (21 days for both sizes) combination by allowing premature slippage.

3. Vicryl^{TM} 5-0 performed poorly with both of the combinations because this small diameter suture slipped through the Hem-o-Lok® even with multiple knots.

4. PDO and PDS*II are not comparable between the two studies, because of the big difference between the observation periods (28 days for this thesis and 120 days for Gupta, et al., 2015). It cannot be predicted whether they would have lasted or not for 44 or 90 days as in Gupta, et al.'s (2014) experiments because they were taken off at the end of 28th day in this research.

4.3.2 Ligation System

The sutures are tested with LAPRA-TY® and Hem-o-Lok® ligation systems at the top, and Hem-o-Lok® and knot at the bottom. Not only sutures, but the ligation system (LAPRA-TY® and Hem-o-Lok®) used in this research is also absorbable. The manufacturer recommends not to use LAPRA-TY® absorbable suture clips in applications where strength requirement exceeds 14 days (Ethicon, Inc., 2015). They also recommend these clips for use with 2-0, 3-0 and 4-0 sizes of

coated Vicryl^{TM} sutures only (Ethicon, Inc., 2015). This information explains the immediate slippages of the Vicryl^{TM} 5-0 sutures. All other fails after 14 days are also supported by this recommendation, which includes the failure of Vicryl^{TM} 2-0 at 19 days. 100% success of Vicryl^{TM} 2-0 over the 14 days period can also be explained on the same ground. However, despite incompatibility of Vicryl^{TM} 0 with LAPRA-TY® according to the recommendation above, this suture had 100% success over 14 days.

Considering the recommended period for LAPRA-TY® (14 days), all samples of Vicryl^{TM} 0, Vicryl^{TM} 2-0 and PDO tensile size 4-0 can be a good choice, as shown in Figure 4.3, page 50, if the tension requirement does not exceed 14 days. If the immediate fail of one PDS*II (size 1) sample is considered as an outlier, this group also passes the criteria. Although, extent of slippage of the loose end for these three types at 14 days is not known (since slippage could only be measured at the end of 28 days).

It was difficult to anchor the LAPRA-TY®s on PDS*II because of comparatively bigger diameter of this suture. A few LAPRA-TY®s were broken while clipping. One sample of PDS*II, appearing as though it slipped, while loading. An opened LAPRA-TY® was found (Figure 4.6-a, page 55) later near its position while recovering the failed ones. This observation and the slippages of the other groups of sutures (Monocryl^{TM}, PGA-PCL, PDO) can be explained as incompatibility with LAPRA-TY® according to the manufacturer's recommendations mentioned above.

Although no other premature opening of LAPRA-TY® was found, varying clipping is observed

from one of the failed sutures (Figure 4.6-b). Whether or not the other LAPRA-TY®s were

Figure 4.6. Open LAPRA-TY® recovered from tank, 4.5-a, and inconsistent clipping of LAPRA-TY® on a PDO size 3-0 sample, 4.5-b (the photos were taken at 28 times magnification using Brown & Sharpe Co-ordinate Measuring Machine; courtesy: Medbio, Inc.)

clamped in a consistent way cannot be said because of the slippages where the fallen LAPRA-

TY®s did not have their sutures with them.

4.3.3   Absorption of Sutures

All of the tested sutures were synthetic and absorbable. As mentioned in the Literature Review

section, during the first stage of the absorption process, tensile strength diminishes in a gradual

and almost linear fashion (Ethicon, Inc., 2009). This occurs over the first several weeks after

implantation. The second stage often follows with considerable overlap, characterized by loss

of suture mass (Ethicon, Inc., 2009). Besides tension durability of LAPRA-TY®, the slippage of a

Vicryl™ 2-0 sample at 19 days may be explained (where the whole of the loose end came out of

clips at the top) by this phenomenon as well. It is possible that the loss of mass of this sample

and LAPRA-TY® (14 days recommendation, as mentioned before in the subsection *Ligation*

System) was enough by that time to cause slippage. The reasons for the other 7 samples not

showing same slippage due to loss of mass can be many, such as:

- The samples were from different lots of production (at least some properties of materials vary across lots of production)

- It (the failed one) was the one non-compliant sample of the lot that was not caught by quality assurance before release

- It (the failed one) was at an optimum position to be more affected by the filter and heater in the tank

- The clipping on this sample (the failed one) affected it to some extent that accelerated its loss of mass at least at or near the clipping point

- Either or both of the top clips (LAPRA-TY®/ Hem-o-Lock®) degraded faster than the others

- Either or both of the top clips Clipping of the top clips was not ideal.

All these possibilities will be present in a real surgery scenario as well.

4.3.4 Failure at the Bottom

While loading batch 1, one Vicryl™ 5-0 sample was observed to fail by the bottom combination (Hem-o-Lok® and knot) coming out of the hole of the bottom clamp (Figure 4.7-a). This sample failed when the tension reached about 3.5 N during loading. It was the sole (out of 88 samples in two batches) event of this failure mode.
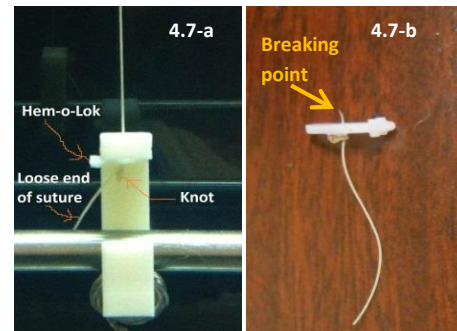
Figure 4.7. Bottom Clamp (a); suture broke at the top of bottom Hem-o-Lok® (b)

Other 14 samples (out of 16) of Vicryl™ 5-0 failed at 3 or 3.5 N tension during hanging, but all of those, including the one that lasted 22 minutes after hanging, slipped out of the top combination (LAPRA-TY® and Hem-o-Lok®). This can be explained as an outlier due to mechanical imperfection of placing the bottom combination during hanging.

The other uncommon failure occurred as breakage at the top of Hem-o-Lok® used in the bottom combination (Figure 4.7-b). The broken bottom part shown in the picture was found in the tank near the Stratafix™ PGA-PCL (size 2-0) group.

4.3.5 Tension

All samples were planned to be tested under 4 (four) Newton tension for 28 days. It was observed while loading the sutures that the tension on all the suture samples reduces from 4N, almost immediately after hanging. It was a general observation after loading batch 1. Formal observation of tension data was taken at 1 (one) hour of hanging the sutures of batch 2 (13 February 2015, 5 pm, Friday). Table 4.2 given on page 47 before, summarized this data.

After 3 days of hanging (16 February 2015, 5 pm, Monday), the tensions remained almost same with a few reduced by an additional 0.2 N. Until the last day, for the ones lasted until then, tension remained same as the third day. This data tells that change in tension with respect to time is not linear and hence, is not a predictor of the survival time for the sutures. At higher tension, change is found higher and after the change within first 1 (one) hour, even a change per day is too small (if any) to be assessable. Some of sutures were observed to have tension as low as 2.5 N at 21 days. On the 28th day, the longest surviving sutures had tension around 3.7 N (all the 4 markers were not exactly on 3.7 N, but were somewhat above or below this point that is smaller than the precision level of 0.1 N of the balance).

4.3.6 Effect of Position on Samples

Positions of the suture samples were studied to identify if there could be any effect of failure of one sample on the other ones nearby (Figure 4.8, Figure 4.9). The dispersion of data did not support any conclusion to be drawn from there.

*Notes for Figure 4.8:

V 0	V 0	V 0	V 0	V 0	V 0	V 0	V 0	V 2-0	V 2-0	V 2-0	V 2-0	V 2-0	V 2-0	V 2-0	V 2-0	V 3-0	V 3-0	V 3-0	V 3-0
V 3-0	V 3-0	V 3-0	V 3-0	V 5-0	V 5-0	V 5-0	V 5-0	V 5-0	V 5-0	V 5-0	V 5-0	V 4-0	V 4-0	V 4-0	V 4-0	V 4-0	V 4-0	V 4-0	V 4-0
				M 4-0	M 4-0	M 4-0	M 4-0	M 4-0	M 4-0	M 4-0	M 4-0								

Figure 4.8. Batch 1 - suture position diagram*

- V refers to Vicryl™.
- M refers to Monocryl™.
- As the first set of Vicryl™ 5-0 failed immediately during hanging, a second set was loaded immediately. Seven samples of the second set failed immediately and one failed at 22 minutes. A set of Monocryl™ was then loaded in the positions of the failed Vicryl™ 5-0s.

St. PGA t4-0, s3-0	St. PGA t4-0, s3-0	St. PGA t4-0, s3-0	St. PGA t4-0, s3-0	St. PGA t4-0, s3-0	St. PGA t4-0, s3-0	St. PGA t4-0, s3-0	St. PGA t4-0, s3-0	St. PGA t3-0, s2-0	St. PGA t3-0, s2-0	St. PGA t3-0, s2-0	St. PGA t3-0, s2-0	St. PGA t3-0, s2-0	St. PGA t3-0, s2-0	St. PGA t3-0, s2-0	St. PGA t3-0, s2-0	St. PDO t1, s2	St. PDO t1, s2	St. PDO t1, s2	St. PDO t1, s2
PDS*II s1	PDS*II s1	PDS*II s1	PDS*II s1	PDS*II s1	PDS*II s1	PDS*II s1	PDS*II s1	St. PDO t4, s3-0	St. PDO t4, s3-0	St. PDO t4, s3-0	St. PDO t4, s3-0	St. PDO t4, s3-0	St. PDO t4, s3-0	St. PDO t4, s3-0	St. PDO t4, s3-0	St. PDO t1, s2	St. PDO t1, s2	St. PDO t1, s2	St. PDO t1, s2

Figure 4.9. Batch 2 - suture position diagram*

*Notes for Figure 4.9:

- St. means Stratafix™.

- PGA refers to PGA-PCL sutures.

- t refers to tensile strength size given on the suture pack.

- s refers to size given on the suture pack.

4.3.7 Summary of Failure Modes

The failure modes observed over the two batches (11 suture groups) are as below:

1. Full slippage out of LAPRA-TY® and Hem-o-Lok® at the top. This is observed in all suture groups except Stratafix™ PDO of tensile strength 4-0 having size 3-0.

2. Breakage within the effective length (Figure 3.1, page 36). This is observed in all the Stratafix™ PDO samples of tensile strength 4-0 having size 3-0. One breakage is observed in Stratafix™ PGA-PCL (tensile strength 3-0, size 2-0) at the top margin of bottom Hem-o-Lok® as shown in Figure 4.7-b (page 56).

3. Opening of LAPRA-TY®. This is observed in only one sample of PDS*II (size 1, metric 4.0) as shown in Figure 4.6, page 55.

4. Sliding out of the bottom ligation (Hem-o-Lok® and knot). This was observed in the immediate failure of a Vicryl™ 5-0 sample while loading. The Hem-o-Lok and knot combination was found out of the bottom clamp. This was an odd occurrence that is an artifact of the apparatus design of the bottom clamp and suture placement. Therefore, it is not included in the results. It was replaced immediately by another sample from the same pack.

4.3.8 Summary of Statistical Analysis

For this study, variances within and across groups are found large. Q-Q plots (detail can be checked from Figure 6.2 and Figure 6.3 given in the Appendix, page 69) showed normality only for the groups of sutures that failed immediately (Vicryl™ 5-0) or almost immediately (Monocryl™ 4-0). Even for the group (Vicryl™ 0) having most consistent durability among the 8 samples, Q-Q plot did not demonstrate normality (Figure 4.10), meaning highest consistency found in the experiment is not consistent enough.
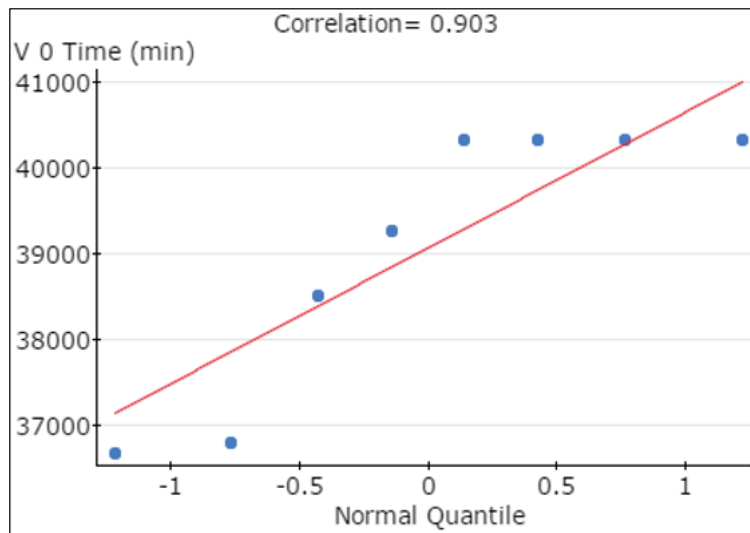
Figure 4.10. Q-Q plot of durability data for Vicryl™ 0 samples

In ideal cases, sample size for an experiment should be a representative of the population based on variance in the population and desired accuracy (i.e., page confidence interval) of the outcome. Variance, effect size and distribution should be known by doing pilot studies that generate consistent (i.e. repeatable) data. Because these information are not known, parametric statistical analysis like Analysis of Variance, cannot be applied to the data set (Rouzer, Goos, & Jones, 2011). For non-parametric tests, like Mann-Whitney test, data from each population must be an independent random sample, and the population distributions

must have equal variances and the same shape (SAS Institute, 2013) – which is not there in the data set of the experiments. In addition, the data are clearly dispersed, and hence the differences or similarities are vivid even without applying these statistical techniques. Table 4.4 and Table 4.5 shows the basic statistics of the data set (raw data are available in the Appendix, Table 6.2 and Table 6.3, page 68).

Table 4.4. Statistics of batch 1 sutures

Statistic	Vicryl™ 0	Vicryl™ 2-0	Vicryl™ 3-0	Vicryl™ 4-0	Vicryl™ 5-0	Monocryl™ 4-0
High	28.00	28.00	28.00	16.98	0.02	0.65
Low	25.47	19.23	1.46	0.01	0.00	0.01
Mean	27.13	26.90	15.15	8.18	0.00	0.26
Median	27.63	28.00	15.62	7.22	0.00	0.23
Mode	28.00	28.00	28.00	None	0.00	None
Variance	1.21	9.63	189.05	37.63	0.00	0.05
Std. Dev.	1.10	3.10	13.75	6.13	0.01	0.22

Table 4.5. Statistics of batch 2 sutures

Statistic	PDS*|| 1	PDO 2	PDO 3-0	PGA-PCL 2-0	PGA-PCL 3-0
High	28.00	28.00	27.43	24.11	22.84
Low	16.02	13.67	15.02	0.17	0.45
Mean	22.28	20.24	20.24	8.61	5.96
Median	21.73	19.72	19.26	5.63	3.23
Mode	28.00	28.00	None	None	None
Variance	30.60	40.72	22.03	91.85	54.87
Std. Dev.	5.53	6.38	4.69	9.58	7.41

5. Conclusion and Recommendations

This research was targeted to find out which types and sizes of sutures can endure the 4 N tension for a medically significant time period. The sample sutures were selected from those commonly used in partial nephrectomy. However, the outcomes can be extrapolated for other surgeries involving tissues of similar characteristics.

As can be recalled from the Introduction and Literature Review sections, at least 2 weeks are needed for the tissues to regain their primary tensile strength that get the wound healing process started. Sutures lose about 30% strength by two weeks (Figure 2.2, page 20). LAPRA-TY® use is recommended for no more than 14 days of tension strength requirement. Hence, a 14 days period is medically significant for durability of sutures under tension, although durability data are available from this study for 28 days.

Thereby, considering 14 days as the cut off time for determination of pass and fail of sutures, the following conclusions can be drawn from a user's (surgeon) point of view:

1. Vicryl^{TM} 0 and Vicryl^{TM} 2-0 are the best choices with 100% (8 out of 8 samples for both sizes) lasting for 14 days (manufacturer's recommended period for LAPRA-TY®) when stopped with LAPRA-TY® and Hem-o-Lok®.

2. Vicryl^{TM} 3-0 follows the above two with the risk of 50% samples slipping before 7 (seven) days.

3. Vicryl^{TM} 4-0 and Vicryl^{TM} 5-0 are not good candidates to be used with LAPRA-TY® and Hem-o-Lok®.

From a perspective of comparison with Gupta, et al.'s (2015) study, the following conclusions can be drawn as well based on the median time to failure:

1. With the use of knots to backstop the Hem-o-Lok® clip in Gupta et al.'s (2015) experiment, Vicryl™ 3-0 and Vicryl™ 4-0 survived 23 days and 22 days of duration which is significantly longer than their durations (15.62 and 7.22 median days respectively) when supported by LAPRA-TY® and Hem-o-Lok®. It may be because one LAPRA-TY® and/ or one Hem-o-Lok® is not a sufficient suture stopper to achieve adequate durability.

2. Stratafix™ PGA-PCL 2-0 and 3-0 had lower durability (5.63 and 3.23 median days respectively) when used with LAPRA-TY® and Hem-o-Lok®, than with knot and Hem-o-Lok® (21 days for both sizes) in Gupta, et al.'s (2015) experiment. These premature failures were due to slippage.

3. With the given set-up (LAPRA-TY® and Hem-o-Lok® at the top, Hem-o-Lok and knot at the bottom, and 4 N tension) of this research, sutures slipping from the LAPRA-TY® and Hem-o-Lok® combination is the weakness. 73.86% samples (65 out of 88) failed in this way over the whole observation period (28 days). The rest failed by breakage and failing of a LAPRA-TY® for improper anchoring as summarized in the subsection 4.3.7 on page 58 .

5.1   *Improvement of Data*

Statistical capability of the experimental process to repeatedly reproduce the same results under same condition in a key underlying factor of whether these conclusions can be generalized or not (Sahay, 2012; NIST, 2015). If the experiment is run in different times and by different operators and still produces the same results under same controlled conditions (e.g.,

concentration of saline, temperature range, filtration speed etc.), then the results can be considered universal. However, the other researches consulted in the various sections of this paper did not claim to have done a capability, or repeatability and reproducibility study on their processes. A few of them used a confidence interval (95%) and as large as possible sample size to defend the appropriateness of their results (Dumville, et al., 2014). As discussed with the statistician (Zeitler, 2014, 2015), confidence interval and sample size can be decided if consistent data can be obtained on variance, effect size and distribution from pilot studies.

5.2   Improvement of Set-up

Experimental set-up can be improved for minimization of agitation from the PVC structure that affects the already loaded sutures while loading the next ones. A structure made of steel with strong footing, or the current structure with a number of suction cup mounts can help reduce the movement of the structure during loading.

Filtration is now done from one side of the tank, for which the samples on that side face more friction of water flowing into and out of the filter pump. This can cause difference in their absorbability and performance. An option of filtration from both sides or from the middle can be explored. However, the data for samples near and far from the filter are wide spread and cannot be used as an evidence of having or not having any impact from the filtration.

Sample loading technique can be rethought. The samples are loaded by pulling (with hand) from one side. This can cause manually inserted slippage even before these are is loaded. An extra Hem-o-Lok® and knot combination can be applied at a known distance from the LAPRA-

TY® to prevent slippage at LAPRA-TY® point during loading

(Figure 5.1). This pair (Hem-o-Lok® and knot) can be cut off
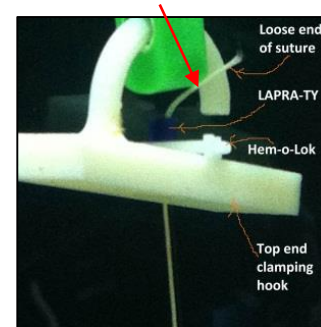
after loading and settling.

Figure 5.1. Point to apply extra Hem-o-Lok® and knot (red arrow)

5.3 Alternative Techniques

Alternative techniques can be explored that offer better

holding strength and yet release the surgeon from knot tying (Orvieto, et al., 2007; Tarin, et al.,

2010; Ames, et al., 2005). As discussed in the Literature Review section, the following two can

be investigated in the follow on studies:

1. Use of two (or more, as reasonable) LAPRA-TY®s to terminate sutures

2. Use of two Hem-o-Lok®s instead of knot or LAPRA-TY®.

3. Use of other clip brands (e.g Endoclip II®, Horizontal Ligating Clips® (Weck), Hem-o-lok

    Medium Polymer Clips® (Weck), Applied Medical Suture-clip)

5.4 More Inclusive Focus

Although manufacturers report tensile strength of sutures in a high range (e.g 35 to 38 N for

size 2-0 smooth, or 0 barbed sutures, given in Table 6.1 on page 67), Endres II, et al. (2014)

found that the tension applied on sutures by the surgeons is in the range of 2 to 5 N. Hence, the

same experiment can also be done at 2 N, 3 N and 5 N to check the durability of the same type

and sizes of sutures, since 4 N tension may not be always applied in real scenario. In addition,

more types and sizes of sutures can be tested at all these tension levels (2, 3, 4, and 5 N) to

have wider menu for the surgeons to choose from. Alternatively, experimentation can be done

at the highest of these tensions (5 N), because it would not be possible using the current

techniques to predict exactly which of these tensions is actually being applied in surgery.

6. Appendix

6.1 Information of Batch 1

January 16, 2015 to February 13, 2015 (28 days). Tested Sutures: Vicry^TM 0, 2-0, 3-0, 4-0, and 5-0

6.2 Information of Batch 2

February 13, 2015 to January 16, 2015 (28 days)

Tested Sutures: Stratafix^TM PGA-PCL 2-0, 3-0, Stratafix^TM PDO 2, 3-0, and PDS*II 1.

6.3 Surgical Clips in Batch 1 and 2

Suture clips: LAPRA-TY®, made by Ethicon, Inc., absorbable.

Ligation systems: Hem-o-Lok®, of the brand Weck®, distributed by Teleflex®, non-absorbable.

6.4 Failed Suture Retrieval

Failed sutures were retrieved from the tank with the help of a hemostat clamp (Figure 6.1). This clamp is used to pick the bottom clamp used to hold the suture, fallen suture pieces if any, dropped LAPRA-TY® and Hem-o-Lok®. The top clamp remained attached to the spring balance; the balance was retrieved by hand.

Figure 6.1. Hemostasis clamp used to retrieve fallen suture and clips

6.5 Manufacturer's Recommendations for Tensile Strength

Table 6.1. Tensile strength of UPS size 2-0 and equivalent sutures *(Dumville, et al., 2014)*

Sutures	Tensile Strength of Barbed Sutures (N)	Tensile Strength of Smooth Sutures (N)
Coated Vicryl™ (size 2-0)	-	35.6
Monocryl™ (size 2-0)	-	35.9
Barbed PDO (size 0)	38.1	-

6.6 Hanging Duration of Suture Samples

Table 6.2. Batch 1 sutures – Raw data of lasting time in hangers

Sample No.	Vicryl 0	Failure Modes	Vicryl 2-0	Failure Modes	Vicryl 3-0	Failure Modes	Vicryl 4-0	Failure Modes	Vicryl 5-0	Failure Modes	Monocryl 4-0	Failure Modes
1	25.47	Slippage	28	No failure	28	Slippage	16.98	Slippage	0	Slippage	0.25	Slippage
2	27.27	Slippage	28	No failure	3.23	Slippage	2.89	Slippage	0	Slippage	0.65	Slippage
3	28	No failure	28	No failure	28	Slippage	9.62	Slippage	0	Slippage	0.21	Slippage
4	28	Slippage	19.23	Slippage	2.65	Slippage	4.34	Slippage	0.02	Slippage	0.09	Slippage
5	25.55	Slippage	28	No failure	1.84	Slippage	4.81	Slippage	0	Slippage	0.01	Slippage
6	26.74	Slippage	28	Slippage	28	No failure	0.01	Slippage	0	Slippage	0.05	Slippage
7	28	No failure	28	No failure	1.46	Slippage	11.30	Slippage	0	Slippage	0.39	Slippage
8	28	No failure	28	Slippage	28	Slippage	15.49	Slippage	0	Slippage	0.40	Slippage

Color Legend:

No failure	28 days with slippage	Highest in the group but < 28 days

Table 6.3. Batch 2 sutures – Raw data of lasting time in hangers

Sample No.	PDS*|| 1	Failure Modes	PDO 2	Failure Modes	PDO 3-0	Failure Modes	PGA-PCL 2-0	Failure Modes	PGA-PCL 3-0	Failure Modes
1	27.65	Slippage	28	No Failure	27.43	Breakage	10.85	Slippage	0.45	Slippage
2	28	No Failure	28	No Failure	15.02	Breakage	0.36	Slippage	6.51	Slippage
3	0.00	Slippage	14.18	Slippage	17.02	Breakage	24.11	Breakage	3.30	Slippage
4	17.46	Slippage	13.84	Slippage	18.88	Breakage	17.51	Slippage	22.84	Slippage
5	16.02	Slippage	13.67	Slippage	19.64	Breakage	0.40	Slippage	8.93	Slippage
6	17.12	Slippage	24.79	Slippage	27.16	Breakage	0.30	Slippage	1.26	Slippage
7	28	No Failure	23.06	Slippage	16.39	Breakage	15.14	Slippage	1.20	Slippage
8	21.73	Slippage	16.37	Slippage	20.36	Breakage	0.17	Slippage	3.17	Slippage

Color Legend:

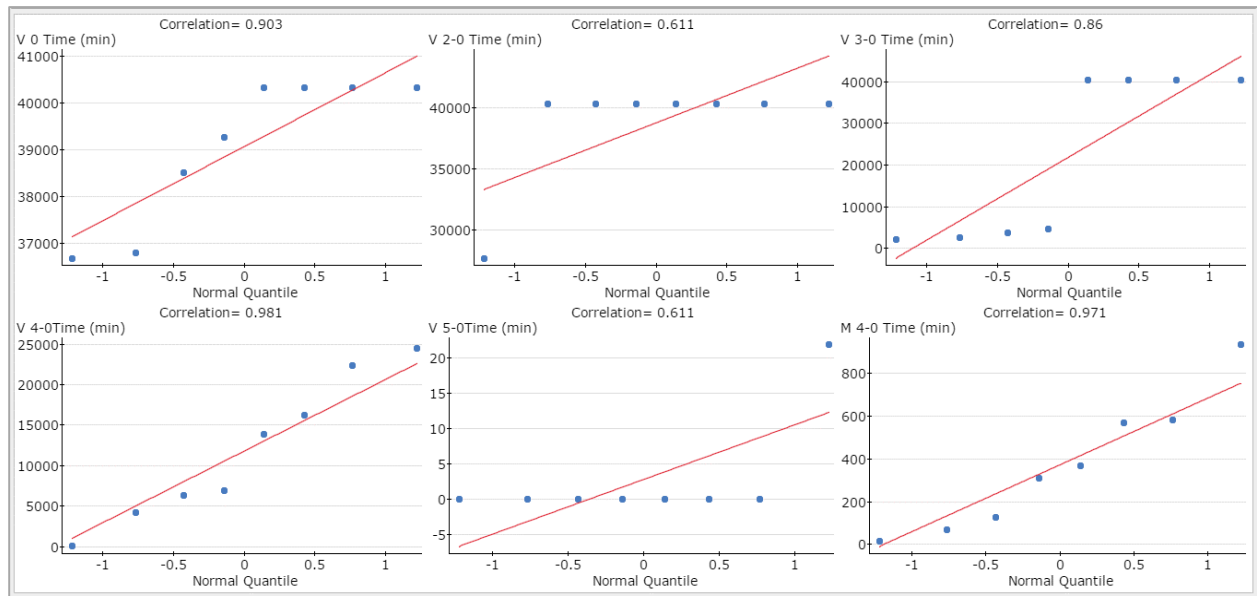| No failure	28 days with slippage	Highest in the group but < 28 days

6.7   Q-Q Plots to Check Normality of Data

Figure 6.2. Q-Q Plots for batch 1 sutures; normality is seen for Vicryl™ 2-0 data with an outlier; Vicryl™ 3-0 shows normality but with bimodality; tentative normality seen for Vicryl™ 4-0 does not add value because only 2 samples survived more than 14 days; Vicryl™ 5-0 and Monocryl™ 4-0 has some normality but do not add value because of failure within a day.
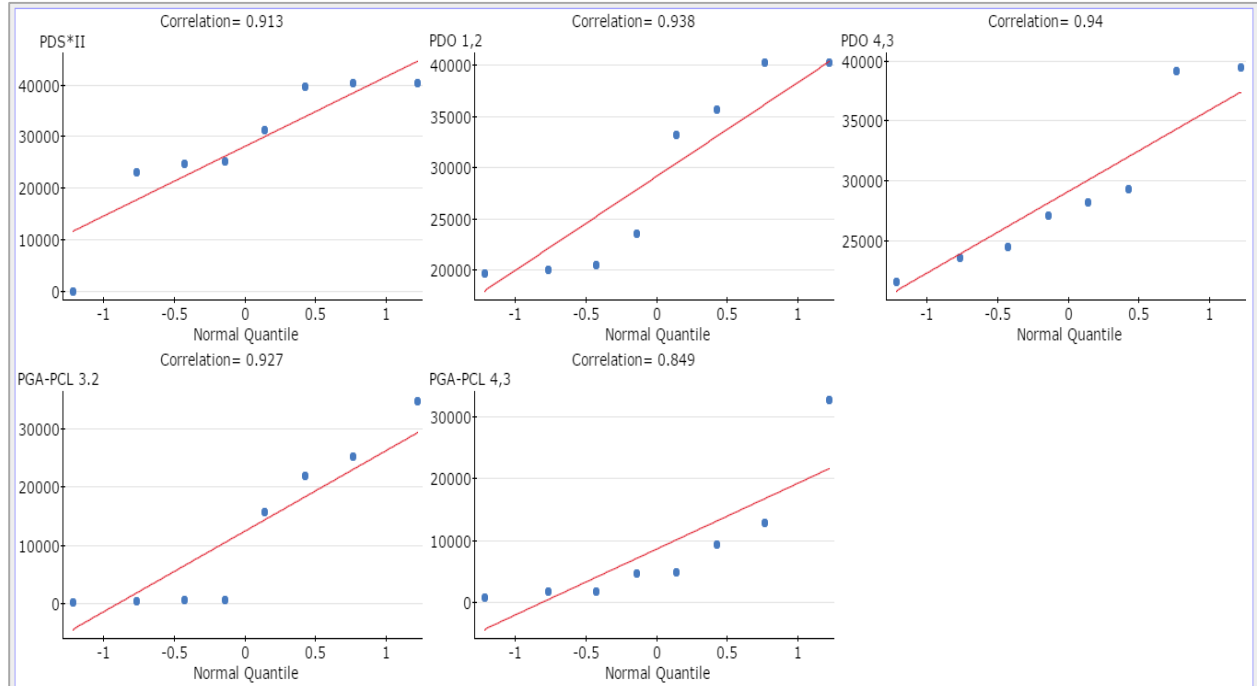

Figure 6.3. Q-Q Plots for batch 2 sutures; normality is not there in any group; as also seen from the raw data (Table 6.3, page 68), the numbers are widely dispersed, only except PGA-PCL size 3-0 because all of those failed within 8 days with an outlier of 22 days.

6.8   Length of Cut End of the Sutures

Table 6.4. Length of cut end of sutures at the top

Hanger Number	Suture**	Length of Loose End (mm)	Hanger Number	Suture	Length of Loose End (mm)
Front 1	PDO (t=1, s=2, big pack)	15	Rear 1	PDO (t=1, s=2, big pack)	15
Front 2	PDO (t=1, s=2, big pack)	15	Rear 2	PDO (t=1, s=2, big pack)	15
Front 3	PDO (t=1, s=2, big pack)	15	Rear 3	PDO (t=1, s=2, big pack)	15
Front 4	PDO (t=1, s=2, big pack)	15	Rear 4	PDO (t=1, s=2, big pack)	15
Front 5	PDO (t=4, s=3-0, small pack)	*14*	Rear 5	PGA-PCL (t=3-0, s=2)	15
Front 6	PDO (t=4, s=3-0, small pack)	15	Rear 6	PGA-PCL (t=3-0, s=2)	*11*
Front 7	PDO (t=4, s=3-0, small pack)	15	Rear 7	PGA-PCL (t=3-0, s=2)	*11*
Front 8	PDO (t=4, s=3-0, small pack)	15	Rear 8	PGA-PCL (t=3-0, s=2)	15
Front 9	PDO (t=4, s=3-0, small pack)	15	Rear 9	PGA-PCL (t=3-0, s=2)	*10*
Front 10	PDO (t=4, s=3-0, small pack)	15	Rear 10	PGA-PCL (t=3-0, s=2)	*10*
Front 11	PDO (t=4, s=3-0, small pack)	15	Rear 11	PGA-PCL (t=3-0, s=2)	*8*
Front 12	PDO (t=4, s=3-0, small pack)	15	Rear 12	PGA-PCL (t=3-0, s=2)	*13*
Front 13	PDS*|| (s=1, m=4.0)	15	Rear 13	PGA-PCL (t=4-0, s=3-0)	15
Front 14	PDS*|| (s=1, m=4.0)	15	Rear 14	PGA-PCL (t=4-0, s=3-0)	15
Front 15	PDS*|| (s=1, m=4.0)	15	Rear 15	PGA-PCL (t=4-0, s=3-0)	15
Front 16	PDS*|| (s=1, m=4.0)	15	Rear 16	PGA-PCL (t=4-0, s=3-0)	15
Front 17	PDS*|| (s=1, m=4.0)	15	Rear 17	PGA-PCL (t=4-0, s=3-0)	15
Front 18	PDS*|| (s=1, m=4.0)	15	Rear 18'	PGA-PCL (t=4-0, s=3-0)	15
Front 19	PDS*|| (s=1, m=4.0)	15	Rear 19	PGA-PCL (t=4-0, s=3-0)	15
Front 20	PDS*|| (s=1, m=4.0)	15	Rear 20	PGA-PCL (t=4-0, s=3-0)	15

** All sutures in batch 1 (Vicryl[TM] and Monocryl[TM]) had 15 mm loose end hanging beyond LAPRA-TY® at the top

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