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Influence of the suture length to wound length ratio in coeliotomy closure: Literature review and relevance in human medicine

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1. Introduction

There is a wide selection of indications for performing a coeliotomy in human as well as in veterinary surgery. Performing a midline laparotomy gives an excellent approach to all abdominal organs and is very commonly used. Unfortunately, complications resulting from an inappropriate closure of the surgical incision are often encountered in the postoperative period and cause patient discomfort, prolonged hospitalization and increased medical costs.

To assess objectively the method of closure has been the object of research in recent years and studies show that introducing a standardized closure technique for midline abdominal incisions can reduce the complication rate in the short- and long-term postoperative period (ISRAELSSON, 2003).

Jenkins first introduced the concept of the suture length to wound length ratio (JENKINS, 1976). This ratio gives the surgeon the possibility to assess his/her closure technique by measuring the total length of suture material used for the closure of the incision and the length of the incision. Israelsson further investigates this geometric approach during numerous clinical trials and records a pattern between the height of the suture length to wound length ratio and the complication rate associated with the laparotomy wound (ISRAELSSON, 2003). Thus, using a higher suture length to wound length ratio can reduce the incidence of complications such as incisional hernia, especially in the long-term postoperative period.

1.1. Thesis and Hypothesis

There are basically no studies, performed in clinical settings, in small animal veterinary surgery about SLWL ratios. Thus, the object of this thesis is to collect the literature focusing on the optimal suture length to wound length ratio for the closure of the abdominal fascia and its role in the complication rates in the postoperative period in human surgery.

The studies are to be divided in categories according to certain criteria and assessed. The grading system that is used in this thesis was designed by the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006).

The hypothesis of this review is that the optimal suture length to wound length ratio recommended for the closure of the abdominal fascia after a coeliotomy is more than 4:1. When applying the recommended ratio the risk for postoperative complications such as incisional hernia is reduced.

1.2. Overview of the literature

1.2.1. Anatomy of the human anterior abdominal wall

The anterior abdominal wall is the area defined proximally by the xiphoid process and the costal margins, distally by the anterior part of the iliac crest, fold of groin, pubic tubercle, pubic crest and pubic symphysis (SINGH, 2011). The lateral border is the mid-axillary line that separates the anterior and the posterior abdominal wall (SINGH, 2011).

The anterior abdominal wall consists of eight layers: skin, superficial fascia, external oblique muscle, internal oblique muscle, transversus abdominis muscle, fascia transversalis, extraperitoneal tissue and the parietal layer of the peritoneum (SINGH, 2011). Since this thesis focuses on the closure of the abdominal fascia formed by the aponeurosis of the abdominal muscles, the anatomy of the skin and the superficial fascia will not be discussed in detail.

1.2.1.1. Muscles of the anterior abdominal wall

There are five pairs of muscles – three pairs of flat muscles (external oblique, internal oblique and transversus abdominis) and two pairs of vertical muscles (rectus abdominis and pyramidalis) (SNELL, 2008). The flat muscles are fleshy posterolaterally and aponeurotic anteromedially (SNELL, 2008). These aponeuroses enclose the vertical muscles and fuse with the muscles of the opposite side the form a median fibrous raphe (linea alba) (SNELL, 2008). The linea alba extends from the xiphoid process to the pubic symphysis (BEER et al., 2009).

1.2.1.2. Microscopic anatomy of the linea alba

Fiber orientation and the exact formation of the linea alba is still under discussion since studies come to different conclusions depending on the methods of evaluation and the acquired specimens (AXER et al., 2001). Studies show that the fiber configuration is regionally and sometimes even individually specific (ASKAR et al., 1977). However, understanding the microscopic configuration of the collagen fibers is of great importance for the healing of the linea alba after a surgical intervention.

A study by Askar (ASKAR et al., 1977) divides the anterior abdominal wall in two functional regions separated by the umbilicus – area for parachute respiratory mechanism and area providing belly support. He shows that the fibers of the aponeuroses of the abdominal muscles pass freely from one side to the other forming a pattern of decussation at the linea alba that is essential for the wound strength after midline abdominal incisions. Above the umbilicus the fibers of the external oblique aponeurosis form a double stratum pattern that is important for the respiration. This pattern is not observed below the umbilicus where the fibers run downwards and medially providing elastic belly support (ASKAR et al., 1977).

This classification of the morphology of the linea alba has been criticized because the results could not be reproduced. The need for further investigation has arisen. In a more recent study Korenkov (KORENKOV et al., 2001) reconstructs Askar's method (ASKAR et al., 1977) but is not able to reproduce the results. Therefore, a different method for histological investigation was performed. This study offers a classification of the linea alba according to the morphology and its correlation with the tensile strength: weak, intermediate and compact. However, one cannot conclude that this classification is uniform since the specimens were taken from cadavers that were over 75 years of age and the study does not offer exact guidelines for the classification.

Another study by Axer presents a more detailed overview on the architecture of the collagen fibers in the linea alba (AXER et al., 2001). He divides the collagen fibers in three groups – oblique I that run right upward to left downward, oblique II that run from left upward to right downward, and transverse. According to the orientation of the collagen fibrils, he divides the linea alba in three zones – superficial ventral zone that contains four to six layers of oblique I and oblique II bundles intermingled with each other; a region of four to six layers of transverse fibers; an inconstant irregular zone of oblique fibrils.

1.2.2 Access to the abdominal cavity

Laparotomy and coeliotomy are generally used as synonyms for a surgical incision into the abdominal cavity (FOSSUM, 2007) even though the term laparotomy is by definition a flank incision. There are lots of different access points to the abdominal cavity. This thesis focuses primarily on the midline incision through the linea alba. The midline incision can extend

through the entire length of the linea alba, from the xiphoid process to the pubic symphysis. It can be divided into upper and lower midline incisions divided by the umbilicus depending on the indication for the surgical procedure (MARTYAK et al., 1976). This is one of the most widely used surgical techniques due to the wide access to the abdominal cavity, important for explorative laparotomies, and easy closure (MARTYAK et al., 1976).

Other surgical incisions are the paramedian incision, the pararectus incision, the transrectus incision, transverse incision and McBurney's incision (SNELL, 2008)

1.2.3. Indications for a coeliotomy

Medical care is undergoing major changes as technology develops and enables higher standards to be achieved. Minimally invasive surgery via laparoscopy and endoscopy has replaced the standard laparotomy techniques in many fields such a gynecology, intraluminal procedures of the upper digestive tract, small bowel obstruction etc. (SOPER et al., 2009). Laparoscopy is often preferred by patients and surgeons due to the shorter hospital stay and lower rate of complications such as wound infection, ileus and pain (SOPER et al., 2009). Even so, laparoscopy cannot yet replace the laparotomy completely.

There is a wide selection of indication for a laparotomy, including abdominal trauma (penetrating abdominal injuries, gunshots, injuries associated with hemorrhage), diaphragmatic defects, gastro-intestinal disorders such as intussusceptions or volvulus, abdominal masses, liver lobectomy, ovarian cysts and masses (KINGSWORTH et al., 2011).

1.2.4. Closure of the midline abdominal incision

To make the decision on the method of closure of a surgical incision the surgeon must consider many variables: suture material, type of suture, layered or mass closure, the length of the incision, the presence of tension in the wound, patient's medical history and preexisting conditions, presence of infection, cosmetic results and personal preference.

1.2.4.1. Suture material

Suture materials can be generally synthetic, organic or metallic, absorbable or non-absorbable, monofilament or multifilament (FOSSUM, 2007).

Natural materials (for example silk or catgut) are no longer recommended for the closure of the fascia because they lose their tensile strength very early in the healing stage of the incision (about 2 weeks) – and can therefore increase the risk for early wound complications (CARLSON, 2000). Metallic material such as stainless steel wire is not used in current surgery for the closure of surgical incisions because it is difficult to handle and tie and can cause discomfort for the patient (CEYDELI et al., 2005).

Monofilament suture materials have been associated with lower rates or wound infection because braided materials have interstices that can harbor bacteria that evade phagocytosis (ISRAELSSON, 2003).

There is still an open discussion if absorbable or non-absorbable materials should be used for the closure of the abdominal fascia. Non-absorbable sutures are widely used because they retain their tensile strength and produce less tissue inflammation (WEILAND et al., 1998; HODGSON et al., 2000; CEYDELI et al., 2005). Complications associated with non-absorbable sutures, however, include sinus formation, wound pain and button-hole hernia (WISSING et al., 1987; CEYDELI et al., 2005). These complications can become evident years after the surgery and can result in long-lasting fascia defects that are problematic in case of multiple surgeries (CARLSON, 2000). Absorbable sutures can be divided in slowly and rapidly absorbable sutures (CARLSON, 2000). Rapidly absorbable sutures such as Polyglactin 910 does not seem to influence the rate of wound dehiscence but can be associated with higher rates of incisional hernia (CARLSON, 2000). Studies that compare the effects of slowly absorbable (polydiaxanone) and non-absorbable materials (polypropylene) show no significant difference between the two materials in terms of wound dehiscence and incisional hernia (KRUKOWSKI et al., 1987). Slowly absorbable sutures like polydiaxanone are associated with lower rates of wound infection (KRUKOWSKI et al., 1987) and are the preferred suture material for the closure of the abdominal fascia according to most studies (CORMAN et al.,1981; KRUKOWSKI et al., 1987; CARLSON, 2000; ISRAELSSON, 2003; DIENER et al., 2010). One study, however, finds that polydiaxanone results in a higher rate of wound infection and failure compared to nylon (LEAPER et al., 1985). Even so, studies comparing different suture techniques and different suture materials show that the choice of suture material is inferior to the suture technique.

1.2.4.2. Layered or mass closure

In a layered closure the peritoneum, the fascia, the subcutaneous tissue and the skin are closed separately, while mass closure is the suturing of all layers except the skin simultaneously (DUDLEY, 1970). The mass suture involves the subcuticular fat, the aponeurosis, muscle and peritoneum (CENGIZ et al., 2001). Generally, the mass closure has been associated with lower rates of wound dehiscence (BUCKNALL et al., 1982; WEILAND et al., 1998) but the strength of a wound closed with the layered technique is greater than a wound closed with the mass technique in the early postoperative period (DUDLEY, 1970). A recent meta-analysis favors the mass closure as there is a statistically significant decrease in the rates of incisional hernia and wound dehiscence (VAN'T RIET et al., 2002).

However, an experimental study shows that a mass closure is not so secure when the intra-abdominal pressure is raised because the wound edges separate further apart than with a layered closure (CENGIZ et al., 2001). The suture cuts through the fat tissue and the peritoneum causing separation of the wound edges and necrosis as a result of the compression.

The closure of the peritoneum was previously considered essential to the closure of the abdominal wall to prevent adhesions (ELLIS et al., 1977). The peritoneum can either be incorporated in the mass suture or be closed as a separate layer. However, an experimental study in rabbits shows that there is no significant difference in the wound healing or the formation of adhesions when the peritoneum is not sutured (ELLIS et al., 1977). The authors of this study also discuss the disadvantages of suturing the peritoneum: prolonged operation time, sutures cutting through the tissue, and additional foreign material in the incision.

1.2.4.3. Suture technique

The suture technique for the closure of the abdominal fascia can generally be divided in simple interrupted and continuous. Continuous suturing is generally preferred because it is easy to perform, reduces operation time and decreases the amount of suture material in the wound (COLOMBO et al., 1997; KRESZINGER et al., 2007). The strength of the wound is higher or comparable when closed with a continuous suture (CEYDELI et al., 2005; KRESZINGER et al., 2007). Possible disadvantages are the limited number of knots holding

the suture and that the strength of the wound is dependent on a single strand of suture material (CEYDELI et al., 2005). The continuous suture technique has no statistically significant negative influence on the development of wound dehiscence and incisional hernia (POLLOCK et al., 1979; WISSING et al., 1987; HODGSON et al., 2000; SEILER et al., 2009; DIENER et al., 2010).

Different types of stitches have been explored to try to increase wound strength. For example, the continuous double loop stitches approximate the wound edges by transmitting the tension from the outer loop to the inner loop (CENGIZ et al., 2000). But in an experimental study the use of the double loop suture did not increase the wound bursting strength in comparison to the running suture (CENGIZ et al., 2000). The double loop suture did not prove beneficial for the development of wound dehiscence in a randomized controlled trial as well (NIGGEBRUGGE et al., 1999). In another experimental study in dogs two techniques were researched, based on the principle of tension banding. The abdominal wall was closed without suturing the incisional region with a mesh attached to the muscle (HÖER et al., 2002). Using these alternative techniques the authors did not observe incisional hernia and adhesion formation 15 months after surgery but development of seroma was an often encountered complication.

To ensure a secure wound closure, especially with a continuous suture where the number of knots is limited and therefore the forces applied to these knots greater, the tensile strength of the knot is worth investigating. A study compares the tensile strength of a surgeon's knot and a square knot, using different suture materials and shows that there is no statistically significant difference in the tensile strength between the two knots (MUFFLY et al., 2010). However, in an experimental trial with four types of knots (surgeon's knot, square, Aberdeen and loop knot) the knot-holding capacity was highest with the loop knot (FONG et. al, 2007). Another study evaluates the suture end length as the variable that determines the likelihood of knot failure and shows that knots with end length of 0mm are more likely to become untied than 3- or 10mm knots (MUFFLY et al., 2009). Therefore, for the security of a knot it is important to consider not only the type of knot but the end length of the knot and it should be avoided to leave less than 3mm end length.

Another attempt to decrease the rate of postoperative complications connected to the incision itself is the use of retention sutures. Retention sutures are stitches placed through all layers of the abdominal wall to reduce tension on the wound. However, more complications than benefits are associated with retention sutures: damage to the intestines, cutting lesions, skin maceration, intense pain and patient discomfort in the early postoperative period (RINK et al., 2000), higher incidence of incisional hernia (GISLASON et al., 1999).

1.2.5. The suture length to wound length ratio

In order to improve the suture technique for the closure of the abdominal wall there must be standardized variables to quantify and objectively assess the suture technique. The suture length to wound length ratio can serve as means to monitor the quality of the suture technique (JENKINS, 1976). This is the ratio between the total length of suture used to close the incision and the length of that incision. To calculate the suture length in a clinical setting one must first measure the original length of the suture material and subtract the length of the suture remnants after suturing the wound. The wound length is defined by the length of the incision (ISRAELSSON, 2003).

The idea behind the suture length to wound length ratio is the understanding of the dynamics of a laparotomy wound. The abdominal wall is mobile and distends during respiration, physiologic activity or increased abdominal pressure. Consequently, an incision in the abdominal wall follows the same pattern. Jenkins measured the increase in the girth and xiphoid-pubis distance during inspiration, Caesarean section and paralytic ileus and found that in the last two cases the wound length can be expected to increase by 30% (JENKINS, 1976). When distention occurs after a laparotomy the wound length increases which leads to a rise in the tension on the suture and the suture cuts through the tissue followed by wound disruption. Jenkins explains the basics of the suture length to wound length ratio with a simplified geometric approach to a single stitch in a continuous suture: if a single stitch forms an isosceles triangle, the length of a dropped perpendicular is equal to the sum of the tissue bites. When the wound is stretched the length of that perpendicular is decreased which leads to a rise in tension and compression of the tissue. Thus, the tissue bites and the stitch interval,

expressed in the suture length to wound length ratio, must be selected as to keep the reduction of the length of the perpendicular and the following rise in tension to a minimum.

The optimal suture length to wound length ratio for the closure of the abdominal wall is the main objective of this thesis and will later be discussed at length.

1.2.6. Wound healing

In order to obtain a deeper understanding of optimal surgical wound closure, one must consider the physiological process of wound healing and how the suture affects this process.

Wound healing consists of three fundamental phases that are the same for all tissues – inflammatory, proliferative and maturation phase – but the timeline for this complex process is very individual for the tissues (RATH et al., 1998). While skin und mucous membranes have a very high regenerative potential due to their high cellular content and rich vascularisation, aponeurotic tissue consists mainly of fibers that are poorly vascularised and healing of this tissue is expected to take longer than healing of epithelial tissues (DOUGLAS, 1952).

The blood supply of the surgical incision is crucial for wound healing to take place. Angiographic techniques have been used to identify the vascular characteristics of laparotomy wound in rats (LEAPER, 1983). Distorsion of the vascular anatomy was evident for 4 weeks after closure of the laparotomy wound and the tension, which the wound was closed with, is of significance. High tension delayed angiogenesis and caused signs of ischemia detected via angiography. Generally, angiogenesis levels correlate inversely with tissue oxygen levels and angiogenic growth factor synthesis is decreased when normal tissue oxygen level is restored (BROWN et al., 2002). A study that explores the level of hypoxia in the healing wound and its correlation with cytokine expression shows that hypoxia is not evident in the inflammatory exudate but is at its peak when granulation tissue is being formed (HAROON et al., 2000). Using hypoxia markers, the authors show that hypoxia does not initiate the angiogenesis cascade but plays a role in its maintenance (HAROON et al., 2000).

1.2.6.1. The inflammatory phase

The inflammatory phase is the acute response of the organism when the continuity of a tissue is disrupted and lasts about 5 days (FOSSUM, 2007). The formation of exudate that is rich in fibrinogen and hyaluronic acid is critical at this stage of wound healing because it creates an optimal milieu for cell activity and serves as a matrix for the later deposition of collagen fibers (RATH et al., 1998). Chemical mediators (histamine, serotonin, prostaglandins) induce vasodilatation that allows cell migration. The first cells to reach the wound are the polymorphonuclear leukocytes (RATH et al., 1998). They produce enzymes and free oxygen radicals that lead to the formation of an area of proteolysis on each side of the incision that can vary from 1.5 mm to 5 mm in breadth under normal conditions but can extend by 1 cm when an infection is present (RATH et al., 1998).

The most important cell of this first phase of wound healing is the macrophage. They are responsible for phagocytosis of bacteria and cell debris and fibroblast recruitment (RATH et al., 1998).

Anti-inflammatory drugs such as steroids, histamine receptor antagonists and the presence of bacteria impair the inflammatory phase and lead to a delayed healing process (RATH et al., 1998).

1.2.6.2. The proliferative phase

This phase is marked by high fibroblastic activity and neovascularisation that under normal conditions lasts for 3 weeks (RATH et al., 1998). Fibroblasts synthesize collagen in the form of trihelical tropocollagen connected via intermolecular links. Wound strength increases with the rise in the number of covalent bonds (RATH et al., 1998). Another crucial process that takes place during this phase of healing is wound contraction conveyed by myofibroblasts which reduces the area needing repair (FOSSUM, 2007). When the wound edges are adequately approximated during closure, wound contraction and initiation of collagen synthesis are sped up (RATH et al., 1998).

Vitamin C, Zn, Fe, Cu and oxygen are essential during this phase of wound healing and deficits can delay the process (RATH et al., 1998). Metabolic and organic diseases can also

impair fibroblastic activity (ELLIS, 1977). Cirrhosis decreases collagen synthesis and causes protein deficiency (RATH et al., 1998). Uremia and jaundice also diminish fibroblast migration and collagen synthesis, as shown in experimental studies in rats (ELLIS, 1977).

1.2.6.3. The maturation phase

In this phase of wound healing, the collagen fibers undergo reorientation (RATH et al., 1998). This phase can last as long as 2 years and is completed when function is reestablished. In healing of aponeurotic tissue, this is when resistance of the abdominal wall has recovered. Experimental studies in rabbits on the lumbar aponeurosis show that 1 year after surgery the aponeurosis at the incision reaches between 60% and 90% of the tensile strength of the parent tissue (DOUGLAS, 1952).

However, another study performed in rats suggests the contrary – abdominal fascia achieves adequate wound breaking strength and tensile strength faster than skin (FRANZ et al., 2001). The authors suggest that even though the recruitment of polymorphonuclear leukocytes and macrophages is simultaneous in fascia and skin, activation of fibroblasts and collagen synthesis are initiated earlier. It is apparent that the research on fascial healing is still a controversial topic and further investigation is required.

1.2.7. Postoperative complications related to the laparotomy wound

Postoperative complications related to the laparotomy wound are directly connected to disruptions of wound healing. They can be categorized as early and late complications (CEYDELI et al., 2005). Early complications are fascial dehiscence and infection; late complications are incisional hernia and suture sinus or incisional pain. Generally, one can categorize the risk factors for surgical complications as surgeon-related and patient-related.

Surgeon-related risk factors are related to the suture technique and the surgeon's expertise. Abdominal closure is considered a basic skill and knowledge about the current methods are a requirement. A study evaluates the knowledge of surgical residents at a medical center in USA and their practical skills to close the abdominal wall. The ability to estimate tissue bites and suture intervals, the choice of suture technique and scientific reasoning behind the choice, and the applied suture tension were evaluated and were found lacking (HOPE et al., 2010).

Even though the sample in this study is small, the fact that only 1 out of 10 residents had knowledge about the suture length to wound length ratio, and 4 out of 10 could support the choice for their suture technique points to existing knowledge gaps. The use of the suture length to wound length ratio can decrease the surgeon-related risk by standardizing the suture technique and providing and objective method to assess the quality of abdominal closure.

Patient-related risk factors are related to the patient's physical condition (age, sex, eating habits, smoking habits) and medical history (chronic and acute diseases, medication). Male gender, age > 65 years, obesity and smoking are well known risk factors for wound dehiscence (ABBAS et al., 2009). Uremia, jaundice (ELLIS, 1977), hypertension, ascites, postoperative ileus, wound or systemic infection (ABBAS et al., 2009) also predispose a patient to wound disruption after surgery. Another common denominator for the development of wound dehiscence is emergency surgery, probably because patients that undergo emergency surgery tend to be in worse medical condition and nutritional state than patients that undergo elective surgery (VAN RAMSHORST et al., 2010). Wound infection is probably the most important risk factor for wound complications and has been thoroughly researched (ELLIS, 1977; GISLASON et al., 1995; RATH et al., 2000; VAN RAMSHORST et al., 2009; ABBAS et al., 2009; VAN RAMSHORST et al., 2010). Bacteria in the wound activate neutrophils, extending the inflammatory phase and delaying collagen synthesis.

Even though the elderly are at an increased risk for wound disruption statistically, wound dehiscence is also a common and life-threatening complication in pediatric surgery. Young age (< 1 year) is associated with poorly developed immune response, impaired wound healing and higher risk for wound infection (VAN RAMSHORST et al., 2009). In this age group indications for elective surgery are scarce and there is a high prevalence for necrotizing enterocolitis that often requires emergency surgery which further increases the risk for wound dehiscence (VAN RAMSHORST et al., 2009). Midline abdominal incisions in children are considered risk factors for development of incisional hernia, and although this hasn't been confirmed, transverse incisions predominate (VAN RAMSHORST et al., 2009).

1.2.8. Incisional hernia

In spite of the advances in surgical technique and materials in abdominal surgery, an ideal method for closure of the abdominal wall has not been identified. Incisional hernia is still a common complication that occurs months after surgery, often requires surgical intervention and can have serious consequences. In 1979 the rate of incisional hernia in the USA was 7.6% (BUCKNALL et al., 1982) and remains high – it has been estimated that in the USA 250 000 hernia repairs are performed yearly (BREUING et al., 2010), in Sweden 869 patients were admitted for surgical hernia repair in 2002 (ISRAELSSON et al., 2006), in Germany the incidence of incisional hernia is 15% (HÖER et al., 2002). Incisional hernia is often associated with the early postoperative wound complications such as wound infection because they weaken the strength of the wound and prolong wound healing (KLINGE et al., 1997). Responsible for the occurrence of incisional hernia is often the suture technique – a higher rate of incisional hernia has been reported among inexperienced surgeons and a decrease in the rate when the suture technique is optimized via the suture length to wound length ratio (KLINGE et al., 1997).

Several methods are available for repair of incisional hernia but as with abdominal closure the available technique require improvement. In a survey in Sweden in 2002 out of the 869 incisional hernia 17% were a recurrence (ISRAELSSON et al., 2006) and the risk for hernia recurrence increases with each operation (BREUING et al., 2010). Techniques for hernia repair are diverse – suture repair, open mesh repair and laparoscopic mesh repair (ISRAELSSON et al., 2006). Suture repair is associated with a high risk of recurrence (ISRAELSSON et al., 2006) and is therefore inferior to mesh repair. However, Jenkins had satisfactory results in repair of incisional hernia with continuous sutures after excision of the scar tissue (JENKINS, 1980). Retrorectus repair, also known as Rives-Stoppa procedure, is an example of open mesh repair where the prosthesis is placed between the rectus abdominis muscle and the posterior sheath (BAUER et al., 2002) without contact to internal organs (BREUING et al., 2010). It is a widely used technique in Europe (BREUING et al., 2010) and has been used successfully performed, reducing the rate of hernia recurrence (BAUER et al., 2002). An alternative method for open hernia repair is the laparoscopic IPOM (intraperitoneal onlay mesh) technique (SCHUMPELICK, 2010; BERGER, 2010). It has the advantage that a

large incision is not required – the prosthetic biomaterial is placed intra-abdominally, directly over the peritoneum, and attached (BERGER, 2010). This technique, however, requires quite a lot of know-how from the surgeon and should be used with caution when it is uncertain that the whole defect can be covered with a broad overlap (at least 5 cm) of prosthetic mesh (BERGER, 2010).

2. Materials and Methods

2.1. Literature research

A search in databanks such as Medline, PubMed, SciVerse Scopus, OvidSP and ISI Web of Knowledge was performed to find papers and studies about closure of the abdominal wall and the suture length to wound length ratio. The search was extended with the use of the "related articles", references of found articles and contents of the catalogue of the library at the Veterinary University of Vienna (VUW) and the general hospital in Vienna (AKH). All articles regarding the optimal technique for the closure of the abdominal wall and the relevance of the suture length to wound length ratio, available in English and German language, were included in this thesis. Since the search was completed in September 2011, articles, published after this date, were not included in this thesis. Exclusion criteria for the papers were studies that compare suture techniques but do not take the suture length to wound length ratio in consideration and studies investigating laparotomy incisions other than the midline incision. The following table 1 presents a detailed overview of the literature search.

Parameter	**Details**
Time interval	Start: February 2011 End: September 2011
Language	English, German
Databanks	• PubMed • Scopus • Medline • OvidSP • SciVerse Scopus • Cochrane Central Register of Controlled Trials • ISI Web of Knowledge • Catalogues of the libraries of VUW and AKH
Keywords	• Suture length to wound length ratio

	• Suture length • Suture length + wound length • Suture length + incision length • Suture length + laparotomy • Suture length + coeliotomy • Suture length + abdominal closure • Suture length + fascia closure • Suture length + abdominal incision • Suture length + midline incision • Suture length + wound dehiscence • Suture length + incisional hernia • Suture length + hernia • Suture technique • Suture technique + laparotomy • Suture technique + coeliotomy • Suture technique + abdominal closure • Suture technique + abdominal incision • Suture technique + midline incision • Suture technique + wound dehiscence • Suture technique + incisional hernia • Suture technique + hernia • Abdominal fascia closure • Abdominal wound closure • Coeliotomy closure • Laparotomy closure • Stitch length • Incisional hernia
Extended search	• Search in “related articles” • Search in the references section of articles

Exclusion criteria	• Papers that investigate suture techniques without considering the suture length to wound length ratio • Papers that investigate closure of laparotomy incisions other than the midline incision

Table 1. A detailed overview of the literature search.

2.2. Criteria for the evaluation of the literature

The studies have been divided in categories according to a system designed by the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006). This grading system, also referred to as the ribbon approach, has four categories: platinum, gold, silver and bronze. The classification of the studies is done according to the following criteria:

- sample size
- participation of patients at the follow up
- random selection of patients and assessors
- blinding of patients and assessors for outcomes
- concealment of treatment allocation

Grade	Criteria
PLATINUM	At least two individual randomized controlled trials, each satisfying the following: • At least 50 patients per group • Blinding of patients and assessors for outcomes • At least 80% of the patients participate in the follow-up examinations • Concealment of treatment procedure
GOLD	At least one randomized controlled trial, satisfying the following criteria: • At least 50 patients per group • Blinding of patients and assessors for outcomes • At least 80% of the patients participate in the follow-up examinations • Concealment of treatment procedure
SILVER	• Randomized trial that does not meet the criteria, required for

	PLATINUM and GOLD grade • Study of nonrandomized cohorts who did or did not receive the therapy • At least one case-control study • A "head-to-head" comparison of agents if there is no provided reference to comparison of one of the agents to placebo with a relative difference of more than 20%
BRONZE	• At least one case series without controls, including before/after studies where the patients act as their own control • An expert's opinion based on clinical experience

Table 2. Grading system according to the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006)

3. Results of the literature search

3.1. Included studies

A total of 23 representative studies were found that investigate the optimal suture length to wound length ratio for the closure of midline abdominal incisions and its clinical significance. Four of these studies are experimental studies performed on rats, one is an experimental study performed on porcine abdominal walls and even though the results cannot be directly applied in human medicine, these studies investigate the effects of the suture length to wound length ratio on the incision thoroughly and are therefore highly relevant. The study by ISRAELSSON (1999) that investigates bias in clinical trials is also included in the grading and the discussion because it focuses on the influence of the surgeon on the suture technique and points to the role of the suture length to wound length ratio as the key to an objective assessment of the suture technique and improvement of the scientific credibility of clinical trials.

The studies by CARLSON (2000), VAN GELDERE (2000), ISRAELSSON (2003), CEYDELI et al. (2005), and BOLLI et al. (2006) are literature reviews dealing with the optimal suture technique for the closure of midline laparotomy incisions with regard to the suture length to wound length ratio. These papers will not be included in the grading but the results will be considered in the discussion. The meta-analysis by VAN'T RIET et al. (2006) is a statistical analysis of published studies about the suture technique for abdominal closure and will not be graded with the rest of the studies as well but will be taken into account in the discussion. The following table 3 outlines the 23 studies that are included in this thesis with a short summary and the language they were published in.

Title	Contents	Language
BOLLI M., SCHILLING M. (2006): Incision and closure of the abdominal wall. Der Chirurg 77, 408 – 413.	This literature review deals with the technique for abdominal incisions and the suture technique for its closure. The suture length to wound length ratio is presented as an	German

	important factor for an optimal closure and means to decrease the rate of wound dehiscence.	
CARLSON M. A. (2000): New developments in abdominal wall closure. Der Chirurg 71, 743 – 753.	A literature review about the optimal suture technique for the closure of the abdominal wall under consideration of the suture length to wound length ratio, suture material, method of closure and incisional hernia repair. The author also outlines the advances of medical research over the years.	German
CENGIZ Y., MANSSON P., ISRAELSSON L.A. (2000): Conventional running suture and continuous double loop closure: an experimental study of wound strength. The European Journal of Surgery 166, 647 – 649.	This study is a comparison of two techniques for closure of midline abdominal incisions in 60 rats – running suture and continuous double loop suture, using a suture length to wound length ratio of 3:1, 4:1 and 7:1. Bursting pressure, bursting volume and the way the sutures cut through the tissue were recorded.	English
CENGIZ Y., BLOMQUIST P., ISRAELSSON L.A. (2001): Small tissue bites and wound strength. Archives of Surgery 136, 272 – 275.	This experimental study deals with wound bursting strength after closure of midline incisions in 51 rats with a suture length to wound length ratio of 4:1. Stitches were placed at a distance of 3, 6 or 10 mm from the wound edge and wound bursting strength was recorded immediately after and 4 days after wound closure.	English

CENGIZ Y., ISRAELSSON L.A. (1998): Incisional hernia in midline incisions: an eight - year follow up. Hernia 2, 175 – 177.	374 patients who underwent midline laparotomy incisions were included in this study and the incidence of incisional hernia was recorded 12 months and 8 years after the surgery. The suture length to wound length ratio of each patients was recorded and evaluated.	English
CEYDELI A., RUCINSKI J., WISE L. (2005): Finding the best abdominal closure: an evidence-based review of the literature. Current Surgery 62, 220 – 225.	This literature review discusses all aspects of abdominal closure, including technique and the significance of the suture length to wound length ratio, suture material and possible postoperative complications.	English
VAN GELDERE D. (2000): One hundred years of abdominal wound dehiscence and nothing has changed. Hernia 4, 302 – 304.	This literature review deals with the historical aspects of the abdominal wall closure, the advances in surgical technique and materials and the remaining complications associated with laparotomies.	English
HARLAAR J. J., van RAMSHORST G. H., NIEUWENHUIZEN J., ten BRINKE J. G., HOP W. C. J., KLEINRENSINK G., JEEKEL H., LANGE J. F. (2009): Small stitches with small suture distance increase laparotomy closure	This experimental study focuses on the size of the stitches and the distance between the stitches, taking also the suture length to wound length ratio into account. The experiments were performed on porcine abdominal walls, removed right after death, closed with two different suturing methods. The first group was closed with large stitches and large suture distance (1cm), the second	English

strength. The American Journal of Surgery 198, 392 – 395.	with small stitches and small suture distance (0.5cm). The strength of the incisions was evaluated using a tensile testing machine.	
HÖER J., JUNGE K., SCHACHTRUPP A., KLINGE U., SCHUMPELICK V. (2002): Influence of laparotomy closure technique on collagen synthesis in the incisional region. Hernia 6, 93 – 98.	In 100 rats median laparotomies were closed with a different suture technique, alternating also the suture length to wound length ratio. Tissue samples were obtained from each rat and the concentration of collagen and collagen composition were analyzed as an indicator for wound strength and rate of wound healing.	English
HÖER J., KLINGE U., SCHACHTRUPP A., TÖNS C., SCHUMPELICK V. (2001): Influence of suture technique on laparotomy wound healing: an experimental study in the rat. Langenbecks Archives Surgery 386, 218 – 223.	The effect of different suture techniques on the rate of wound healing of midline incisions was studied in 50 rats. Single or running sutures, different size tissue bites, different suture tension and different suture length to wound length ratios were used and the resulting wound strength assessed and compared to the controls.	English
ISRAELSSON L. A. (2003): Abdominal closure and incisional hernia. The European Journal of Surgery 35, 5 – 10.	This literature review discusses how to accomplish the optimal abdominal closure with the role of the suture length to wound length ratio as a monitoring device for the suture technique, giving details about the	English

	means to calculate it in a clinical setting.	
ISRAELSSON L. A. (1999): Bias in clinical trials: the importance of suture technique. The European Journal of Surgery 165, 3 – 7.	In this clinical trial the role of bias was explored by introducing a new suture material for closure of abdominal incisions and monitoring the effect of the new material on a surgeon's suture technique, reflected in the suture length to wound length ratio. The author accentuates the falsified results at the end of such clinical trials.	English
ISRAELSSON L.A. (1999): Incisional hernias in patients with aortic aneurismal disease: the importance of suture technique. European Journal of Vascular and Endovascular Surgery 17, 133 – 135.	The aim of this prospective study is to assess the risk for patients undergoing aortic aneurysm repair compared to other patients to develop wound complications such as wound infection and incisional hernia taking into account suture technique and suture length to wound length ratio. A total of 1023 patients were included in the study and examined 12 months after surgery for the presence of incisional hernia.	English
ISRAELSSON L.A. (1998): The surgeon as a risk factor for complications of midline incisions. The European Journal of Surgery 164, 353 – 359.	The author compares the suture technique of surgeons in the County hospital in Sweden and its role in formation of incisional hernia, recording the surgery details and the suture length to wound length ratio of 1013 patients. Wound infection and incisional hernia rates were assessed and compared to length of surgical experience of the surgeons.	English

ISRAELSSON L.A., JONSSON T. (1994): Closure of midline laparotomy incisions with polydiaxanone and nylon: the importance of suture technique. The British Journal of Surgery 81, 1606 – 1608.	This randomized clinical trial studies the effect of suture technique and suture material on the healing of midline incisions. The suture materials used in the trial were polydiaxanone and nylon; suture technique was monitored through the suture length to wound length ratio. Wound infection and incisional hernia were assessed 12 months after surgery.	English
ISRAELSSON L.A., JONSSON T. (1993): Suture length to wound length ratio and healing of midline laparotomy incisions. The British Journal of Surgery 80, 1284 – 1286.	In this prospective clinical trial 454 patients undergoing laparotomy through a midline incisions were evaluated. The suture length to wound length ratio was recorded and incidence of wound infection, wound dehiscence and incisional hernia was assessed 12 month after surgery.	English
JENKINS T. P. N. (1976): The burst abdominal wound: a mechanical approach. The British Journal of Surgery 63, 873 – 876.	This study introduces the concept of the suture length to wound length ratio by creating a mathematical model for the closure of abdominal incisions and applying this model in clinical trials. To evaluate the correlation between the suture length to wound length ratio and postoperative complications related to the surgical wound 127 wound closures were investigated.	English

KENDALL S.W.H., BRENNAN T.G., GUILLOU P.J. (1991): Suture length to wound length ratio and the integrity of midline and lateral paramedian incisions. British Journal of Surgery 78, 705 – 707.	This study compares the incidence of incisional hernia in midline and paramedian laparotomy incisions and its correlations with the suture length to wound length ratio used for the wound closure. A total of 349 patients were randomized and evaluated over a period of 18 months.	English
MILLBOURN D., CENGIZ Y., ISRAELSSON L. A. (2009): Effect of stitch length on wound complications after closure of midline incisions. A randomized controlled trial. Archives of Surgery 144, 1056 – 1059.	Evaluation of the significance of the stitch length on postoperative wound complications in 737 patients undergoing coeliotomies over a period of 5 years. In all patients suture length to wound length ratio was more than 4:1. Wound dehiscence, surgical site infection and incisional hernia were evaluated at 4 weeks and 12 months after surgery.	English
MILLBOURN D., CENGIZ Y., ISRAELSSON L. A. (2011): Risk factors for wound complications in midline abdominal incisions related to the size of stitches. Hernia 15, 261 – 266.	This study focuses on the stitch size while closing a midline laparotomy incisions and maintaining a suture length to wound length ratio of more than 4:1. Patients' incisions were closed either with small or large stitches, suture length to wound length ratio of each patient was recorded. The main aim of this study was to determine if a very high suture length to wound length ratio would affect the rate of complications, including incisional hernia.	English

MILLBOURN D., ISRAELSSON L. A. (2004): Wound complications and stitch length. Hernia 8, 39 – 41.	This study evaluates a cohort that has already been studied, including only patients whose wound was closed with a suture length to wound length ratio of more than 4:1. Mean stitch length was calculated for each patient and linked to the occurrence of postoperative wound infection and incisional hernia.	English
VAN'T RIET M., STEYERBERG E. W., NELLENSTEYN J., BONJER H. J., JEEKEL J. (2002): Meta-analysis of techniques for closure of midline abdominal incisions. The British Journal of Surgery 89, 1350 – 1356.	This meta-analysis investigates the ideal method of closure of the abdominal wall by comparing the results of 15 studies dealing with this topic.	English
VARSHNEY S., MANEK P., JOHNSON CD (1999): Six-fold suture: wound length ratio for abdominal closure. Annals of the Royal College of Surgeons of England 81, 333 – 336.	100 patients undergoing laparotomy through a midline incision were included in this study and the suture length to wound length ratio of each patients was recorded. Incidence of incisional hernia and burst abdomen was evaluated 12 months after surgery. A mathematical model was developed to support the thesis that a suture length to wound length ratio of more than 6:1 reduces the risk for the development of incisional hernia.	English

Table 3. Overview of the studies included in this thesis, a short summary of the contents and language of the original article

3.1.1. Listing of the included studies according to the criteria of evaluation

In order to assess the literature and divide it in the four grades: platinum, gold, silver and bronze (SANTESSO et al., 2006), certain criteria must be examined in each study:

- sample size
- group size
- randomized selection of patients into the groups
- participation of patients at the follow up: patient loss
- random selection of patients and assessors,
- blinding of patients and assessors
- case studies and expert's opinions

Blinding of the assessors in the studies was not always possible in cases where a different suture material was introduced and different suture techniques were compared because surgeons can notice the difference in the suture material and were instructed to use a different technique. In order to avoid bias the different suture techniques/material were used on alternating weeks. This is acceptable, though, because it cannot influence the development of postoperative complications. In one study (ISRAELSSON et al., 1999a) the focus is exactly how an introduction of a new suture material would affect the surgeon's technique, monitored by the suture length to wound length ratio.

At the follow up examination, however, blinding of the assessors is an important point since the occurrence of incisional hernia was examined in correlation to the suture length to wound length ratio. Therefore in the studies where the authors examine the patients and it is not specifically emphasized that the assessor is blinded will be evaluated as not blinded studies. In only two studies (MILLBOURN et al., 2009, MILLBOURN et al., 2011) was pointed out that the examining surgeon was blinded for the actual randomization.

Control groups were not essential for the evaluation of clinical trials because one cannot compare the suture length to wound length ratio or the incidence of incisional hernia in cases where no operation was performed. In experimental studies, however, a control group is very important for the evaluation of the results. For example, in the study done by HÖER et al.

(2000) the tensile strength of the abdominal wound after coeliotomy was measured and compared to the tensile strength of the intact abdominal wall.

Patient loss refers to the number of patients that were not able to complete the study protocol, died, developed other complications after surgery or had to be re-operated. In the experimental studies, where the groups consist of animals, all animals were sacrificed at the end of the experiment.

The study by JENKINS (1976) does not contain all details about the clinical trials required for the grading but will be included as an expert's opinion because it builds the foundation for the concept of the suture length to wound length ratio.

The literature reviews (CARLSON, 2000; VAN GELDERE, 2000; ISRAELSSON, 2003; CEYDELI et al., 2005; BOLLI et al., 2006;) as well as the meta-analysis by VAN'T RIET et al. (2002) will not be included in the grading but their results will be incorporated in the discussion.

The following table 4 outlines the studies included in the grading according to the grading criteria.

Study	Group size	Randomized	Control group	Blinding	Patient loss
CENGIZ et al., 2000	60 rats Group A: unknown Group B: unknown	Not specified	No	Not specified	60 rats sacrificed
CENGIZ et al., 2001	51 rats Group A: unknown Group B: unknown	Yes	No	Not specified	51 rats sacrificed
CENGIZ et al., 1998	374 patients	Yes, for the choice of suture material	No	No	Follow up: 1 year: 3 8 years: 140
HARLAAR et al., 2009	38 porcine abdominal walls Group A: 19 Group B: 19	Not specified	No	Not specified	–
HÖER et al., 2002	100 rats, 20 groups with 5 animals per group	Yes	No	Not specified	Follow up: 14 days: 50 28 days: 50 Sacrificed
HÖER et al., 2001	55 rats, 10 groups with 5 animals per group	Yes	Yes, 5 animals	No	55 rats sacrificed after 14 days

ISRAELSSON, 1999a	224 patients, Group A: 102 Group B: 122	Yes	No	No	55 patients
ISRAELSSON, 1999b	1023 patients Group A: 85 Group B: 938	Yes, for the choice of suture material	No	Not specified	210 patients
ISRAELSSON, 1998	1013 patients Group A: 25 Group B: 30 Group C: 35 Group D: 50 Group E: 80 Group F: 34 Group G: 39 Group H: 74 Group I: 136 Group J: 145 Group K: 152 Group L: 213	Yes	No	Not specified	215 patients

ISRAELSSON et al., 1994	813 patients Group A: 405 Group B: 408	Yes	No	Not specified	170 patients
ISRAELSSON et al., 1993	454 patients	No	No	Not specified	91 patients
JENKINS, 1976	127 patients	Not specified	No	Not specified	Not specified
KENDALL et al., 1991	349 patients Group A: 137 Group B: 104 Group C: 108	Yes	No	Not specified	
MILLBOURN et al., 2009	737 patients Group A: 381 Group B: 356	Yes	No	Yes	215 patients
MILLBOURN et al., 2011	691 patients Group A: 321 Group B: 370	Yes	No	Yes	Not specified
MILLBOURN et al., 2004	369 patients Group A: 103 Group B: 117	No	No	Not specified	78 patients

	Group C: 148				
VARSHNEY et al., 1999	100 patients	No	No	Not specified	15 patients

Table 4. List of all included studies according to the grading criteria

3.1.2. Grading of the studies

According to the grading system developed by the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006) the studies were evaluated, using the criteria in table 4:

Platinum:

None of the studies meet the criteria for this category since it requires two individual randomized controlled trials. Even though four studies by ISRAELSSON (ISRAELSSON, 1994; ISRAELSSON, 1998; ISRAELSSON, 1999a; ISRAELSSON, 1999b) have more than 50 randomized patients per group, it is not specifically outlined that assessors and patients were blinded and none of the trials could present at least 80% participation at follow-up.

Gold:

Similarly, none of the studies meet the requirements for the category "gold". In the study by KENDALL et al. (1999) there are more than 50 patients per group but it is not specified if they are blinded and the data about the patient participation at follow-up is incomplete – only patients lost due to death are noted as a percentage of the patients that entered the study. Two of the studies by MILLBOURN (MILLBOURN et al., 2009; MILLBOURN et al., 2011) meet almost all criteria – group size, patients and assessors were blinded and randomized but patient participation at follow-up in the former is less than 80%, in the latter it is not specified.

Silver:

All studies but one fall into the category "silver". Five studies are experimental trials; four of them are performed on rats, one on porcine abdominal walls. The study by HÖER et al. (2001) has a control group, the other four studies (CENGIZ et al., 2000; CENGIZ et al., 2001; HÖER et al., 2002; HARLAAR et al., 2009) have at least one comparison group that qualifies them for this category. The other twelve studies are randomized controlled trials that do not fulfill the criteria for the "platinum" or "gold" category.

Bronze:

The only study that falls into the category "bronze" is the study by JENKINS (1976) as an expert's opinion, because the author applies his theory in his patients and presents only the results of his own experience without publishing an official randomized clinical trial.

The results of the grading are summarized in the table below.

Study	Design of the study	Grade
CENGIZ et al., 2000	An experimental study on the effects of the running suture and the continuous double loop closure, under consideration of the suture length to wound length ratio, on wound strength	Silver
CENGIZ et al., 2001	An experimental study on the effect of a suture length to wound length ratio of at least 4:1, achieved with small tissue bites, on wound bursting strength	Silver
CENGIZ et al., 1998	A randomized controlled trial about the incidence of late incisional hernia in patients after laparotomy, where the technique is monitored via the suture length to wound length ratio.	Silver
HARLAAR et al., 2009	An experimental study performed on fresh porcine abdominal walls, comparing small and large suture distance and tissue bites and the suture length to wound length ratio and the effects the closure has on wound strength.	Silver
HÖER et al., 2002	An experimental study on the effect of different suture length to wound length ratios on the collagen synthesis in the laparotomy wound in rats.	Silver
HÖER et al., 2001	An experimental study on the effect of the suture length to wound length ratio on the mechanical strength of a wound.	Silver
ISRAELSSON, 1999a	A randomized controlled trial on the effect of the introduction of a different suture material on a surgeon's suture technique and the used suture length to wound length ratio	Silver
ISRAELSSON, 1999b	A randomized controlled study that compares the incidence of incisional hernia	Silver

	in patients with aortic aneurismal disease and patients with other diseases where the suture technique is monitored via the suture length to wound length ratio	
ISRAELSSON, 1998	A randomized controlled study about the role of the surgeon in the occurrence of wound complications and the suture length to wound length ratio used by surgeons depending on their expertise	Silver
ISRAELSSON et al., 1994	A randomized controlled trial that compares two different suture materials for the closure of laparotomy wounds, taking into account the suture length to wound length ratio	Silver
ISRAELSSON et al., 1993	A randomized controlled trial about the effect of the suture length to wound length ratio on the healing of midline incisions	Silver
JENKINS, 1976	A study on the mechanics of the laparotomy wound and introduction of a mathematical model for the closure of midline incisions, represented by the suture length to wound length ratio	Bronze
KENDALL et al., 1991	A randomized controlled trial that compares the incidence of incisional hernia after laparotomies closed with different suture techniques and suture length to wound length ratio of more than 4:1	Silver
MILLBOURN et al., 2009	A randomized controlled trial that investigates the rate of wound complications after closure of laparotomy wounds with a suture length to wound length ratio of at least 4:1	Silver
MILLBOURN et al., 2011	A randomized controlled trial about the effect of suture technique and the suture length to wound length ratio on	Silver

	postoperative wound complications	
MILLBOURN et al., 2004	A randomized controlled trial about the effect of stitch length and the suture length to wound length ratio on the rate of wound complications after a laparotomy	Silver
VARSHNEY et al., 1999	A randomized controlled trial about the importance of a high suture length to wound length ratio in the closure of midline abdominal incisions supported by a mathematical model	Silver

Table 5. Grading of the studies according to the system developed by the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006)

3.2. Results

Since both experimental studies performed on animals and clinical trials performed on human patients are included in this thesis and the results cannot be directly compared, the studies will be divided in two main groups that will be evaluated separately.

3.2.1. Experimental studies

There are five experimental studies included in this thesis; four of them performed on rats, one of them – on porcine abdominal walls. It is essential to make a distinction in the main outcome measures among the studies. In the studies by CENGIZ et al. (2000), CENGIZ et al. (2001), HÖER et al. (2001), and HARLAAR et al. (2009) the effect of the suture technique and the suture length to wound length ratio on the mechanical strength of a laparotomy wound is investigated. The study by HÖER et al. (2002) explores the influence of the suture length to wound length ratio on the collagen composition of the wound, directly related to wound strength.

3.2.1.1. Short recapitulation of the experimental studies

Study 1: CENGIZ, Y., BLOMQUIST, P., ISRAELSSON, L. A. (2001): **Small tissue bites and wound strength**

In this study fifty-one female Sprague-Dawley rats with a mean weight of 242g had their midline incisions closed with a running suture, using monofilament suture material. They were randomized to be studied immediately after closure and after 4 days. The stitches were

placed by the means of templates to ensure that tissue bites are exactly 3, 6 or 10 mm and the suture length to wound length ratio is 4. The templates were selected randomly. The suture tension used during the closure of the incisions was defined as just enough to approximate the wound edges. Wound bursting strength and volume were measured and recorded. The results of the study, immediately after wound closure, showed that the highest bursting pressure was achieved with stitches placed 10 mm away from the wound edge. However, both bursting pressure and bursting volume were lower 4 days after the surgical intervention in the wounds where stitches were placed 10 mm from the wound edge, than in the wound closed with smaller tissue bites. In this study it was additionally observed and recorded how the wound dehiscence occurred. The abdomen burst outside the suture line in 14 of 17 wounds closed with stitches placed 3 mm from the wound edge, 11 of 17 wounds closed with stitches placed 6 mm from the wound edge and 6 of 17 wounds closed with stitches placed 10 mm from the wound edge. These results lead the authors to believe that with the increase in the number of stitches placed and a suture length to wound length ratio of least 4:1, wound strength also increases.

Study 2: CENGIZ, Y., MANNSSON, P., ISRAELSSON, L. A. (2000): **Conventional running suture and continuous double loop closure: an experimental study of wound strength**

In this study equally long midline incisions were performed on 60 female Sprague-Dawley rats with a mean weight of 260g. The wounds were closed either with a running suture or continuous double loop technique, varying the suture length to wound length ratio. Templates were used to achieve a suture length to wound length ratio of 3, 4, and 7, keeping the stitch bite and stitch interval constant in wounds closed with the same ratio. Bursting pressure and bursting volume were measured the same way as in the previous study (CENGIZ et al., 2001). When the suture length to wound length ratio was 7:1, wound bursting pressure and volume, and consequently wound strength, was similar with both suture techniques. With a lower suture length to wound length ratio, wounds closed with a running suture had higher bursting pressure and volume. As in the previous study, observations were made on the mechanics of the burst wound – in 50 rats, the suture cut through the tissues.

Study 3: HÖER, J., KLINGE, U., SCHACHTRUPP, A., TÖNS, C., SCHUMPELICK, V. (2001): **Influence of suture technique on laparotomy wound healing: an experimental study in the rat**

Fifty-five male Wistar rats with a mean weight of 290g were used in this study. Five animals served as a control group and their abdominal walls were left intact. The rest of the animals were divided in 10 groups of 5 animals. Suture technique was varied among the groups, alternating single and running sutures, normal and high suture tension and the suture length to wound length ratio. Different suture length to wound length ratio was achieved by keeping the tissue bites at 5mm, but alternating the stitch distance. The resulting ratios were 2:1, 4:1 and 8:1. Since suture tension was also a variable in this experiment, the author's definition of 'normal' or 'high' tension is important; the wound was closed under normal tension when the wound edges were approximated without overlapping of tissue, and under high pressure when there was a macroscopically visible discoloration of the tissue. In two groups the size of tissue bites was reduced to 2mm, resulting in a suture length to wound length ratio of 1.7:1. All animals were sacrificed after 14 days and the tensile strength of each wound was examined by excising strips of the abdominal wall and fixed in a digital tensiometer. The results were statistically analyzed. Generally, the tensile strength of the wound was significantly higher when it was closed with a running suture and suture length to wound length ratio of at least 4:1. The wounds closed with high tension produced significantly weaker regenerating tissue, irrespective of the suture technique. Overall, the authors concluded that applying normal tension in the closure and a suture length to wound length ratio of at least 4:1 has a positive effect of the mechanical strength of a midline abdominal incision.

Study 4: HARLAAR, J. J., VAN RAMHORST, G. H., NIEUWENHUIZEN, J., TEN BRINKE, J. G., HOP, W. C. J., KLEINRENSINK, G., JEEKEL, H., LANGE, J. F. (2009): **Small stitches with small suture distances increase laparotomy closure strength**

In this study the abdominal walls from thirty-eight Yorkshire pigs with weight between 20 and 40 kg were excised after death and frozen for a minimum of 4 days. After defrosting, equally long midline incision were made and closed with a continuous double loop technique. Stitch distance and tissue bite in the first group were 1cm and referred to as 'large' (group A), and in the second group they were 0.5cm and referred to as 'small' (group B). The suture length to wound length ratio was also calculated and the mean ratio was 4.1:1 in group A and 6.9:1 in group B. The tensile strength of the closed incisions was measured via a tensile testing machine and each test was filmed. Generally, the results showed that the tensile forces

required to cause dehiscence in the aponeurosis in group B were significantly higher than in group A. There was a distinct positive correlation between the suture length to wound ratio and the tensile strength in group A, but no significant relation in group B. The dehiscence in group A was, as expected, caused by sutures cutting through the tissue. Overall, the authors concluded that small stitches and small suture distances combined with a suture length to wound length ratio of at least 4:1 lead to higher tensile strength of a laparotomy wound.

Study 5: HÖER, J. J., JUNGE, K., SCHACHTRUPP, A., KLINGE, U., SCHUMPELICK, V. (2002): **Influence of laparotomy closure techniques on collagen synthesis in the incisional region**

This study differs from the other experimental studies included in this thesis, because it does not directly investigate wound strength but the collagen configuration of the regenerating tissue. One hundred male Wistar rats with a mean weight of 290g were used in this experiment. Equally long midline abdominal incisions were closed, alternating the suture technique, the suture length to wound length ratio and the suture tension. Suture length to wound length ratios of 8:1, 4:1, 2:1 and 1:1 were achieved by keeping the tissue bites constant at 5mm but alternating the suture distance. All animals were sacrificed and full-thickness tissue samples were obtained from the incisional region. After undergoing a preparation process, samples were stained with Sirius-Red and Fast-Green and analyzed with a spectrophotometer to obtain the amount of collagen protein. The stained samples were also analyzed microscopically and with image analysis software to determine the percentage of collagen type-III in relation to the total collagen content. The results 2 and 4 weeks after the surgical intervention showed that a suture length to wound length ratio of at least 4:1 and a running suture lead to a significant higher collagen content in the incisional region. Additionally, wounds closed with high suture tension had a significant higher content of collagen type-III.

3.2.1.2. Summary of the main outcome measures in the experimental studies

All experimental studies focused on the effect of suture technique and the suture length to wound length ratio on wound strength but used different methods to measure and evaluate it. The following table 6 gives an overview of these methods and if there is an existing correlation with the suture length to wound length ratio.

Study	Main outcome measure	Method	Correlation with SLWL
CENGIZ et al. (2001)	Bursting pressure, bursting volume	A metal trocar with an attached balloon was inserted through a vaginal perforation into the abdominal cavity. The balloon was gradually distended with water from an infusion pump with a constant flow rate until the occurrence of complete wound dehiscence. The pressure was monitored by computerized device. The bursting volume was measured by detecting the increase in body weight.	Yes, bursting pressure is higher when a SLWL of 4 is applied and stitches are placed 3 or 6 mm from the wound edge
CENGIZ et al. (2000)			Yes, bursting pressure was higher when the SLWL>4
HÖER et al. (2001)	Tensile strength	Strips of the abdominal wall (2x4cm) were excised and fixed in a digital horizontal tensiometer, consisting of a board with two clamps. One clamp was free to move at a rate of 2cm/min and the load was registered on a computer.	Yes, tensile strength was higher in wound closed with SLWL>4
HARLAAR et.al. (2009)	Tensile strength	Removed abdominal walls were fixed on a tensile testing machine, that pulls apart the specimen at a constant rate of 10mm/min.	Yes, in the group with SLWL>4, the tensile forces were also higher
HÖER et al. (2002)	Collagen content	Four tissue samples (3x3mm) were removed from the incisional region, fixed in phosphate-buffered Formalin and embedded in Paraffin. Slices (15µm thick) were prepared and stained with Sirius-Red and Fast-Green. The tissue bound dye was removed, using 0.1 N sodium-hydroxide in	Yes, collagen content was higher when the SLWL≥4

		absolute methanol. After spectro-photometrical analysis with the wavelengths 535nm and 605nm, the amount of collagen protein was calculated.	

Table 6. An overview of the methods used in the experimental studies and the correlation with the suture length to wound length ratio

SLWL: suture length to wound length ratio

3.2.1.3. Results of the experimental studies

All experimental studies included in this thesis come to the conclusion that a suture length to wound length ratio of at least 4 has a positive effect on midline abdominal incisions, increasing wound strength expressed by higher bursting pressure (CENGIZ et al., 2000), higher tensile strength (HÖER et al., 2001; HARLAAR et al., 2009) and promoting a favorable collagen composition during the healing process (HÖER et al., 2002).

The suture technique has also been investigated in these studies. The three techniques tested in the five experimental studies are: running, single and continuous double loop closure. The conventional running suture has proven to have the most benefits regarding wound strength, especially when the suture length to wound length ratio is taken into account (CENGIZ et al., 2000; HÖER et al., 2001) and cause an earlier initiation of collagen synthesis and replacement of the weaker collagen type-III by the stronger collagen type-I (HÖER et al., 2002).

The size of the tissue bites and the stitch interval, which the suture length to wound length ratio is achieved with, are also important as shown by CENGIZ et al. (2001) and HARLAAR et al. (2009). The traditional recommendation for the closure of abdominal wound is with 10 mm tissue bite and stitch interval (HOPE et al., 2010) is put to a test in these studies. Both studies showed that placing the stitches less than 10mm from the wound edge but keeping the suture length to wound length ratio above 4, increases the strength of the wound.

The effect of suture tension is a topic of interest in the studies by HÖER et al. (2001) and HÖER et al. (2002). Even though there was no quantification of the tension used during closure, tension was applied until a discoloration and overlapping of tissue occurred and referred to as ‘high’ tension. In both studies, it had a significant negative effect on both wound strength and collagen synthesis.

3.2.2. Controlled clinical trials

There are 11 randomized controlled trials, performed in a clinical setting, that are included in this thesis, and one study by JENKINS (1976) classified as an expert’s opinion that is supported by data, obtained from the author’s patient load. These studies will be presented with a short summary of each one, followed by the criteria for the patient selection and findings. The findings of the literature reviews (CARLSON, 2000; VAN GELDERE, 2000; ISRAELSSON, 2003; CEYDELI et al., 2005; BOLLI et al., 2006) as well as the meta-

analysis by VAN'T RIET et al. (2002) will not be recapitulated at this point but will be included in the discussion.

3.2.2.1. Short recapitulation of the clinical trials

Study 1: CENGIZ, Y., ISRAELSSON, L. A. (1998): **Incisional hernias in midline incisions: an eight-year follow up**

In the period between August 1989 and December 1990, 374 patients operated on through a midline incision were included in this study. The medical data of all patients was recorded. All incisions were closed with a continuous suture in one layer; patients were randomized for the choice of suture material – monofilaments of nylon or polydiaxanone. The length of the used suture was recorded for the calculation of the suture length to wound length ratio. The patients were examined 12 months and 8 years after surgery for signs of incisional hernia by the authors of this study, except for patients that moved away and were examined by local physicians. This study showed that incisional hernias that have clinical implications and require repair are usually detected after 12 months and the rate of hernia occurrence correlates with the suture length to wound length ratio.

Study 2: ISRAELSSON, L. A. (1999): **Bias in clinical trials: the importance of suture technique**

In this study the effect of introduction of new suture material in the County hospital in Sweden was investigated. Each material was used on alternate weeks on patients, operated on through a midline incision. The incisions were closed with a continuous mass closure technique. The suture length to wound length ratio was calculated by recording the length of the wound and measuring the remnants of the used suture and subtracted from the original suture length. One surgeon examined all patients that remained in the area for incisional hernia after 12 months. The study showed that the suture length to wound length ratio was higher with the new suture material and consequently, the rate of incisional hernia in these patients lower after 12 months and points to the possible falsified results in previous studies where the suture technique was not monitored.

Study 3: ISRAELSSON, L. A. (1999): **Incisional hernias in patients with aortic aneurismal disease: the importance of suture technique**

This study investigates the theory that patients with abdominal aortic aneurismal disease have a higher risk to develop incisional hernia than others. 1023 patients, 85 of whom underwent

aortic aneurysm repair, were operated on through a midline incision and included in this study. The medical data of all patients was recorded. The incisions were closed with a continuous mass closure technique with either polydiaxanone or nylon as the suture material. The suture length to wound length ratio was calculated by measuring the used suture and incision length. After 12 months, the patients were examined for the presence of incisional hernia by one surgeon, except for those that moved away and were examined by local physician. The study showed that the overall rate of incisional hernia is lower when the suture length to wound ratio is at least 4 and aortic aneurismal disease is not a risk factor for wound complications when the suture technique is taken into account.

Study 4: ISRAELSSON, L. A. (1998): **The surgeon as a risk factor for complications of midline incisions**

A total of 1029 patients in the period from August 1989 to June 1993 in the County hospital in Sweden, operated on through a midline abdominal incision were included in this study. The medical history of all patients was recorded. The incisions were closed with a continuous mass technique, using a monofilament suture (either polydiaxanone or nylon). The suture length to wound length ratio was calculated by measuring the incision length and the suture remnants. Patients were examined 12 months after surgery for incisional hernia by one surgeon, except for those who moved away. The surgeons that performed the operations were divided in two major groups; surgeons that had less than 10 years experience and on night duty in the emergency unit were regarded as junior and surgeons with more experience and were consultants on call – as senior. In the evaluation of the results, the wound complications and the suture technique of the 12 surgeons was individually assessed. The study showed the use of the suture length to wound length ratio as means to monitor the quality of suture technique and overall senior surgeons had lower mean ratio than juniors but overall the length of surgical experience did not significantly influenced the rate of incisional hernia and wound infection.

Study 5: ISRAELSSON, L. A., JONSSON, T. (1994): **Closure of midline laparotomy incisions with polydiaxanone and nylon: the importance of suture technique**

813 patients, undergoing laparotomy through a midline incision in the Sundsvall County Hospital in Sweden, were included in this study. The medical history of each patient was recorded. The incisions were closed with a continuous mass technique with polydiaxanone or nylon and the length of the incision as well as the length of the suture remnants were

measured in order to calculate the suture length to wound length ratio. All patients were examined by one of the authors for the presence of incisional hernia 12 months after surgery, except those who moved away that were examined by a local physician. The study showed no significant difference between the two suture materials but a suture length to wound length ratio more than 4 was associated with a significantly lower rate of incisional hernia with both suture materials.

Study 6: ISRAELSSON, L. A., JONSSON, T. (1993): **Suture length to wound length ratio and healing of midline laparotomy incisions**

454 patients undergoing laparotomy through a midline incision in the period between August 1989 and March 1991 were included in this study. The medical history of all patients was recorded. The incisions were closed with a continuous mass closure technique with either polydiaxanone or nylon. The suture length to wound length ratio was calculated by measuring the incision length and the suture remnants. Patients were examined 12 months after surgery for incisional hernia by one of the authors, except the patients that moved away and were examined by a local physician. The study found a strong positive correlation between the suture length to wound length ratio and the rate of incisional hernia.

Study 7: KENDALL, S. W. H., BRENNAN, T. G., GUILLOU, P. J. (1991): **Suture length to wound length ratio and the integrity of midline and paramedian incisions**

In this study patients admitted in the care of two of the authors were included in this study and randomized to have their laparotomies either through a paramedian or a midline incision and closed with either a mass technique or layered closure. The medical history of all patients was recorded. The 137 lateral paramedian incisions were closed using a layered technique with chromic catgut for the posterior sheath (0.5 cm tissue bites at 2 cm intervals) and polydiaxanone for the anterior sheath (0.5 cm tissue bites at 2 cm intervals). The midline incisions were closed either with mass or layered technique. The 104 midline incisions closed with mass technique were sutured with polydiaxanone with 2 cm tissue bites at 1 cm intervals starting from both ends of the wound, so that the suture was completed in the middle of the incision. The layered closure was performed in 108 patients and the peritoneum and the linea alba were closed separately. The closure of the linea alba was with polydiaxanone with 2 cm tissue bites at 1 cm intervals. The suture length to wound length ratio was also calculated. The patients were examined 1, 6 and 12 months after surgery for incisional hernia and were also sent a questionnaire at 12 months follow-up. The resulting mean suture length to wound

length ratios were as follows: 2.6 for the lateral paramedian group, 5.0 for the midline mass technique group and 3.7 for the midline layered technique group. There were no patients with incisional hernia in the lateral paramedian group, whereas 14 patients with midline incisions were presented with a clinically evident incisional hernia. The authors conclude from these results that even though there is a correlation between the suture length to wound length ratio and the integrity of a midline incision, the lateral paramedian incision is the superior technique because of its independency of this ratio.

Study 8: MILLBOURN, D., CENGIZ, Y., ISRAELSSON, L. A. (2009): **Effect of stitch length on wound complications after closure of midline incisions**

In this randomized controlled trial a total of 737 patients, undergoing a laparotomy through a midline incision in the Department of Surgery of the Sundsvall Hospital in Sweden, were examined. All incisions were closed with a running suture, using the mass closure technique. The patients were randomized to have their incisions closed with either a long stitch (at least 10 mm tissue bite) or a short stitch (5 – 8 mm tissue bite). The techniques were used on alternating weeks to avoid bias. All medical histories of the participating patients were recorded. The suture length to wound length ratio, the mean stitch length and mean stitch interval were calculated. Patients were examined for wound dehiscence, wound infection 4 weeks after surgery and for incisional hernia after 12 months. The results showed that rates of surgical site infection and incisional hernia were lower in patients, whose laparotomy wounds were closed with a suture length to wound length ratio of at least 4, achieved with a short stitch. The authors indicated a long stitch length and the suture length to wound length ratio of less than 4 as independent risk factors for the occurrence of incisional hernia.

Study 9: MILLBOURN, D., CENGIZ, Y., ISRAELSSON, L. A. (2011): **Risk factors for wound complications in midline incisions related to the size of stitches**

In this study all patients operated on through a midline abdominal incision in the Sundsvall Hospital in Sweden between January 2001 and January 2006 were included. The 691 patients that entered the trial were randomized to have their incisions closed either with a long stitch, placed at least 10 mm from the wound edge, or a short stitch, placed 5 – 8 mm from the wound edge. Surgeons were instructed to achieve a suture length to wound length ratio of at least 4 and a higher ratio was encouraged. The suture material was polydiaxanone and all incisions were closed using the mass technique. The medical history of all patients was recorded. The suture length to wound length ratio, the mean stitch length and the mean stitch

interval were calculated. Patients were examined for early complications such as wound infection 4 weeks after surgery and for incisional hernia after 12 months. The main aim of this study was to investigate the effect of a very high suture length to wound length ratio achieved with small stitches on wound complications. The results of this study showed that a very high suture length to wound length ratio (higher than 5:1) does not affect the rate of wound complications when it is achieved with short stitches. A suture length to wound length ratio of at least 4, achieved with small stitches had a beneficial effect on the laparotomy wounds, lowering the rates of surgical site infection and incisional hernia significantly.

Study 10: MILLBOURN, D., ISRAELSSON, L. A. (2004): **Wound complications and stitch length**

368 patients, undergoing a midline laparotomy were included in this study. The incisions were closed using the mass closure technique with a suture length to wound length ratio of at least 4. Mean stitch length was calculated. Early postoperative complication such as wound dehiscence and wound infection were registered and patients were examined for incisional hernia 12 months after surgery. The statistical analysis in this study showed a clear linear correlation between stitch length and wound infection – with each centimeter increase of stitch length, the rate of wound infection doubled. The rate of incisional hernia was also influenced – with a stitch length of 4 cm or more, incisional hernia occurred three times more often.

Study 11: VARSHNEY, S., MANEK, P., JOHNSON, C. D. (1999): **Six –fold suture: wound length ratio for abdominal closure**

This study investigates the suture length to wound length ratio and the rate of postoperative complications in 100 patients, undergoing laparotomy through a midline incision. All incisions were closed using the mass closure technique with polydiaxanone. Stitches were placed 10 mm from the wound edge at 1 cm intervals. Patients were examined 4 weeks and 12 months after surgery for wound infection or dehiscence and incisional hernia, respectively. The mean suture length to wound length ratio was 6.2 and mean stitch interval was 10 mm. Incisional hernias, detected at 12 months, were present in 5 patients that also had had wound infection in the early postoperative period. This study underlines the beneficial effect of a high suture length to wound length ratio on wound complications and also presents a mathematical model, suggesting that the optimal suture length to wound length ratio is 6:1 or more. This mathematical model is an expansion to the model, developed by JENKINS (1976),

and takes the three dimensional structure of the surgical wound into consideration. By placing stitches 1 cm from the wound edge at 1 cm intervals and assuming the depth is also 1 cm, the required suture length for each centimeter wound length is 6.236 cm that closely matches the results from the clinical trial.

Study 12: JENKINS, T. P. N. (1976): **The burst abdominal wound: a mechanical approach**

This study has an exceptional position in this thesis because it is the first published article, introducing the concept of the suture length to wound length ratio by presenting a mathematical model and supporting it with results from the experience of the author. The abdomen distends during respiration or postoperative complications such as paralytic ileus which puts a strain on the midline incision after a laparotomy. The author measures the resulting lengthening of the surgical wound in 50 patients during voluntary inspiration, caesarean section and gut obstruction or paralytic ileus and finds out that the length of the wound can increase by 30% when distention occurs. Considering these results, the author suggests that the suture material has to allow this lengthening to occur without increasing the tension on the incision and expresses this theory by the suture length to wound length ratio. A single stitch in a continuous suture can be regarded as an isosceles triangle. A dropped perpendicular in this triangle represents the sum of tissue bites. When the wound stretches, the length of that perpendicular decreases, leading to tissue compression. This brings about the statement that the shorter the suture, the greater is the decrease in that perpendicular resulting in a higher probability of wound complications. By observing the relationship between the suture length to wound length ratio and the tension in the wound, the author concluded that a suture length to wound length ratio of 4 or more keeps the tension in the wound to a minimum. The author then applies this hypothesis in clinical trials by estimating the used suture length to wound length ratio based on the popular closure tendency in these periods of time and finds that when suturing with a higher ratio, the evisceration rate is significantly lower.

3.2.2.2. Patient selection and data

In most studies the patients entering the study were randomly selected. In studies where the patients were divided in 2 groups, the group allocation was also random. In the study by KENDALL et al. (1991) the patients were divided in three groups because wound strength was examined after a lateral paramedian incision and midline incision closed either with the

mass or layered technique. In the study by ISRAELSSON (1998) the suture technique of junior and senior surgeons was compared forming two general groups, that were further divided in a total of 12 subgroups because the suture technique of each surgeon was individually assessed. In the other studies, where group allocation was appropriate, the different aspects of suture technique in the midline incision were explored by forming comparison groups. Three studies (MILLBOURN et al., 2004; MILLBOURN et al., 2009; MILLBOURN et al., 2011) compare the implications a suture length to wound ratio of 4 achieved with two different stitch lengths; one study compares the risk for incisional hernia in patients with aortic aneurismal disease compared to other medical conditions (ISRAELSSON, 1999b). In the study by CENGIZ et al. (1998) no such groups were formed because the study is based on the observation of how the rate of incisional hernia is affected by the generally used suture technique.

Age

The age of the included patients was not widely distributed. One of the reasons for this is that some studies allow only patients over 18 years to enter the study as in the studies by MILLBOURN et al. (2009) and MILLBOURN et al. (2011). It is also possible that most patients undergoing abdominal surgery are middle aged or older. In most studies the mean age of patients was stated and it ranged between 41 years in the study by VARSHNEY et al. (1999) and 70 years in the study by ISRAELSSON (1999b).

Weight/BMI

The weight of the patients was recorded in most studies for the calculation of the body mass index since obesity is considered a risk factor for postoperative wound complications. As overweight were considered patients with a BMI of 25 or more. Due to the large samples, only the mean BMI was stated in the studies and it ranged from 23 to 27 in the study by MILLBOURN et al. (2004). In some studies the BMI was not stated but the number of patients regarded as overweight was accounted for (ISRAELSSON, 1998; CENGIZ et al., 1998). In four studies neither the number of overweight patients nor the mean BMI were stated in the statistics (KENDALL et al., 1991; ISRAELSSON et al., 1994; ISRAELSSON et al., 1993; VARSHNEY et al., 1999).

Sex

The sex of all patients was recorded as part of their general medical history and data and to note any trends of predisposition for wound complications. In almost all studies the male patients predominate. In only one study by KENDALL et al. (1991) the percentage of male patients is less than 50% in each group.

The following table 7 gives an overview of the patient selection including sample size, patients per group, mean age, mean BMI or number of overweight patients and sex.

Study	Sample Size	Group Size	Age	BMI/Number of overweight patients	Sex	
					F	M
CENGIZ et al., 1998	374 patients	-	12 months:63 8 years:62	12 months: 45 patients 8 years: 4 patients	12 months: 27 8 years: 2	12 months: 31 8 years: 3
ISRAELSSON (1999a)	224 patients	Gr. A: 102 Gr. B: 122	Gr. A: 60 Gr. B: 59	Gr. A: 26 Gr. B: 25	Gr. A: 40 Gr. B: 60	Gr. A: 55 Gr. B: 67
ISRAELSSON (1999b)	1023 patients	Gr. A: 85 Gr. B: 938	Gr. A: 70 Gr. B: 61	Gr. A: 25 Gr. B: 25	Gr. A: 9 Gr.B: 478	Gr. A: 76 Gr.B: 460
ISRAELSSON (1998)	1013 patients	Gr. A: 25 Gr. B: 30 Gr. C: 35 Gr. D: 50 Gr. E: 80 Gr. F: 34 Gr. G: 39 Gr. H: 74 Gr. I: 136 Gr. J: 145 Gr. K: 152 Gr. L: 213	Gr. A: 67 Gr. B: 63 Gr. C: 70 Gr. D: 66 Gr. E: 64 Gr. F: 61 Gr. G: 54 Gr. H: 68 Gr. I: 67 Gr. J: 55 Gr. K: 62 Gr. L: 56	Gr. A: 11 Gr. B: 6 Gr. C: 12 Gr. D: 19 Gr. E: 36 Gr. F: 14 Gr. G: 23 Gr. H: 28 Gr. I: 57 Gr. J: 77 Gr. K: 68 Gr. L: 94	Gr. A: 14 Gr. B: 13 Gr. C: 17 Gr. D: 21 Gr. E: 35 Gr. F: 26 Gr. G: 27 Gr. H: 27 Gr. I: 45 Gr. J: 71 Gr. K: 75 Gr. L: 112	Gr. A: 11 Gr. B: 17 Gr. C: 18 Gr. D: 29 Gr. E: 45 Gr. F: 8 Gr. G: 12 Gr. H: 47 Gr. I: 91 Gr. J: 74 Gr. K: 77 Gr. L: 101

ISRAELSSON et al. (1994)	813 patients	Gr. A: 405 Gr. B: 408	Gr.A: 62 Gr. B: 62	unknown	Gr.A: 185 Gr.B: 196	Gr.A: 220 Gr.B: 212
ISRAELSSON et al. (1993)	454 patients	Gr. A: 122 Gr. B: 241	Gr. A: 57 Gr. B: 60	unknown	Gr. A: 66 Gr.B: 107	Gr. A: 56 Gr.B: 134
JENKINS, 1976	127 patients	-	unknown	unknown	unknown	Unknown
KENDALL et al., 1991	349 patients	Gr.A: 137 Gr.B: 104 Gr.C: 108	Gr. A: 61 Gr. B: 65 Gr. C: 60	unknown	Gr.A:64% Gr.B:57% Gr.C:64%	Gr.A:36% Gr.B:43% Gr.C:36%
MILLBOURN et al., 2009	737 patients	Gr.A: 381 Gr.B: 356	Gr.A: 64 Gr.B: 65	Gr.A: 26 Gr.B: 26	Gr.A: 153 Gr.B: 155	Gr.A: 228 Gr.B: 201
MILLBOURN et al., 2011	691 patients	Gr.A: 321 Gr.B: 370	Gr.A: 65 Gr.B: 64	Gr.A: 26 Gr.B: 26	Gr.A: 143 Gr.B: 148	Gr.A: 178 Gr.B: 222
MILLBOURN et al., 2004	369 patients	Gr. A: 103 Gr. B: 117 Gr. C: 148	Gr. A: 65 Gr. B: 62 Gr.C: 56	Gr. A: 23 Gr. B: 26 Gr. C: 27	Gr. A: 49 Gr. B: 53 Gr. C: 75	Gr. A: 54 Gr. B: 64 Gr. C: 75
VARSHNEY et al., 1999	100 patients	-	41	unknown	39	61

Table 7. Overview of the patient selection including sample size, patients per group, mean age, mean BMI or number of overweight patients and sex.

Gr.: Group

BMI: Body mass index

3.2.2.3. Exclusion criteria for patients

In most studies the main outcome measure is the occurrence of incisional hernia 12 months after surgery. In order to investigate this phenomenon it is important that patients with a higher risk for incisional hernia due to previous laparotomy or history of incisional hernia occurrence are excluded from the study. Most studies investigate the mechanics of the midline incision, so patients that are not eligible for a midline laparotomy are excluded. In only one study by KENDALL et al. (1991) patients undergoing lateral paramedian incisions were also included in the study protocol. Since a series of other factors such as preexisting medical conditions or life threatening diseases that can affect wound healing are considered by some of the authors as exclusion criteria, they will be summarized in the following table as 'others'. In all studies, even though the urgency of operation is recorded, patients undergoing emergency surgery are included in the trials. Even though in the study by JENKINS (1976) detailed data of the patients is not stated, the results will be considered in the discussion. Table 8 gives an overview of the patient related exclusion criteria such as type of laparotomy incision, previous laparotomy, emergency surgery, previous incisional hernia and additional criteria.

Study	Previous Laparotomy	Emergency surgery	Previous incisional hernia	Others
CENGIZ et al., 1998	-	-	+	-
ISRAELSSON (1999a)	-	-	-	-
ISRAELSSON (1999b)	-	-	+	-
ISRAELSSON (1998)	-	-	+	-
ISRAELSSON et al. (1994)	-	-	+	-
ISRAELSSON et al. (1993)	-	-	+	-

JENKINS, 1976	unknown	unknown	unknown	unknown
KENDALL et al., 1991	-	-	+	Previous encroaching scars, hemorrhage, lack of skin staples, surgeon's preference
MILLBOURN et al., 2009	+	-	+	Preexisting ventral hernia, patients younger than 18 years
MILLBOURN et al., 2011	+	-	+	Preexisting ventral hernia, patients younger than 18 years, Closure of the incisions with SLWL≤4
MILLBOURN et al., 2004	-	-	+	Closure of the incisions with SLWL≤4
VARSHNEY et al., 1999	-	-	+	Hemorrhage, shock, jaundice, uremia, steroid treatment

Table 8. Overview of common exclusion criteria for patients in the studies.

(+): Patients with this condition/medical history are excluded from the protocol

(-): Patients with this condition/medical history are not excluded

SLWL: suture length to wound length

3.2.2.4. Summary of the main outcome measures in the clinical trials

All studies investigate the effect of suture technique, monitored by the suture length to wound length ratio on the rate of incisional hernia. Some studies additionally record the occurrence of wound infection in the incisional region after midline laparotomies. The methods of examination for incisional hernia and who the examining physician is are important factors that have to be standardized to avoid bias. The following table 9 gives on overview of the

main outcome measure, the method of detection of incisional hernia in the studies and whether a correlation exists between the suture technique and the rate of wound complications.

Study	Main outcome measure	Method of examination	Correlation with SLWL
CENGIZ et al., 1998	Incisional hernia 12 months and 8 years after surgery	Incisional hernia is defined in this study as palpable defect in the fascia or a protrusion beyond this level. All patients are examined supine lifting both legs and coughing or straining in an erect position.	Yes, a higher SLWL lowers the rate of incisional hernia.
ISRAELSSON (1999a)	Incisional hernia 12 months after surgery		
ISRAELSSON (1999b)	Incisional hernia at 12 months in patients with aortic aneurismal disease		Yes, a SLWL ratio of 4 or more decreases the rate of incisional hernia
ISRAELSSON (1998)	Wound infection, incisional hernia at 12 months		
ISRAELSSON et al. (1994)	Incisional hernia at 12 months		
ISRAELSSON et al. (1993)	Early wound complications and incisional hernia 12 months after surgery		Yes, a SLWL ratio of 4 or more decreases the rate of incisional hernia
JENKINS, 1976	Evisceration after midline laparotomy	Unknown	Yes, the author reckons that evisceration is less common with a SLWL ratio of least 4
KENDALL et al., 1991	Incisional hernia and other wound complication 1, 6 and 12 months after surgery	Unknown	A correlation in this study is not confirmed
MILLBOURN et al., 2009	Early wound complications and incisional hernia 12 months after surgery	Incisional hernia is defined in this study as palpable defect in the	Yes, a SLWL ratio of 4 or more achieved with a

MILLBOURN et al., 2011		fascia or a protrusion beyond this level. All patients are examined supine lifting both legs and coughing or straining in an erect position.	short stitch can decrease the rate of incisional hernia.
MILLBOURN et al., 2004	Incisional hernia 12 months after surgery	Any detectable defect in the abdominal wall in the incisional region or adjacent to it is considered an incisional hernia. Patients are examined coughing or straining in both erect and supine positions.	Yes, a SLWL ratio of 4 or more achieved with a short stitch can decrease the rate of incisional hernia.
VARSHNEY et al., 1999	Incisional hernia 12 months after surgery		Yes, a SLWL ratio of 6 is optimal for the undisturbed wound healing and decreases the rate of incisional hernia

Table 9. An overview of the main outcome measures, method of examination in the clinical trials and correlation between the rate of incisional hernia and the suture length to wound length ratio

SLWL: suture length to wound length

3.2.2.5. Results of the clinical trials

All studies acknowledge the importance of the suture length to wound length on the rate of both early and late wound complications. All studies but one agree that a suture length to wound length ratio of at least 4 is optimal for wound healing, decreasing significantly the rate of incisional hernia after 12 months. The study by VARSHNEY et al. (1991) is the only study that concludes that the optimal suture length to wound length ratio is 6, creating also a mathematical model that supports this theory.

Mass and layered closure techniques were compared in only one study since it has been widely accepted that mass closure is the method of choice when closing midline incisions. In the study by KENDALL et al. (1991) both techniques resulted in similar rates of incisional hernia at 12 months, but burst abdomen was present when using the latter technique. However, a mean suture length to wound length ratio above 4 was achieved only with the mass technique making the credibility of this result questionable.

Suture material has been the object of investigation in the study by ISRAELSSON et al. (1994). The authors found that wound complications are not influenced by the choice of suture material when a suture length to wound length ratio of 4 or more is accomplished. However, the importance of the suture material is not so much in the properties of the available materials but in its effect on the surgeon's technique when a different material is introduced as confirmed by the study by ISRAELSSON (1999a). When a new suture material is introduced, the surgeons tend to suture with a higher suture length to wound length ratio that can falsify the results in studies where the suture technique is not monitored.

Naturally, the surgeon's experience, knowledge and preference play a very important role when investigating suture technique. The importance of these factors and their effect on the suture length to wound length ratio, as well as their influence on the rate of wound complications was examined in the study by ISRAELSSON (1998). The author found the senior surgeons tend to suture with a lower ratio but the mean ratio was in both groups above 4. However, monitoring the technique with the suture length to wound length ratio of each individual can help identify deficiencies and optimize the suture technique, thus, reducing the rate of incisional hernia and additional costs and improve patient comfort.

The size of the tissue bites and the stitch interval are investigated in three of the studies. Similarly to the results in the experimental studies, the hypothesis that stitches should be placed at least 10 mm from the wound edge is debated. The studies show that a suture length

to wound length ratio of 4 or more achieved with small stitches (tissue bites of 5 – 8 mm) can not only decrease the rate of incisional hernia but also the rate of wound infection. In the study by MILLBOURN et al. (2004) the statistical analysis of the results showed that with a centimeter increase of stitch length, the rate of wound infection is doubled. A long stitch length is also identified as an independent risk factor for the occurrence of surgical site infection in the study by MILBBOURN et al. (2009).

3.2.3. Overview of the results of the experimental studies and the clinical trials

The results of the experimental studies and the clinical trials are very consistent. All studies agree that a higher suture length to wound length ratio decreases the rate of incisional hernia at 12 months. All studies but one set the cut off value for the suture length to wound length ratio at 4; in the study by VARSHNEY et al. (1991) a suture length to wound length ratio of 6 is considered optimal. Both experimental studies and randomized controlled trials that investigate the optimal stitch length conclude that a short stitch has a beneficial effect on wound strength and can also lower the rate of wound infection. Table 10 summarizes the recommended suture length to wound length ratio in the studies and if using that ratio lowers the rate of incisional hernia.

Study	Recommended SLWL ratio	Effect on the rate of incisional hernia
Experimental studies		
CENGIZ et al., 2000	SLWL ≥ 4:1	-
CENGIZ et al., 2001	SLWL ≥ 4:1	-
HARLAAR et al., 2009	SLWL ≥ 4:1	-
HÖER et al., 2002	SLWL ≥ 4:1	-
HÖER et al., 2001	SLWL ≥ 4:1	-
Clinical trials		
CENGIZ et al., 1998	SLWL ≥ 4:1	↓
ISRAELSSON, 1999a	SLWL ≥ 4:1	↓
ISRAELSSON, 1999b	SLWL ≥ 4:1	↓
ISRAELSSON, 1998	±	±
ISRAELSSON et al., 1994	SLWL ≥ 4:1	↓
ISRAELSSON et al., 1993	SLWL ≥ 4:1	↓
JENKINS, 1976	SLWL ≥ 4:1	-

KENDALL et al., 1991	±	±
MILLBOURN et al., 2009	SLWL ≥ 4:1	↓
MILLBOURN et al., 2011	SLWL ≥ 4:1	↓
MILLBOURN et al., 2004	SLWL ≥ 4:1	↓
VARSHNEY et al., 1999	SLWL ≥ 6:1	↓

Table 10. A summary of the recommended suture length to wound length ratio in each study and its effect on the rate of incisional hernia.

SLWL: suture length to wound length

(↓): using the recommended ratio lowers the rate of incisional hernia

(±): there is no effect on the rate of incisional hernia

(-): not investigated in the study

4. Discussion

The aim of this thesis is to collect the available literature on the use of the suture length to wound length ratio for the continuous closure of midline abdominal incisions and its relevance in lowering the rate of late wound complications in order to test the hypothesis that the optimal ratio is at least 4:1 or more and applying this ratio can lower the rate of incisional hernia after abdominal surgery. For the purpose of evaluating the literature, the studies were classified according to the system, developed by the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006) and assigned one of four categories – "Platinum, Gold, Silver and Bronze".

There is strong evidence in the presented literature to suggest that a higher suture length to wound length ratio influences the rate of postoperative wound complications and 14 out of the 17 classified studies recommend a ratio of 4 or more. This leads us to view the hypothesis as confirmed while taking the following points into consideration:

- There are no studies that fulfill the criteria of the categories "Platinum" and "Gold".
- In most clinical studies, there is a high percentage of patients lost at follow up which makes the credibility of the results questionable.
- The experimental studies are all performed in a short period of time testing wound tensile or bursting strength which are variables that are not applicable in clinical trials.
- Some studies take into account stitch length and stitch interval in addition to the suture length to wound length ratio while others do not.
- Some studies exclude patients whose midline incisions are closed with a lower ratio than 4, so no comparison can be made in the rate of incisional hernia at follow up.
- In the clinical trials the most common closure technique is the mass closure of abdominal wall, so it is unclear if the recommended suture length to wound length ratio can also be applied in the layered closure with similar results.
- Other predisposing factors for postoperative wound complications such as medical diseases are not always taken into account.

These arguments will be considered in the following discussion, showing that the suture length to wound length ratio is essential to the successful incision closure but other factors need to be taken into account in order to lower the rate of postoperative wound complications.

The evaluation according to the grading system developed by the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006) shows that the available literature on this topic has a

similar quality because 16 out of 17 studies are assigned the grade “Silver” and one – “Bronze”. There are no available studies, however, that satisfy the requirements for the categories “Platinum” and “Gold”.

All clinical trials show that postoperative wound complications are unavoidable regardless of the technique. But most studies agree that by applying a suture length to wound length ratio of 4:1 or more one can at least lower the rate of incisional hernia and by adjusting the stitch length and interval also reduce wound infection significantly.

At this point it is important to state that the results of the clinical trials are easily comparable because physical examinations for the presence of incisional hernia are conducted in all studies at 12 months and the methods of examination as well as the definition of the term incisional hernia is unanimous. One could argue the period of time in which the follow up examination is performed but the study by CENGIZ et al. (1998) shows that majority of incisional hernias are detected at 12 months which makes the results obtained at this point in time also representative.

The only study where in one of the groups no incisional hernias were present at 12 months was in the study by KENDALL et al. (1991) but the patients in this group were randomly assigned to have a lateral paramedian incision performed instead of a midline incision. However, the paramedian incision is not relevant in the thesis. An important piece of evidence is pointed out in this study – the author compares the mass and layered closure of midline incisions and shows that the rate of incisional hernia does not differ significantly in the two groups. Yet, further investigation is required to find out what implications the suture length to wound length ratio has for the layered closure and what the optimal ratio for this technique is.

While the studies by KENDALL et al. (1991), ISRAELSSON et al. (1993), ISRAELSSON et al. (1994), CENGIZ et al. (1998), ISRAELSSON (1998), VARSHNEY et al. (1999), ISRAELSSON (1999a), and ISRAELSSON (1999b) only monitor the suture length to wound length ratio used by the surgeons, some of the clinical trials and the experimental studies investigate the stitch length and interval which a ratio of 4:1 or more should be achieved with. The two experimental studies by HARLAAR et al. (2009) and CENGIZ et al. (2001) both show that a stitch placed less than 10 mm from the wound edge and a suture length to wound length ratio of least 4 result in a stronger surgical wound than when the tissue bites are larger. In the randomized controlled trials by MILLBOURN et al. (2004), MILLBOURN et al.

(2009), and MILLBOURN et al. (2011) it is confirmed that a shorter stitch and a ratio of least 4 lower the rate of incisional hernia and wound infection.

Since the general recommendation in the studies does not define an upper boundary for the suture length to wound length ratio, the effect of a higher ratio is investigated in the study by MILLBOURN et al. (2011). The highest ratio achieved in this study was 12:1 and that did not affect the rate of wound complications in a negative way.

It is clear that a direct comparison of the results of the experimental studies and the clinical trials is challenging because the main outcome measures in the studies are different and the rate of incisional hernia and wound infection cannot be measured in an experimental trial. However, the occurrence of incisional hernia and wound infection is directly dependent on wound strength and the creation of optimal wound healing environment. Therefore, the consistency of the results provides for a very strong piece of evidence that the findings are reliable.

Even though the major outcome measures in the clinical trials are comparable, a difficulty in comparing the results arises because there are different exclusion criteria for patients from the protocol. All studies agree that patients with the history of incisional hernias or ventral hernias are not eligible for such a study other factors are not always taken into account. Only the study by VARSHNEY et al. (1999) excludes patients that have medical conditions such as uremia and jaundice that are known to disrupt wound healing. In the studies by MILLBOURN (2004) and MILLBOURN (2011) patients, who had their incisions closed with a suture length to wound length ratio lower than 4:1, are excluded from the study that eliminates the possibility to compare the rate of incisional hernia when the ratio is lower.

As shown by the article by VAN GELDERE (2000) the problem with wound complications resulting directly from inappropriate suture technique is not a recent problem. The author explores the advances made in the surgical technique for closure of midline incisions over the past hundred years and states that no visible improvement has been achieved and wound dehiscence is still a common complication. However, these results should be regarded as incomplete because only 10 references are used in this article to support the arguments and very few of them take the suture length to wound length ratio into account. The studies included in this thesis show that the use of this ratio as a monitoring device and adjusting stitch length cannot eliminate but significantly lower the rates of wound complications.

In the meta-analysis by VAN'T RIET et al. (2002) fifteen studies on the closure of midline abdominal incision are selected and compared according to the choice of suture material and suture technique. The authors concluded that a continuous mass closure technique with a slowly absorbable suture material and suture length to wound length ratio of 4:1 is the optimal. However, these results should be critically reconsidered because the recommendation for the ratio is based on two studies and the author focuses more on the choice of suture material and the choice between interrupted or continuous closure than the suture length to wound length ratio.

Unfortunately, there is no literature review that considers all aspects of the suture length to wound length ratio. Three of the literature reviews by CARLSON (2000), CEYDELI et al. (2005), and BOLLI (2006) that try to find the best technique for closure of midline incisions and include studies about the suture length to wound length ratio acknowledge the importance of a ratio of 4:1, based mostly on the findings by JENKINS (1976), but only the review by ISRAELSSON (2003) also integrates studies that recommend that the ratio of 4:1 is to be achieved with small stitches placed less than 10 mm from the wound edge. Even so, the recommendation for the size of the tissue bites in the study by ISRAELSSON (2003) is supported mainly by the results in the experimental study by CENGIZ et al. (2001).

Even so, considering the problems encountered during the comparison and evaluation of the results, it is clear that the suture length to wound length ratio plays a critical role in the closure of the midline incision. Applying a ratio of at least 4:1 achieved with small stitches can significantly decrease the rates of incisional hernia and wound dehiscence and therefore minimize patient discomfort, additional surgical interventions and medical costs. The literature presented in this thesis shows that the suture length to wound length ratio is not only applicable in a clinical setting, but can also be seen as means of assessment of the surgeon's technique and subsequently improve it.

All of these studies focus primarily on the significance of the suture length to wound length ratio in human medicine. Generally, the considerations regarding the suture technique used for closure of the midline abdominal incision of dogs and cats are similar to those presented in this thesis (FOSSUM, 2007). Studies that explore the effects of different suture materials or techniques in dogs (KIRPENSTEIJN et al., 1993) and horses (MAGEE et al., 1999; FREEMAN et al., 2002) are available but they do not record or compare the suture length to wound length ratio. Therefore, the next step for future research will be to determine if the

results presented in this study regarding the optimal suture technique and SLWL ratio in terms of lowering the rate of wound complications can be applied to veterinary abdominal surgery.

4.1. Conclusion

The research in this surgical field is still expanding as new suture materials and minimally invasive surgical techniques become available but for the time being the closure of the midline incision remain a current issue. From the presented evidence one can conclude that the hypothesis that a suture length to wound length ratio of at least 4:1 is optimal for the closure of the midline abdominal incision is credible, however, taking into account the arguments presented in the discussion. Unfortunately, the suture length to wound length ratio cannot completely eliminate the problem with wound complications but can at least reduce their occurrence and is a useful monitoring tool for the suture technique.

5. Abstract

Introduction:

Laparotomy through a midline incision is a common surgical intervention. Complications such as incisional hernia resulting from inappropriate closure are often encountered and the need for improvement of the suture technique has been the object of research in recent years. As means to lower the rate of these complications the concept of the suture length to wound length ratio is introduced. This thesis aims to evaluate the available studies in the search of the optimal ratio and its relevance in practical surgery in order to investigate if a ratio of at least 4:1 can reduce the rate of wound complications such as incisional hernia.

Materials and Methods:

Between February and September 2011 databanks such as Medline, PubMed, SciVerse Scopus, OvidSP and ISI Web of Knowledge were searched for literature about the closure of the abdominal wall using the suture length to wound length ratio. The search was performed using the resources of the library of the Veterinary University of Vienna (VUW) and the general hospital in Vienna (AKH). The studies were then evaluated and graded according the system developed by the Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006).

Results:

A total of 17 studies were divided in the following categories: “Platinum”, “Gold”, “Silver”, and “Bronze”. Sixteen studies were assigned the grade “Silver” and one – “Bronze”. Fourteen studies strongly agree that the optimal suture length to wound length ratio for the closure of the midline incision after a laparotomy is 4:1 or more. One study suggests that the optimal ratio is 6:1. Several experimental studies as well as clinical trials also investigate the optimal stitch length used to achieve this ratio and conclude that a short stitch had a positive influence on wound strength. The results of five literature reviews and one meta-analysis incorporated in this thesis also support the hypothesis that the optimal ratio is 4:1 or more is optimal.

Conclusion:

Based on the found studies the optimal suture length to wound length ratio for the closure of the midline incision is 4:1 or more achieved with small stitches. The suture length to wound length ratio can serve as a monitoring device for the suture technique and applying the recommended ratio can reduce the rate of wound complications.

6. Zusammenfassung

Einleitung:

Die Laparotomie ist eine häufig angewendete chirurgische Methode um einen Zugang zum Abdomen zu schaffen. Obwohl in den letzten Jahren die Medizinforschung viele minimal invasive Techniken eingeführt hat, die Laparotomie kann immer noch nicht ersetzt werden. Aber diese chirurgische Intervention ist mit vielen postoperativen Komplikationen verbunden, die aus einem unangemessen Verschluss der chirurgischen Wunde resultieren. Um die Komplikationsrate zu minimieren wurde das Prinzip der Nahtlänge-zu-Wundlänge Verhältnis entwickelt. Das Ziel dieser Diplomarbeit ist die vorhandenen Studien über dieses Thema zu evaluiren, das optimal Verhältnis zu bestimmen und zu untersuchen ob ein Nahtlänge-zu-Wundlänge Verhältnis von 4:1 das Auftreten von postoperativen Komplikationen reduzieren kann.

Material und Methode:

Zwischen Februar und September 2011 wurden die Datenbanken Medline, PubMed, SciVerse Scopus, OvidSP and ISI Web of Knowledge durchsucht und alle Studien über den Verschluss der Abdominalwunde nach einer Laparotomie unter Berücksichtigung der Nahtlänge-zu-Wundlänge Verhältnis wurden erfasst. Alle Studien wurden nach den Kriterien der Cochrane Musculoskeletal Review Group (SANTESSO et al., 2006) beurteilt und in vier Evidenzklassen eingeteilt – “Platin, Gold, Silber und Bronze”.

Ergebnisse:

Siebzehn repräsentative Studien wurden erfasst und evaluiert. Sechzehn Studien wurden in der Evidenzklasse “Silber” eingeteilt und eine Studie – in der Evidenzklasse “Bronze”. Vierzehn Studien ziehen die Schlussfolgerung, dass das optimale Nahtlänge-zu-Wundlänge Verhältnis für den Verschluss der Laparotomiewunde 4:1 oder mehr ist. In einer Studie ist die Meinung vetreten, dass das optimale Nahtlänge-zu-Wundlänge Verhältnis 6:1 ist. Die evaluierten experimentellen Studien untersuchten auch die optimal Stichlänge für das Erreichen von einem Verhältnis von 4:1 und beschliessen, dass die Anwendung von kürzeren Stichen für die Wundheilung vorteilhaft ist. Fünf Literaturübersichten und eine Meta-Analyse unterstüzen auch die Hypothese dieser Diplomarbeit, dass ein Nahtlänge-zu-Wundlänge Verhältnis von 4:1 mit wenigen postoperativen Komplikationen verbunden ist.

Schlussfolgerung:

Die evaluierte Literatur deutet darauf hin, dass das optimale Nahtlänge-zu-Wundlänge Verhältnis fü den Verschluss einer Lapatomiewunde 4:1 oder mehr ist. Dieses Verhältnis kann als Parameter für die Überwachung von der chirurgischen Technik und die richtige Anwendung dieser Methode kann die postoperative Wundheilungsstörungen reduzieren.

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