Mechanical comparison of median sternotomy closure in dogs using polydioxanone and wire sutures

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OBJECTIVES: To compare the mechanical properties of two different materials for canine median sternotomy closure.

STUDY DESIGN: In vitro biomechanical study.

SAMPLE POPULATION: Twelve canine cadaveric entire sternum and portion of associated ribs and musculature.

METHODS: Median sternotomy leaving the manubrium intact was closed using polydioxanone and stainless steel wire in a figure of eight pattern. Constructs were loaded in a servohydraulic material testing system and displacement was compared at loads of 125, 150, 200, 250, 300, 350 and 400 N, and at failure.

RESULTS: Displacement at loads up to 400 N and failure did not show any statistical difference between the polydioxanone and the stainless steel wire. However, the loading forces to create failure of the construct were superior for the stainless steel. Polydioxanone and stainless steel wire had the same response to distractive forces for loads applied up to 400 N.

CLINICAL SIGNIFICANCE: This study cannot recommend the use of polydioxanone over wires but suggests that polydioxanone can potentially be an alternative for primary median sternotomy closure in selected patients.

INTRODUCTION

Despite the increased use of minimally invasive approaches to the chest, median sternotomy in the dog remains the approach most commonly performed when exploration of the entire thoracic cavity is needed. However, a high rate of postoperative complications has been reported in dogs after median sternotomy, ranging from 17 to 78% (Bright and others 1983, Ringwald and Birchard 1989, Burton and White 1996, Pelsue and others 2002). These complications vary from postoperative pain and sternal fixation dehiscence to wound and sternal infections. Non-infectious complications are presumably due to a lack of adequate fixation of the sternotomy site whereas the association between infection and instability remains unclear. Benefits of stable fixation are classically emphasised in reference surgical textbooks recommended leaving the manubrium or xiphoid process intact, to increase the stability of the sternotomy after closure (Orton 1995, 2003).

In small animals, sternal closure has been most commonly described using wire or heavy gauge suture material. Studies comparing methods of closure are scant. The peristernal figure of eight cerclage around the costosternal junction is considered optimal as it provides the least displacement at high loads and the least malalignment during tensioning (Davis and others 2006). In another study, wire closure resulted in faster...
and stronger healing than polybutester suture closure in dogs as demonstrated by the presence of cartilage (versus fibrous tissue) in the group sutured with wire at 28 days postsurgery (Pelsue and others 2002). The amount of fibrous tissue in an osteotomy healing process is directly related to the osteotomy gap and motion between the fragments. Studies on diaphyseal fractures have shown that when interfragmentary movement is allowed (interfragmentary strain of 7 and 31% respectively in Augat and others 1998 and Claes and others 1998) and the osteotomy gap is bigger than 2 mm, the healing process in osteotomised long bones is impaired and histological quality of the callus and cellular migration are negatively impacted (Augat and others 1998, Claes and others 1998).

In human beings, median sternotomy is associated with a complication rate of 0·3 to 5% of cases and instability, non-union and infection are common complications (Kreitmann and others 1992, Cohen and Griffin 2002, Luciani and others 2006, Ramzi and others 2009). The use of polydioxanone has recently been validated as an alternative to wires in selected patients (infants and patients with body surface area <1·5 m²) to prevent poststernotomy dehiscence (Keceligil and others 2000). However, no biomechanical studies have compared polydioxanone and stainless steel wire.

The purpose of this study was to biomechanically compare stainless steel wire and polydioxanone for median sternotomy closure in a medium to large size dog cadaver models using a peristernal figure of eight suture undergoing constant distraction. It was hypothesised that wires would resist gap formation better than polydioxanone.

MATERIALS AND METHODS

The sternum was collected from 12 mature greyhounds, which were euthanased for reasons unrelated to this study. The weight of the dogs was recorded. Samples were collected within 8 hours of euthanasia. Each specimen was composed of all sternebrae and at least 6 cm of costal cartilage and intercostal muscles. Specimens were wrapped in saline soaked (0·9% NaCl) large swabs and frozen at −20 °C until testing.

The samples were stabilised in a custom-made frame that did not allow separation of the two halves of the sternebrae during the sternotomy. A number 22 scalpel blade was used to mark the centre of each sternebrae to achieve as accurate a median sternotomy as possible. The blade was placed mid-way between the sternocostal junctions and was rocked in the sagital plane to mark the mid-line. A median sternotomy was performed using a sagital saw (Stryker UK Limited, Newbury, UK) leaving the manubrium intact.

The specimens were randomly assigned to one of the closure methods. The sternotomy was closed using one of the following methods:

1. Four metric polydioxanone (PDS II, Ethicon Ltd, Edinburgh, UK) peristernal in a figure of eight pattern centred on the sternal synchondrosis and tied with a pair of needle holders using a sliding knot with a total of five throws. Suture tags were cut at 3 mm. A total of six sutures per sternum were used.

2. Stainless steel wire 20 gauge (Veterinary Instrumentation, Sheffield, UK) peristernal in a figure of eight pattern centred on the sternal synchondrosis and tensioned by pulling and twisting with the wire twister in a clockwise direction. The wire was cut leaving a total of five twists and was not bent. A total of six sutures per sternum were used.

Before and after each test, radiographs of the specimens were obtained and specimens were visually inspected to determine the mode of failure. The failure of the stabilisation was defined as a fracture of any sternebrae or sternocostal junction, or rupture of wire or suture.

For testing, each specimen was attached to a custom-made fixture with an inside grip designed to retain the sample and create displacement in distraction of the sternum across the sternotomy (Fig 1). The clamps were placed on either side of the sternum, approximately 2·5 cm from the sternotomy and secured with stainless steel screws and nuts. The screws entered the intercostal space and the sample was firmly secured using the grip previously mentioned. The clamps were placed in a servohydraulic material testing system (Instron Ltd., Bucks, UK).

The specimens were tested under displacement control mode to pull them apart at a constant rate of 15 mm/min until failure. Load and displacement were recorded continuously until failure. The response to displacement was linear and the stiffness for both materials was calculated. The test was stopped when a drop in load was recorded. Specific displacements at 125, 150, 200, 250, 300, 350 and 400 N of load and at failure were used for further data analysis. The maximal load at failure was recorded.

Displacements were measured based on the Instron actuator and for each specimen visual inspection at the sternotomy site was performed to determine the presence of a gap at the end of testing (Fig 2). Comparisons of body weight between the two suture groups, displacement at each load level for each type of closure, and for each specimen visual inspection at the sternotomy site was performed.

FIG 1. Sternum mounted in a custom made clamp and secured with stainless steel screws and nuts, attached to the mechanical testing device.
RESULTS

Body weight of the dogs included in this study ranged from 25 to 37 kg (mean 30·8 ±3·87 kg). Body weight was not significantly different between the two groups of closure materials (P=0·82). Each sternum was split in half from the second to seventh sternebra in all cases; however, the xiphoid process was only cut through the mid-line in eight cases (four in each group) and for the others, cut was not made on the mid-line.

The displacement recorded with each closure material at the different loads varied between 0·88 and 4·02 mm (at loads of 125 and 400 N, respectively) for the orthopaedic wire and between 0·72 and 3·80 mm (at loads of 125 and 400 N, respectively) for the polydioxanone (Fig 3). There was no significant difference in displacement between the two different closure materials (P=0·481). Stiffness for the orthopaedic wire (mean 106·55 ±29·48 N/mm) and polydioxanone (mean 86·59 ±14·39 N/mm) were not significantly different (P=0·175).

The mode of failure for the sternotomy closed with orthopaedic wire was fracture of the sternocostal junctions. When polydioxanone was used the mode of failure was suture failure in five cases and fracture of the manubrium in one case likely because the manubrium had to bear significant load because the suture stretch.

For each specimen a gap at the sternotomy site was visually confirmed. The load at failure for the stainless steel wire (mean 1754 ±124 N) was significantly superior to the polydioxanone (1345 ±278 N) (P=0·036). No significant difference was seen when the displacement at failure was analysed. At high loads, the displacement observed, when the stainless steel wire was used, was due to deformation of the soft tissue surrounding the wire and fracture of the sternocostal junctions while it was mainly due to the stretching of the suture for polydioxanone.

The radiographic analysis of the specimens before testing revealed a cranio-caudal displacement of the distal sternebrae in two specimens (one each group), although displacement was minimal (~1 mm). The evaluation of the post-testing radiographs showed that the stainless steel wire group did not have any implant failure.

DISCUSSION

Although studies on objective assessment of sternal fixation are scant, it is very likely that veterinary surgeons would not intuitively consider polydioxanone as a suitable material for sternal closure in medium to large size dogs mainly because they would consider the risk of non-union or malunion unacceptably high.

The weight of the dogs in the present study (mean 30·8 ±3·9 kg) was very similar to the one presented in the Pelsue study (mean 29 ±3·0 kg) and twice the weight recommended by some authors when polydioxanone is used for primary sternal closure in dogs (Fossum 2007). Pelsue and others have shown that sternal closure with polybutester healed slower and allowed more fragment motion than closure with wires supporting the idea that weight should be a major criterion for choosing the method of sternal suture. The design of the present study is different from Pelsue and others (2002) and direct comparison between the two studies will be difficult to make. Even if the modes of failure between polydioxanone and wires are different, our findings support the idea that use of absorbable suture might be an acceptable alternative to the use of stainless steel wires. However, we cannot draw any conclusion regarding sternal healing based on our study.

Indeed, satisfactory results in people are usually obtained if the closure method provides adequate rigidity and strength (Cohen and Griffin 2002). However, in human beings, none of
the approaches with the use of traditional steel wires seems to be free of wound complications. Failure of the wire system usually involves the wire cutting into the bone under load. This produces a separation of the sternum, which can result in a non-union and other complications (Cohen and Griffin 2002). In human beings, there are recognised risk factors for sternal complications including diabetes, advanced age and osteoporosis (Luciani and others 2006) that seem to be relatively independent of the weight of the patient. The incidence of foreign body-induced wound infection (Losanoff and others 2002) and aseptic instability (Luciani and others 2006) has prompted surgeons to use absorbable sutures in median sternotomies where the need for rigid and stable closure is well known, advocating that stability might not be the only decision maker in closure method selection. The use of polydioxanone in the primary closure of sternotomy has been largely reported in human beings (van Sterkenburg and others 1990, Kreitmann and others 1992, Schwab and others 1994, Keceligil and others 2000, Losanoff and others 2002, Luciani and others 2006). Initially, the use of polydioxanone was recommended for sternotomy closure in paediatric open cardiac surgery (Keceligil and others 2000) to prevent sutures from remaining permanently in immature patients. A prospective trial using polydioxanone and stainless steel wire for sternotomy closure with a figure of eight pattern in high-risk human patients, showed that the polydioxanone suture could protect effectively against development of bone dehiscence (Luciani and others 2006). This study recommends the use of polydioxanone suture in patients with a body surface area less than 1.5m² (~56 kg). Although it is desirable to use a closure method that prevents bone dehiscence, it is important that the closure method provide adequate stability for rapid bone healing.

A strict case selection is needed in order to take advantage of the properties of polydioxanone as outlined in the present study and based on the current recommendations for humans. We propose that dogs with severe muscle wasting, bone loss (osteoporotic patients), paediatric patients, dogs with unequal sternal halves postostectomy or dogs with prominent sternal bone should be considered high risk patients for sternal closure complications and therefore a population that could benefit from an alternative to wires for sternal closure. This classification should be further refined based on clinical studies, as the present study does not provide the necessary evidence to allow definitive recommendations.

A figure of eight pattern was used in our study, as it is the pattern associated with the least displacement at high loads in in vitro mechanical testing in dogs (Davis and others 2006). The number of twists employed for the stainless steel wire was five as this appears sufficient to gain maximum strength and prevent possible sternal dehiscence (Shih and others 2004), and the number of throws employed for the polydioxanone was five as this maximises the tensile strength and minimises rate of untwisting (Muffly and others 2011).

Initially in this study, surgical knots were used with the polydioxanone to close the sternotomy; however, manual manipulation of the sternotomy sites showed instability, probably as a result of loss of tension of the first throw, and these samples were not tested mechanically. One way to avoid this could be to hold the first knot tensioned while the second knot is made and tied. However, this technique has been shown to alter structural damage of the some suture materials (Huber and others 1999). Structural damage will significantly decrease the load to failure and the ultimate tensile strength (Wright and others 2006) and can lead to suture failure. We tentatively recommend to perform sliding square knots as we found that the tension generated kept the sternotomy stable, similar to the stainless steel wire on manual manipulation but acknowledge that this represents a crude assessment of the stability.

None of the sternum examined fractured at high load (400 N). A previous study using different wire closure methods in segmental sternum reported a high incident of sternal fracture with a 200-N load (Davis and others 2006). The load applied in our study to create a fracture (sternocostal junction or manubrium) was 1754 ±124 N for the stainless steel wire and 1570 ±279 N for the polydioxanone group. It is very likely that the difference in experimental settings (complete versus incomplete sternum, number of points of fixation) is the reason for this discrepancy.

Although pivotal to assess the clinical implication of mechanical testing, maximal load that will be applied in a sternotomy site has not been systematically studied. A maximal load of 400 N was used in this study for comparison between closure methods, which theoretically, is more than the physiological loads suggested in the studies on human beings (McGregor and others 1999). Coughing is one of the main concerns related to sternal stability in human beings. In adult patients a normal cough may produce a disrupting force in the sternotomy as high as 56 kg (550 N) (Losanoff and others 2002). In dogs, the force can be estimated by applying the mathematical model described by Casha and others (1999). This model assumes that all the forces will be exerted radially, which is reflected by the formula: $T=rlP$, where $r$ is the radius of the chest, $l$ the length of the sternum, $P$ the distending pressure on the chest walls and $T$ the resultant force across the sternotomy. With an estimation of maximal cough reaching 100 mmHg (P=13.3 kPa) for dogs (42 to 100 mmHg has been found in humans),

$$T=rlP=0.10~m\times0.26~m\times13.3~kPa=346~N$$

The estimated force using this model at the sternotomy site in a medium/large dog should therefore not be more than 350 N. However, this estimation appears to be significantly higher than the physiological forces at the level of the sternotomy. In a porcine model, the forces acting on the sternal midline were considerably smaller, with less than 80 N across the sternum when a cough was generated by stimulation of the phrenic nerve (Pai and others 2008). Therefore, it appears that our testing scheme is well within the range of forces that can clinically apply on a sternotomy.

Our study comprises a fairly small number of data (six cadavers per group) and it could be argued that this is the reason for the lack of a significant difference between the groups (Type II error). However, it is critical to realise when doing a power calculation that we should consider the power to detect a clinically significant difference [an effect size (displacement) i.e. established before data collection] rather than using the observed
data to construct this effect size. In that respect a 2-mm gap for a load of 125 N (which is already more than the 80-N force found by Pai and others) was chosen as an effect size — i.e. a gap that will affect the healing process of the sternotomy creating a fibrous tissue healing (Aro and Chao 1993, August and others 1998, Claes and others 1998, Pelsue and others 2002). A power analysis with these settings was performed and only three cadavers per group were required to achieve a power of 0.9 (software used: http://www.stat.uiowa.edu/~rlenth/Power/). We therefore felt that increasing the number of animals would not contribute to show clinical differences. We believe that refinement methods should apply also for use of cadavers in experimental settings and therefore did not perform unnecessary additional experiments. However, the measurement of the displacement was performed at the actuator of the Instron machine and not at the level of the sternotomy, and it is very likely that differences exist between those two measurements.

One limitation of our study is that both materials were tested only with a single distinctive force until failure. Other forces as transverse and longitudinal shear forces can be present at the sternotomy site as described in other studies (Cohen and Griffin 2002, Pai and others 2008). Longitudinal shear is applied to the sternum during skeletal movement but leaving the manubrium intact (recommended for most clinical situations) decreases this force. It is difficult to test these forces in an experimental model, however, the latter force appears to be the most important as smaller forces will be necessary to generate the same gap when compared with the other forces (McGregor and others 1999). In addition, we have only tested one pattern (figure of eight).

As previously mentioned, another limitation is that we did not measure the gap at the sternotomy site but relied on the actuator displacement to quantify it. We used a custom jig to fix the tested sample and have minimised slippage at the grip by designing a jig with indentations that firmly hold the rib and soft tissue. However, this method is not as accurate as direct quantification of the gap and we acknowledge that the measurements given in the present study are not reflective of the absolute value of the sternal gap. Calibration of the instron machine usually minimises this issue; however, it could lead to discrepancies especially for small gap measurement (i.e. clinically relevant forces in the presented study). Furthermore, the different modes of failure may reflect differences in gap formation between the two groups that the testing method did not detect because we inspected the sternae at failure only visually. A final limitation here is that results of an ex vivo experimental study may show differently in a clinical setting.

Nevertheless, our study suggests that the sternum closed with polydioxanone or stainless steel wire has similar mechanical properties. The canine sternae is much thinner than human sternae and risk of the wire cutting through the bone is potentially higher. Polydioxanone can be an alternative to conventional stainless steel wire closure in selected cases of dogs weighing up to 30 kg. Heavier dogs may benefit from the use of polydioxanone but we have not mechanically tested polydioxanone on dogs with weights greater than 30 kg. However, it is beyond the scope of this study to recommend usage of polydioxanone over wires as more studies including other mechanical testing with cyclic loading and clinical studies should be performed.

Conflict of interest
None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

References


J. A. Gines and others