



Quantifying tension in tension-free hiatal hernia repair: a new intra-operative technique

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Abstract

Background A similar technique to measure crural closure tension has not been described before and with this method there is now a possibility to optimise this operation with objective measures, a hundred years after it was first described. The aims of this study were to develop a reliable method for measuring the tension of crural closure during hiatal hernia repair and to describe the tension characteristics of crural closure.

Methods 50 patients underwent crural tension measurement. Hiatal surface area (HSA) was measured intraoperatively and a Sauter FH 50 Universal Digital Force Gauge was used to measure the tension of crural closure during cruroplasty. Outcome measures included the mean tension of the crural closure and the presence of any muscle splitting during the cruroplasty.

Results A combined total of 148 interrupted cruroplasty sutures were performed in all fifty patients. Each interrupted suture had three tension measurements recorded. The mean standard deviation amongst 148 sets of tension measurements was 0.27. Age, hiatal width and HSA were positively correlated with crural tension with r values of 0.44 ($p=0.0015$), 0.81 ($p<0.0001$) and 0.78 ($p<0.0001$), respectively. Strength of association was low for age ($r^2=0.19$) but moderate for hiatal width and HSA ($r^2=0.65$ and 0.61, respectively). The presence of muscle splitting occurred at higher crural closure tension (5.3 N vs. 1.62 N, $p<0.0001$). The lowest observed mean crural closure tension causing muscle splitting was 3.52 N (IQR 3.93–6.77 N).

Conclusions We have developed a technique for measuring the tension of crural closure during laparoscopic repair of hiatal hernia which is reproducible, quick, of low cost and requires only minimal additional equipment. Initial findings suggest that crural closure tension up to ~4 N could be the permissible tension threshold for suture cruroplasty and higher tension often results in muscle splitting during cruroplasty.

Keywords Suture cruroplasty · Mesh cruroplasty · Crural tension measurement · Hiatal hernia · Hiatal surface area

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Crural repair is a crucial part of hiatal hernia surgery and can be achieved by primary suture, mesh reinforced or bridging mesh cruroplasty. Limited evidence from randomised trials suggest that the use of prosthetic mesh reinforcement may reduce recurrence rates [1–3]. However, the use of prosthetic mesh has also been associated with visceral erosion, ulceration, dysphagia and stricture [3–6]. Biologic mesh originally showed promise in a prospective multicentre randomised study with reduced recurrence rates at 6 months [7]. Unfortunately, its benefit was diminished at long-term follow up with similar rates of objective recurrence [8]. Two systematic reviews have been conducted recently and authors from both studies agree that evidence supporting routine use of mesh cruroplasty is low and should be used at the surgeons discretion based on the operative findings [9, 10]. Furthermore, a survey revealed diverse practices amongst European surgeons for routine, selective or no use of mesh

in laparoscopic large hiatal hernia repair surgery and the preference of mesh material (prosthetic versus biologic) [11]. With opinion divided within the upper gastrointestinal surgery community, there is currently no clear guidance on which patients should receive mesh repair.

Bradley et al. published an intraoperative method to evaluate baseline tension of the diaphragmatic hiatal muscle closure during hiatal hernia repair [12]. The authors found that there was a positive correlation between hiatal width and tension but the strength of association was low. One of the conclusions drawn from their study was that a simple measurement such as crural width does not account for all the tensile forces at the diaphragmatic hiatus during hernia repair. It is not surprising that primary repair of large hiatal hernia by suturing the pillars of the diaphragm (crus muscles) together under tension is at significant risk for disruption. One of the tenets of hiatal hernia repair is to perform a tension-free closure of the hiatal defect. However, it is not known what exactly is tension-free, if a permissible tension threshold exists or what tension may predispose to a higher risk of recurrence.

The aims of this paper were to develop a feasible method for measuring the tension of crural closure in laparoscopic hiatal hernia repair surgery, describe tension characteristics of crural closure and its application in future research.

Methods

Patients

50 patients underwent crural tension measurement (CTM) during primary laparoscopic repair of hiatal hernia between April 2017 and February 2018. Included in this analysis are patients with symptomatic sliding or paraesophageal hernias with or without obstructive symptoms, Barrett's oesophagus, oesophagitis and short oesophagus. Patients were excluded if they had prior hiatal hernia or anti-reflux surgery. Data collected from patients on enrolment included age, gender, height, weight, smoking status, medical co-morbidity and medication history. During CTMs, the level of patient anaesthesia and paralysis was not standardised between patients within the series. Drugs administered during anaesthesia were used at the discretion of the anaesthetist. The decision to use mesh (reinforcing or bridging) cruroplasty was at the surgeons' discretion and was based on operative findings (e.g. the presence of muscle splitting and quality of the crus muscles). No relaxing diaphragm incisions were performed in any of the patients included in this study. Outcome measures included the mean tension of crural closure and the presence of any muscle splitting during cruroplasty. All patients gave their written consent prior to inclusion into the study and this project was approved by the local research

and ethics committee (London—Hampstead Research Ethics Committee: Reference 17/LO/0567).

Surgical equipment

The measurement of crural tension during cruroplasty requires some additional equipment (Fig. 1). The Sauter FH 50 Universal Digital Force Gauge (SAUTER GmbH, Balingen, Germany) was selected as the measuring instrument of choice due to its capacity (50 N), accuracy (0.25 N) and readability (0.01 N). The Sauter FH 50 Universal Digital Force Gauge is CE marked. Laparoscopic repair of hiatal hernia with anti-reflux surgery was performed through the standard placement of ports (Fig. 2). The Digital Force Gauge was set to peak hold mode when taking measurements (see Online Appendix).

Intraoperative measurement of hiatal surface area

The maximum height (H) and width (W) of the hiatal defect was measured using an endoscopic ruler. The hiatal surface area (HSA) was then calculated using the following formula as described by Granderath et al. [13]

$$\text{HSA} = \pi \times H^2 \times \sin^{-1} \frac{(W \div 2H)}{180}$$

Surgical technique: crural tension measurement

The hook attachment was securely fitted to the Digital Force Gauge and placed inside a sterile camera bag (Fig. 1). The Digital Force Gauge was then set to peak hold mode (see supplementary material: *Setting the Digital Force Gauge to peak hold mode*). If the crura were able to be approximated, the hiatal opening was closed primarily starting posteroinferiorly. Interrupted sutures were performed in turn in an anterosuperior direction until the cruroplasty was completed using 2–0 48" (122 cm) ETHIBOND™ polyester suture mounted on a 19 mm ski taper needle (ETHICON, A Johnson & Johnson Company, Somerville, NJ, USA). The ETHIBOND™ suture was kept long with the introduction of the ski needle through port 1 (Figs. 2 and 3A) ensuring that the loose end of the suture remained extracorporeal. Once the suture had been placed through the left and then right bundles of the right crus muscle (Fig. 3B) it was exteriorized through the same port and the needle removed (Fig. 3C). The Maryland Dissector Insert (MDI) was placed through the suction/irrigation shaft (SIS) (Fig. 3D). The ends of the ETHIBOND™ suture were then tied around the handle end of the MDI (Fig. 3E) and the suture pulled through the entire length of the SIS (Fig. 3F). The MDI was then removed and

Fig. 1 Equipment required for CTM. From left to right: Sauter FH 50 Universal Digital Force Gauge with hook attachment placed inside a sterile camera bag; Laparoscopic MDI; Laparoscopic suction/irrigator shaft (SIS); Endoscopic ruler (cut); 2–0 48" (122 cm) ETHIBOND™ polyester suture mounted on a 19 mm ski taper needle

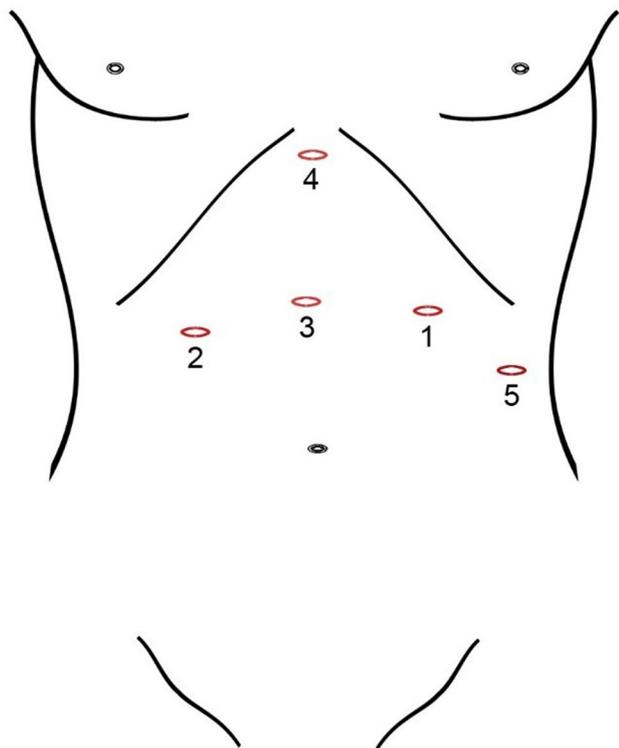


Fig. 2 Port placement during laparoscopic repair of hiatal hernia with anti-reflux surgery and CTM. Ports placed in numerical order. 1, Surgeon right hand; 2, surgeon left hand; 3, camera/assistant left hand; 4, Nathanson liver retractor; 5, assistant right hand

the extracorporeal knot secured (Fig. 3G). The hook attachment of the Digital Force Gauge was placed through the closed suture loop (Fig. 3H) and the Digital Force Gauge was orientated to align its axis with the direction of the port, SIS and suture (Fig. 3I). The tip of the SIS was then positioned adjacent to the left bundle of the right crus (Figs. 3I and 4). Prior to taking the first measurement, the Digital Force Gauge was zeroed whilst aligned with the port, SIS and suture (see supplementary material: *Setting the Digital Force Gauge to peak hold mode*). The pressure of pneumoperitoneum during measurements was 8–12 mmHg. After the Digital Force Gauge had been set to peak hold mode and primed for taking measurements, it was gently pulled away from the patient whilst maintaining alignment with the port, SIS and suture (Figs. 3I and 4). When the left and right bundles of the right crus opposed or ‘kissed’ each other (Fig. 4), the Digital Force Gauge was moved back towards the patient resulting in the peak tension being automatically recorded. This was then repeated twice more in order to obtain three measurements for that suture. The suture was then cut short and the knot tied with a minimum of four throws.

To begin with, a square knot (1:1) was attempted with an initial single throw. If the first tie was held with a single throw then the square knot was completed with three further throws and the next suture was performed following the same process. If the single throw tie was not held (due to too much tension), then a surgeon’s knot (square 2:1) was attempted with an initial double throw. If the first tie was held with a double throw then the knot was secured with two subsequent throws and the next suture was performed

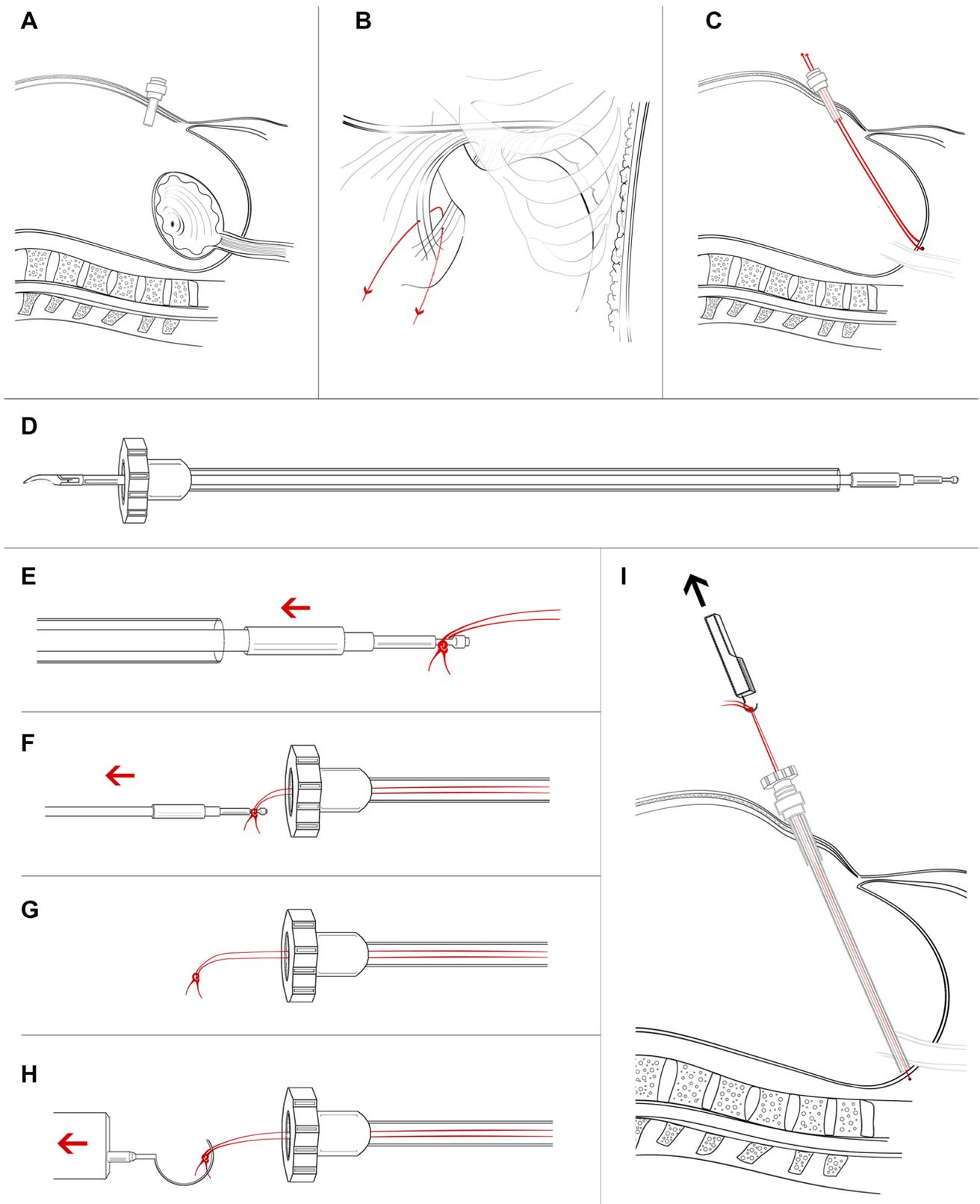


Fig. 3 CTM technique

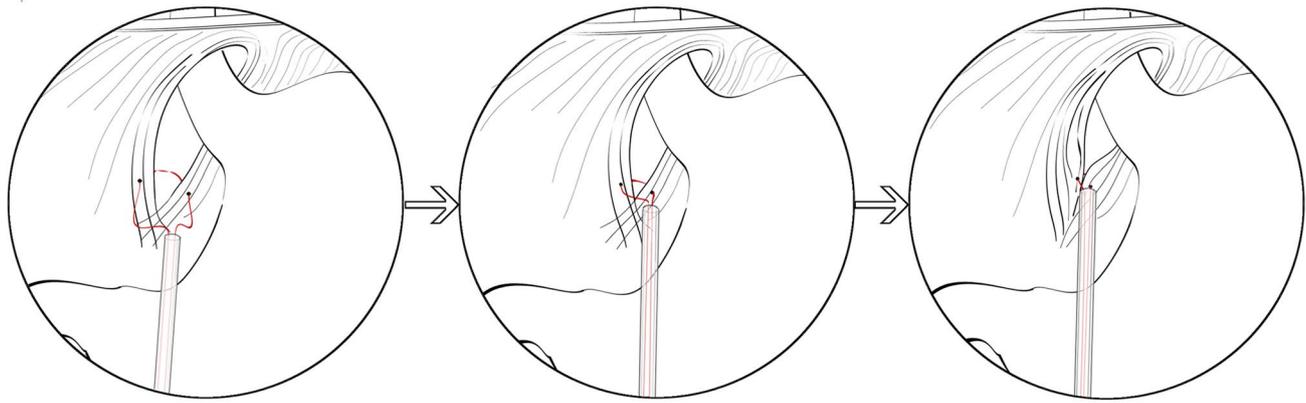


Fig. 4 View of hiatal defect whilst performing CTM. Left to right: as the Digital Force Gauge is gently pulled the left and right bundles of the right crus come together allowing the peak tension of crural closure held by that stitch to be recorded

following the same process. However, if the double throw tie did not hold, then a slip knot was performed in order to secure the first throw followed by two further throws to secure the knot.

The presence of crural muscle splitting during knot tying was observed for and recorded as absent or present. Therefore, for each suture, three corresponding tension measurements, a method used to secure the first throw (single, double or slip knot) and whether or not there was any muscle split present at that tension was recorded.

Statistical analysis

Normally distributed continuous data were reported as mean (with standard deviation), whereas skewed or ordinal data were reported as medians (with interquartile range). Statistical analysis of categorical data was performed using Chi square or Fisher's exact tests, whilst the unpaired *t* test or Mann–Whitney was used for parametric or non-parametric continuous data where appropriate. A *p*-value of <0.05 was considered statistically significant. Pearson correlation coefficient (*r*) and/or linear regression (least squares fit) was used to correlate age, body mass index (BMI), HSA and crural tension. An *R* square value of 0.8 was used as a cut-off for goodness of fit. Data for this study were stored and collated using Microsoft Excel (Microsoft, Redmond, WA, USA), GraphPad Prism 7 (GraphPad, Software Inc, La Jolla, CA, USA) and SPSS 25 (Chicago, IL, USA) statistical packages.

Results

50 patients underwent CTM during the study period. The male-to-female ratio was 24:26 and the median age was 57.5 years (interquartile range (IQR) 41.5–67.5 years). Mean BMI was 27.0 kg/m² (95% confidence interval (CI)

25.6–28.4 kg/m²). Mean HSA was 536 mm² (95% CI 446–627 mm²) and mean hiatal width was 21.8 mm (95% CI 19.5–24.2 mm). For all patients, the median CTM was 2.2 N (IQR 1.3–3.9 N). In all patients, the crura were able to be approximated. A combined total of 148 interrupted cruroplasty sutures were performed in all fifty patients. The median number of sutures per cruroplasty was 3 (IQR 2–4). Each interrupted suture had three tension measurements recorded. To assess the reliability of the technique, the standard deviation of the three tension recordings per interrupted suture was calculated. The range of standard deviation amongst 148 sets of tension measurements was 0.015–1.3 (mean 0.27 and 95% CI 0.23–0.30).

Age, BMI, hiatal width and HSA were correlated with crural tension using Pearson correlation coefficient (*r*) (Fig. 5). Age, hiatal width and HSA were positively correlated with crural tension with *r* values of 0.44 (*p*=0.0015), 0.81 (*p*<0.0001) and 0.78 (*p*<0.0001), respectively. Strength of association was low for age (*r*²=0.19) but moderate for hiatal width and HSA (*r*²=0.65 and 0.61 respectively). BMI was not correlated with either HSA or crural tension. From the fifty patients included in this study, an equation to estimate mean crural tension from crural splaying (hiatal width) and HSA was calculated using linear regression (goodness of fit *R*²=0.6528 and 0.6084, respectively):

$$\text{Mean crural tension (N)} = [0.1936 \times \text{hiatal width (mm)}] - 1.361$$

$$\text{Mean crural tension (N)} = [0.004807 \times \text{HSA (mm}^2\text{)}] + 0.2896$$

34/50 (68%) patients had higher crural tension within the anterior most suture (last suture) of the posterior cruroplasty when compared with the posterior most suture (first suture). In three (6%) patients, the anterior and posterior

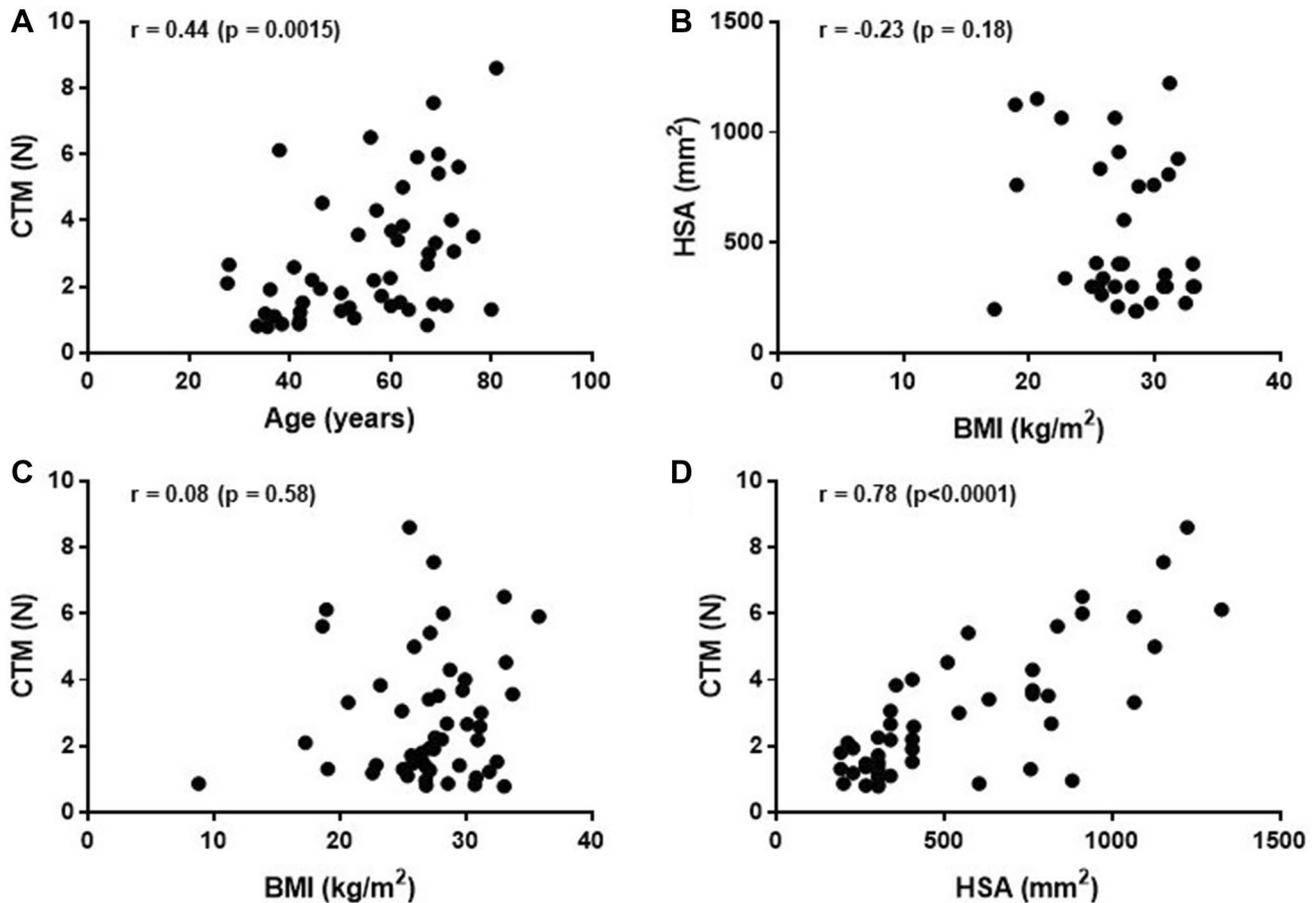


Fig. 5 Pearson correlation coefficient (r). A, age correlated with CTM. B, BMI correlated with HSA. C, BMI correlated with CTM. D, HSA correlated with CTM

sutures were the same (two patients only required 1 cruroplasty suture). The anteriormost suture placed during the posterior cruroplasty from the fifty patients had higher mean crural closure tension when compared to the posterior most suture (3.44 N vs. 2.33 N, $p=0.0002$).

For each interrupted suture during cruroplasty, the method of the first throw used to secure the initial tie was recorded. An initial single throw was adequate to keep the crus together in 66/148 knots. In 52/148 knots, an initial single throw was not able to keep the crus approximated; however, an initial double throw was able to do so. When an initial double throw was also not able to keep the crus together, a slip knot had to be employed and was required in 30/148 knots. The single-throw method had median tension of 1.31 N (IQR 0.91–1.88 N). Double-throw tension had a median value of 3.12 N (IQR 2.38–4.75 N), whereas the slip knot when required had median tension of 6.56 N (IQR 5.42–8.08 N) (Fig. 6).

Eleven patients (22%) showed signs of muscle splitting during cruroplasty. The group with muscle splitting had a higher proportion of current or ex-smokers but this was

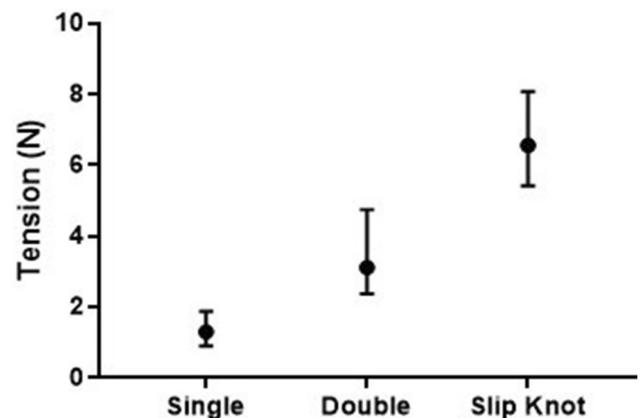


Fig. 6 Median crural tension with interquartile range for each type of first throw when securing the initial tie during cruroplasty. Single ($n=66$), double ($n=52$) and slip knot ($n=30$)

not statistically significant (36.4% vs. 23.1%, $p=0.4446$). However, the group with muscle splitting was older in age (68.5 vs. 52.8 years, $p=0.0098$), had larger hiatal defects

(910 vs. 339 mm², $p < 0.0001$) and had higher crural closure tension (5.62 N vs. 1.72 N, $p < 0.0001$) (Fig. 7A). The lowest observed mean crural closure tension causing muscle splitting was 3.52 N. Nine out of 11 (82%) patients who had observed muscle splitting had crural tension > 4 N.

During the study period, 38 patients underwent suture (S) cruroplasty, whereas 12 patients received mesh (M)-reinforced cruroplasty with biological mesh. The decision to use mesh cruroplasty was at the surgeons' discretion and was based on standard operative findings (e.g. the presence of muscle splitting and quality of the crus muscles) rather than the crural closure tension. All 12 patients who received a mesh underwent an initial suture cruroplasty with biological mesh reinforcement (on-lay). No patients received a bridging mesh or relaxing diaphragm incision and mesh in this study. Patients who received biological mesh-reinforced cruroplasty had significantly larger median HSA (990 vs. 320 mm², $p < 0.0001$), hiatal width (33 vs. 15 mm, $p < 0.0001$) and mean crural tension closure (5.8 N vs. 1.6 N, $p < 0.0001$) than patients who received suture cruroplasty alone (Fig. 7B).

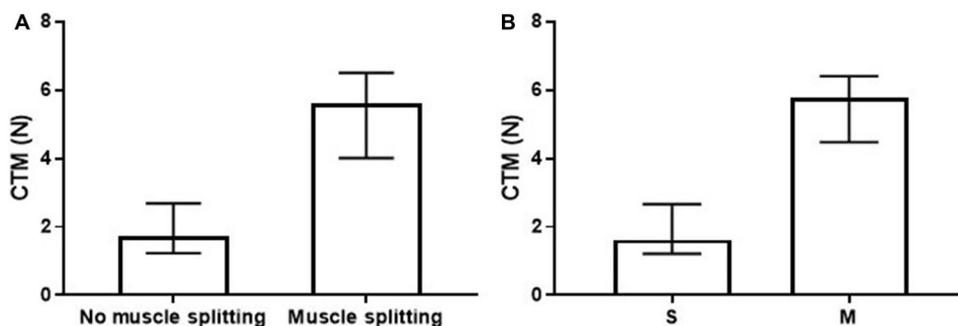
Discussion

A reliable method for measuring the tension of crural closure during laparoscopic repair of hiatal hernia has been described. The technique is reproducible, quick, of low cost and requires only minimal additional equipment.

An intraoperative method to evaluate baseline tension (after complete hiatal dissection) of the diaphragmatic hiatal muscle closure has been described before [12]. A comparable sample size was reported in their study and the authors similarly found that hiatal width was positively correlated with crural tension closure but found that the strength of association was much lower than that found in our study ($r^2 = 0.31$ vs. 0.65). There are several differences between the aims and methodology of the two studies. Firstly, one of the main focuses of their study was to evaluate whether tension was reduced by relaxing manoeuvres, whereas in the present study one of the main aims was to provide objective

data on the permissible tension threshold that defines a tension-free repair. Furthermore, it is our preference not to perform relaxing manoeuvres and/or relaxing diaphragm incisions during hiatal hernia repair and therefore this was not performed in any of the patients in this series. Secondly, in the previously described technique, a mechanical force gauge with a visual scale was used which would produce less accurate measurements of tension when compared to a digital force gauge with a peak hold function (see supplementary material: *Setting the Digital Force Gauge to peak hold mode*). In addition, the authors did not report the reliability of their method and solely reported the average of three to four measurements that were taken. It is unsure whether or not such a technique resulted in reproducible measurements. In the previous study, all the measurements were taken completely intracorporeally and therefore in the present study a criticism would include that there are no data to validate that tension measurements are accurate. However, the same standardised technique was used for all measurements within this series. Thirdly, Bradley et al., only took a single measurement taken at the presumed level of the highest posterior hiatal suture to estimate the tension of the entire crural closure prior to any cruroplasty sutures had been placed. The technique described in the present study allows for tension to be measured at each individual suture starting posteriorly and moving anteriorly and it is therefore possible to investigate the difference in tension between the anterior and posterior most aspect of the cruroplasty. Fourthly, and perhaps most importantly, the use of the previously reported technique did not describe the presence of muscle splitting and at what tension any muscle splitting occurred. We chose the presence of muscle splitting as a marker of those hiatal hernia repairs at risk of recurrence due to compromise of the structural integrity of the crura secondary to higher tension and/or poor muscle quality. Muscle splitting was chosen as the clinically relevant threshold for reinforcement or “too much tension” instead of recurrence because the majority of patients with muscle splitting (9 out of 11) went on to have reinforced biological mesh cruroplasty. Therefore, the presence of recurrence would not be a fair marker of “too much tension” because of the use of mesh reinforcement in

Fig. 7 **A** The relationship between the presence of muscle splitting and crural tension (median and interquartile range). **B** Crural tension (median and interquartile range) for patients receiving suture (S) cruroplasty or mesh (M) cruroplasty



the majority of patients with muscle splitting and/or higher crural tension. Furthermore, the findings reported in this study provide the surgeon an objective estimation of crural closure tension from the type of knot used to secure the first throw of each suture.

CTM is likely to be most useful when repairing larger hiatal defects as smaller hernias tend to be amenable to suture cruroplasty. The definition of large hiatal hernia varies considerably amongst foregut surgeons. Three different methods for defining large hiatal hernias are commonly referred to in literature. Firstly, the size of the hiatal defect measured either intraoperatively or on pre-operative upper gastrointestinal barium swallow has been described by several authors [1, 2, 7, 14–16]. Amongst these studies, a 5- or 8-cm hiatal defect threshold were chosen empirically. Secondly, the degree of gastric herniation has been used as defining criteria by other investigators [16–19]. However, the lower limit of herniation to qualify for large hiatal hernia varies between 30 and 50% within these studies. Furthermore, the degree of gastric herniation is not necessarily correlated with the size of the hiatal defect and therefore its use as criteria to define hiatal hernia may be limited. Thirdly, hiatal surface area (HSA) has been described by Granderath et al. [13], and used in a large study to classify hiatal hernia based on long-term results [20]. The authors suggest that hiatal hernias should be grouped into small ($HSA < 10 \text{ cm}^2$), large ($10\text{--}20 \text{ cm}^2$) or giant ($> 20 \text{ cm}^2$) with small hernias receiving suture cruroplasty only and giant hernia receiving mesh cruroplasty. The large hiatal hernia group were randomly assigned to either suture or mesh cruroplasty with no significant difference in anatomic and reflux recurrence (symptomatic or asymptomatic) between the groups. It is this intermediate size group ($HSA 10\text{--}20 \text{ cm}^2$) where crural tension would be most useful to guide the surgeon towards either suture or mesh cruroplasty. We advocate measuring the maximum height and width of the hiatal defect which allows not only an assessment of the hiatal defect size (hiatal width) but also an estimation of HSA. Up until now, much emphasis has been placed on size or area of the hiatal defect. It has been assumed that hiatal width and HSA are associated with crural tension; however, this study has demonstrated that the strength of such associations are at best moderate ($r^2 = 0.65$ and 0.61 respectively). When the crus can be approximated, we believe that it is the higher tension in crural closure that poses risk of recurrence rather than the hiatal size alone. Furthermore, one of the tenets of hiatal hernia repair is a ‘tension-free’ closure of the crus and therefore without knowing about the tension properties of crural closure we are not able to understand what tension threshold should be designated ‘tension free’.

It may not be realistic to perform CTM in all operations, therefore the method used to secure the first throw of the knot was investigated to see if there was an easily

reproducible intraoperative surrogate that could estimate crural tension. Silver et al. measured knot security in relation to different surgical tying techniques and specifically investigated square, surgeon’s and sliding knots [21]. A similar principle was used in this study by first attempting a single throw and escalating the method to a surgeon’s knot (double throw) or slip knot if required. With a degree of overlap, the results from 148 knots show that an initial single throw square knot equates to 0.5–2 N, a double throw (surgeon’s knot) 2–5 N and slip knot 5–9 N. Knowledge of tension properties of ties/knots within the hiatus can give the surgeon more objective information on estimating the tension held by the cruroplasty and can identify those repairs which are under greater tension.

We believe that there are three main factors to consider when performing a hiatal hernia repair and whether a mesh is required. Firstly, the tension of the crural closure is the most likely factor to relate to recurrence. We hypothesise that there is a ‘permissible tension threshold’ for which suture cruroplasty can offer a conventional ‘tension-free’ repair. The results from this study suggest that the permissible tension threshold is approximately 4 N. Crural tension greater than 4 N appears to result in more trauma (muscle splitting) to the crura and most patients who had observed muscle splitting had mean crural tension greater than 4 N. In this series, all but one patients (92%) who received biological mesh reinforcement had crural tension greater than 4 N. Secondly, hiatal size is clearly important. Giant hiatal hernias where the crura cannot be approximated without muscle splitting may require a bridging mesh. Furthermore, as this study had demonstrated, hiatal size and surface area are positively correlated with tension. Using the linear regression equation relating HSA to crural tension, a crural tension of 4 N equates to an HSA of approximately 770 mm^2 . Thirdly, muscle quality of the crura should also be assessed during surgery. It may be possible to estimate crural muscle bulk on pre-operative computed tomography and we hypothesise that various subfactors may contribute to muscle quality such as age, smoking, BMI/nutrition status and inflammation caused by gastroesophageal reflux as well as others.

The results of this preliminary study suggest that the method of securing the first throw of the knot in conjunction with the permissible tension threshold can be used as a supplementary tool to guide the surgeon as to whether a mesh is required. If a single throw holds the crura together, then this is low tension and within the permissible tension threshold and therefore suture cruroplasty alone is the optimal choice. If a slip knot is required, then this equates to tension above 4 N and therefore the surgeon should consider mesh reinforcement. As the range of tension for the double throw (surgeon’s knot) is 2–5 N, we hypothesise that if the double throw does not result in any muscle splitting then suture cruroplasty alone should be considered. However, if

a double throw is required and there is evidence of muscle splitting, then the tension is likely to be in the upper region of the 2–5 N bracket and therefore mesh reinforcement would be advised.

There are limitations to this technique. In the ideal scenario, the tension of crural closure during cruroplasty would be measured using a technique that is reliable, accurate and completely objective. Although the ability to set the Digital Force Gauge to peak hold mode allows for the measurements to be blinded from the investigator and reliably records the peak tension, a degree of subjectivity is unavoidable as the investigator has to consistently judge when the free edges of the crura oppose each other. We recommend that both surgeons verbally communicate with each other whilst observing the laparoscopic monitor to try and mitigate this. The second limitation of the technique was that during CTMs, the level of patient anaesthesia and paralysis was not standardised between patients within the series. Drugs administered during anaesthesia were used at the discretion of the anaesthetist. Thirdly, the hiatal defect is assumed to be the shape of a circular sector when calculating the HSA which is not always the case. Crural splaying (hiatal width) may be a more consistent marker to use when assessing hiatal size. Fourthly, the single value of crural tension was taken from the mean of the tension values from each of the interrupted sutures of the cruroplasty. This was chosen to represent the tension of the entire repair and the tension ‘shared’ by all the sutures. This simplified view of complex mechanical properties was chosen to be able to describe the basic principles of tension within hiatal surgery. The fifth limitation of this study was that the peritoneal lining overlying the crural muscle fibres was not intact in all patients after hiatal dissection (as demonstrated in the accompanying video), and therefore splitting of the fibres may be more common compared to cases where the lining is left on the muscle. Finally, as previously mentioned, we chose the presence of muscle splitting as a marker of those hiatal hernia repairs at risk of recurrence due to compromise of the structural integrity of the crura secondary to higher tension and/or poor muscle quality. Therefore from the data presented here, it is unclear if the tension measured has any effect on clinical outcomes including recurrence rates.

Conclusion

We have developed a reliable method for measuring the tension of crural closure during laparoscopic repair of hiatal hernia. The technique is reproducible, quick, of low cost and requires only minimal additional equipment. Tension of crural closure during cruroplasty may be more useful than hiatal size to guide the operating surgeon to selective use of mesh repair and may predict patients at higher risk of

complications. It appears that a permissible tension threshold of up to 4 N exists for primary suture cruroplasty repair of hiatal hernia, and above this tension muscle splitting of the crura is seen. By offering a technique to measure crural closure tension, there is now a possibility to optimise this operation with objective measures a hundred years after it was first described [22]. Future studies should be aimed at validating this technique by randomising patients to suture versus mesh cruroplasty when crural closure tension is greater than 4 N.

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Compliance with ethical standards

Disclosures Lalin Navaratne, Hutan Ashrafiyan and Alberto Isla have no conflicts of interest or financial ties to disclose.

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