European Journal of Cardio-thoracic Surgery 20 (2001) 1072–1073

EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY

www.elsevier.com/locate/ejcts

Reply to the Letter to the Editor

Reply to Jutley et al.

A.R. Casha[a,*], M. Gauci[b], L. Yang[c], P.H. Kay[a], G.J. Cooper[c]

[a]Department of Cardiothoracic Surgery, Leeds General Infirmary, Leeds LS1 3EX, UK
[b]Department of Anaesthesia and Intensive Care, University of Wales College of Medicine, Cardiff CF14 4XN,UK
[c]Departments of Biomechanics and Cardiothoracic Surgery, Northern General Hospital, Sheffield S5 7AU,UK

Received 6 June 2001; accepted 25 July 2001

We thank Dr Jutley and associates for their comments. Hertzian contact analysis predicts the elastic behaviour of contacting surfaces and was first described by Heinrich Hertz in 1882. We do not believe that Hertzian contact analysis applies to contact between wire and bone in sternotomy closures because:

1. The theory does not apply for conforming surfaces e.g. when wire is pushed through and embedded and surrounded by bone [1].
2. The theory applies to a hard body indenting an elastic surface. Bone is not an elastic material, strictly speaking it is a visco-elastic material (differing strength and elasticity depending on speed of load or applied strain rate).
3. Using Jutley's figures for stress for polyester suture (nominal 0.5 mm, 240 MPa stress) versus steel (0.7 mm, 203 MPa stress) would not explain why polyester cut through at more than 4 times the rate of steel.
4. We do not agree that a Sterna-band (3.64 mm wide per unit length) is necessarily equivalent to a wire of 2.32 mm diameter. This was not tested by us; and would need to be tested experimentally before such information could be used as a statement.

We agree that demonstration of stress magnitude can lead to a better understanding of the mechanisms of dehiscence. Fig. 1 compares levels of von Mises stress in wire and Sterna-band.

We believe that sternal cortical bone behaves rather like femoral trabecular bone since it fails by gradual yielding rather than fracturing; and the rate of yield (or rate of wire cutting through bone) is proportional to the force and inversely proportional to the area of contact [2]: rate of yield $\propto$ force/area of contact.

Yielding takes place when the mean pressure exceeds the yield stress. Since bone is visco-elastic, low ratios can induce a permanent plastic deformation, whilst high ratios induce collapse. With good quality bone, compaction occurs increasing the effective contact area and slowing the rate of cutting through. This does not occur with osteoporotic bone.

It follows that in order to decrease cutting through bone, any combination of three strategies may be used namely:

1. The use of better quality bone by recruiting the lateral cortex of the sternum by placing the device parasternally [3].
2. Decrease the force per device by increasing the number of devices [4] or using an external chest compressing device.

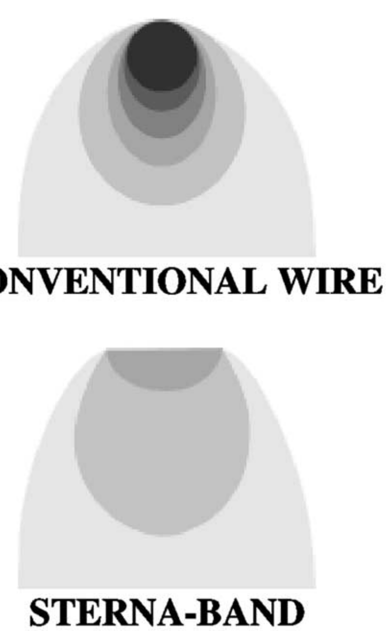

Fig. 1. Von Mises contact stresses induced in the sternum by conventional stainless steel wire no. 5 and Sterna-band as shown by finite element computer analysis. Note the higher levels of localised stress (darker grey) with the wire. After Soroff 1999, personal communication.

* Corresponding author. Tel./fax: +44-1482-845253.
E-mail address: aaron@casha.fsbusiness.co.uk (A.R. Casha).

PII: S1010-7940(01)00943-5

3. Increase the area of bone contact by the use of flexible braided wire [5], bands [6], cannulated screws, grommets [7], struts [8] or simply by reinforcement with staples [9].

Sterna-bands are useful in that all strategies are applicable as opposed to, for example, the case with cannulated screws since these cannot be placed parasternally.

References

[1] Flugge W, editor. Handbook of engineering mechanics 1st ed. New York: McGraw-Hill, 1962. pp. 716–720.

[2] Mow VC, Hayes WC. Basic orthopaedic biomechanics, 2nd ed. Philadelphia: Lippincott-Raven, 1997. pp. 82–95.

[3] Casha AR, Gauci M, Yang L, Saleh M, Kay PH, Cooper GJ. Fatigue testing median sternotomy closures. Eur J Cardio-thorac Surg 2001;19:249–253.

[4] Opie JC. Avoidance of sternal nonunion. Ann Thorac Surg 1997;64:888–889.

[5] Dali DM, Miles AW. Re-attachment of the greater trochanter. The use of the trochanter cable-grip system. J Bone Joint Surg Br 1983;65(1):55–59.

[6] Soroff HS, Hartman AR, Pak E, Sasvary DH, Pollak SB. Improved sternal closure using steel bands: early experience with three year follow up. Ann Thorac Surg 1996;61:1172–1176.

[7] Labitzke R, Schramm G, Witzel U, Quisthout P. 'Sleeve-rope' closure of the median sternotomy after open heart operations. Thorac Cardiovasc Surgeon 1983;31:127–128.

[8] Scovotti CA, Ponzone CA, Leyro-Diaz RM. Reinforced sternal closure. Ann Thorac Surg 1991;51:844–845.

[9] Zurbrugg HR, Freestone T, Bauer M, Hetzer R. Reinforcing the conventional sternal closure. Ann Thorac Surg 2000;69:1957–1958.

ELSEVIER

European Journal of Cardio-thoracic Surgery 20 (2001) 1071

EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY

www.elsevier.com/locate/ejcts

Letter to the Editor

Calculating stress magnitude between sternotomy closures and sternum

R.S. Jutley[a,b], D.E.T. Shepherd[a,*], D.W.L. Hukins[a], R.R. Jeffrey[b]

[a]Department of Bio-Medical Physics and Bio-Engineering, Aberdeen University, Foresterhill, Aberdeen, AB21 2ZD, UK
[b]Department of Cardiothoracic Surgery, Aberdeen Royal Infirmary, Aberdeen, AB21 2ZN, UK

Received 15 May 2001; accepted 25 July 2001

Casha et al. [1] describes fatigue testing of sternotomy closures and concludes that polyester closures cut through bone faster than wires of the same diameter. Sterna-bands also displace least into bone when cycled at forces simulating repeated coughing.

We have been evaluating the stress generated between wire closure and sternum using an established method, Hertzian contact analysis [2]. We believe that by quantifying stress new techniques can be devised or old methods reaffirmed that minimise this stress. Dehiscence occurs when failure stress of sternum is exceeded as forces such as those produced by coughing are applied to the sternotomy. The wire can then cut into bone. The failure stress of human bone is 205 MPa [3].

The Hertzian analysis demonstrated that an exponential relationship exists between wire diameter and generated stress. For example, at a cough pressure of 120 mmHg (similar to that used by Casha et al. [1] in the fatigue test) the stress generated between a peristernal transverse stainless-steel wire of 0.7 mm is 203 MPa, assuming six wires are used for closure. As wire diameter increases, the stress generated decreases as the force is distributed over a larger surface area. Increasing the diameter beyond 4 mm, however, is accompanied by a proportionally small decrease in stress. On the contrary, decreasing the wire diameter less than 0.7 mm results in very high stress. For example, a 0.5 mm calibre suture generates a 240 MPa stress. This may explain why the polyester suture in Casha's study cut through bone more readily than wire. During cycling, the suture stretched thereby reducing its diameter. The resulting stress from the narrowed suture would have then exceeded the failure stress of bone leading to dehiscence.

Hertzian analysis also explains why Sterna-bands displace least through bone. The contact area for Sterna-band was 3.64 mm/unit length. This contact area is also produced by a wire of 2.32 mm diameter. Hertzian analysis predicts that during a 120 mmHg cough, a 2.32 mm calibre wire generates 111 MPa stress, or 55% of that generated by steel wire. This finding correlates well with the differential percentage cut-through between wire (100%) and Sterna-band (51 ± 29%; mean ± SD) reported in Casha's paper.

In conclusion, we believe it is possible to quantify stress magnitude between sternal closure methods and bone by applying contact analysis. This method has now been validated using the data by Casha et al. A better recognition of stress magnitudes would lead to better understanding of the mechanisms that lead to dehiscence. Increasing the diameter of wire can reduce stress but this involves use of wire too bulky to manipulate. An alternative is to make the sternum non-penetrable by placing devices such as grommets suggested by McGregor et al [4] or cannulated screws [5] through which conventional wire is threaded. Alternatively, the total surface area presented by the closure points may be increased with multiple wires [6]. Either method serves to prevent dehiscence by reducing the mean stress between closure and bone, the magnitude of which may be predicted using Hertzian analysis.

References

[1] Casha AR, Gauci M, Yang L, Saleh M, Kay PH, Cooper GJ. Fatigue testing median sternotomy closures. Eur J Cardo-thorac Surg 2001;19:249–253.
[2] Johnson KL. Contact mechanics. Cambridge: Cambridge University Press, 1985.
[3] Reilly DT, Burstein AH. The elastic and ultimate properties of compact bone tissue. J Biomech 1975;8:393–405.
[4] McGregor WE, Trumble DR, Macgovern JA. Mechanical analysis of midline sternotomy wound closure. J Thorac Cardiovasc Surg 1999;117:1144–1150.
[5] Medical device. Patent number WO0105315, Grampian University Hospitals NHS Trust, January 2001; www.patent.gov.uk
[6] Opie JC. Avoidance of sternal non-union. Ann Thorac Surg 1997;64:888–889.

* Corresponding author. Tel.: +44-1224-553489; fax: +44-1224 685645.
E-mail address: d.shepherd@biomed.abdn.ac.uk (D.E.T. Shepherd).

PII: S1010-7940(01)00944-7