Calculating stress magnitude between sternotomy closures and sternum

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Casha et al. \cite{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 \cite{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 \cite{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. \cite{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 \cite{4} or cannulated screws \cite{5} through which conventional wire is threaded. Alternatively, the total surface area presented by the closure points may be increased with multiple wires \cite{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.

\begin{thebibliography}{9}
\bibitem{3} Reilly DT, Burstein AH. The elastic and ultimate properties of compact bone tissue. J Biomech 1975;8:393–405.
\bibitem{5} Medical device. Patent number WO0105315, Grampian University Hospitals NHS Trust, January 2001; www.patent.gov.uk
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