Revista Mexicana de Física **41**, *No. 5 (1995) 771–776*

The design of an elasticity exercise for applied physics students in the health sciences

M. DOLZ PLANAS

Departamento de Termodinámica, Facultad de Farmacia
Universidad de Valencia, 46100 Burjassot, Valencia, España

M. BUENDÍA GÓMEZ

Departamento de Fisiología, Facultad de Medicina
Universidad de Valencia, Valencia, España

F. GONZÁLEZ RODRÍGUEZ, M.J. HERNÁNDEZ LUCAS AND J. DELEGIDO GÓMEZ

Departamento de Termodinámica, Facultad de Farmacia
Universidad de Valencia, 46100 Burjassot, Valencia, España

Recibido el 20 de septiembre de 1994; aceptado el 24 de abril de 1995

ABSTRACT. We describe an elasticity exercise for physics students in the health sciences. The experimental setup is detailed, and flexibility measurements are made with different central venous catheters. Determination of the elastic hysteresis cycles proposed for silicon, PVC and polyurethane catheters. Finally, the results obtained are presented.

RESUMEN. Describimos una práctica de elasticidad para los alumnos de física en ciencias de la salud. Se ha especificado el montaje experimental y se ha medido la flexibilidad de distintos catéteres de implantación venosa central. Se han determinado los ciclos de histéresis elásticos para catéteres de silicona, PVC y poliuretano. Por último se presentan los resultados obtenidos.

PACS: 01.40; 46.30.Rc; 46.30.Cn

1. INTRODUCTION

Many areas in physics offer possibilities for preparing interesting and not too complicated exercises for first year university students in physics. However, in the case of elasticity, few experiments are available that prove to be of sufficient interest for physics students in the health sciences, *e.g.*, in pharmacy, medicine, etc.; these being disciplines where the elastic behaviour of biological materials is of particular relevance.

The aim of the present paper is to describe an elasticity exercise developed from research work carried out in our Unit of Physics Applied to Pharmacy, in collaboration with the Intensive Care Unit of Dr. Peset Hospital (Valencia, Spain). The method determines the elastic characteristics of different polyurethane, PVC and silicon central venous catheters and their possible modification through clinical use [1].

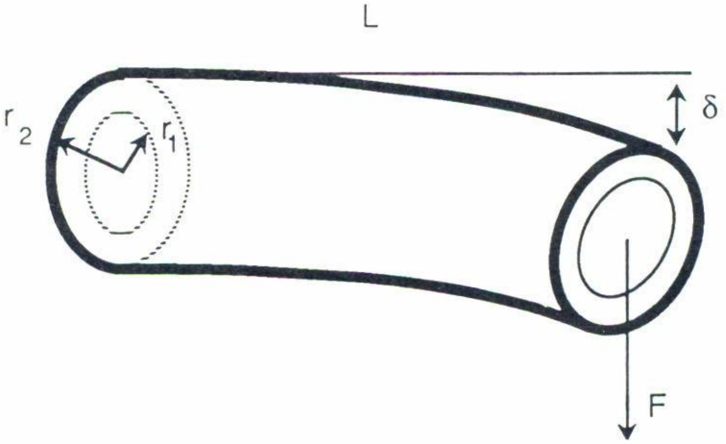

FIGURE 1. Deformation (δ) of a solid of length L, subjected to force perpendicular to the longitudinal axis.

2. JUSTIFICATION

Catheters developed for clinical use must be sufficiently flexible to prevent laceration or tearing of the vascular intimacy during implantation; moreover, catheter introduction using an internal guide should avoid possible bending or permanent constrictions. Consequently, the physical parameter to be considered in any elastometric exercise (Fig. 1) is the deflection or displacement per unit force perpendicular to the catheters (δ/F) this in turn being related to Young's elasticity modulus (E), the material employed and the geometric characteristics of the deformed body [2] via the following equation:

$$\frac{\delta}{F} = \frac{L^3}{3EI}, \tag{1}$$

where I is the geometric moment of inertia. For an internal and external radius of r_1 and r_2, respectively, I is determined by

$$I = -(r_2^4 - r_1^4)\frac{\pi}{4}. \tag{2}$$

Consequently, greater-or-lesser flexibility is not only determined by the material employed but also by the geometrical characteristics of the catheter, *i.e.*, flexibility is a function of the product EI. On the other hand, this product has considerable clinical importance, for as demonstrated by Stenqvist *et al.* [4] and Bennegård *et al.* [5], EI exerts a determining influence on thrombus formation during central venous catheterization. Indeed, thrombus formation increases appreciably for catheters with EI products in excess of 1.6×10^{-5} Nm^2.

Thus, in view of the clinical relevance of the product EI and the difficulty involved in developing an experimental setup to evaluate catheter deflection when subjected to forces perpendicular to the longitudinal axis, we proposed the determination of Young's modulus

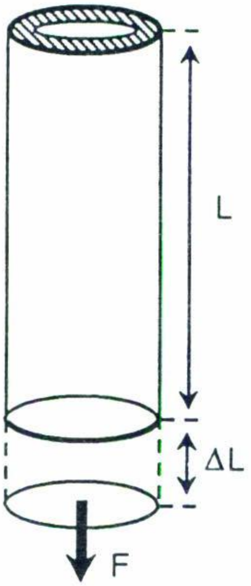

FIGURE 2. Deformation due to unidirectional traction on a solid subjected to longitudinal force.

during unidirectional traction as an alternative approach to study catheter deformation (Fig. 2) [3].

3. EXPERIMENTAL SETUP

For a body subjected to lengthening by unidirectional traction to satisfy the law $(\Delta L/L) = F/ES$, the material employed must undergo deformation within the corresponding elastic limits. In the practical example of central venous catheters, the latter are manufactured from plastic materials such as PVC, silicon, etc., and limited forces must be applied to secure very small deformations. Moreover, we have determined whether by measuring lengthenings after constant time intervals following each load a near-elastic catheter behaviour may be obtained with a consequently acceptable E value.

The proposed experimental setup is shown in Fig. 3. One end of the catheter (C) is suspended from a screw (T), which is in turn fixed to a rigid bar (B) of adequate length and stability. Weights (preferably flat and of 10 g each) are added to a small metal plate (P) suspended from the lower tip of the catheter, to produce lengthening.

With the plate initially unloaded and the micrometer (M) setting at zero, the catheter and plate are lowered via T until the base of the plate contacts with the micrometer tip. In order to eliminate subjectivity in establishing the moment of contact, we use an electrical system (Fig. 3) in which a milliamperimeter (A) registers current passing through a resistance (R) when the circuit closes as P contacts with the tip of M (switch (I) turned on). We consider this initial zero setting to be of particular teaching interest, as it stresses the need to calibrate zero when using a measuring device.

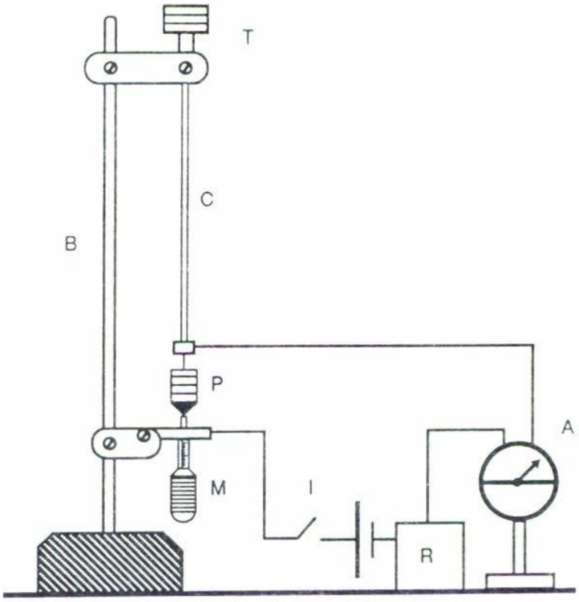

FIGURE 3. Experimental setup employed.

Having completed zero setting, the first measurement is made by reducing the micrometer screw so that free lengthening of the catheter may be achieved on loading P with a first weight. After a prefixed equilibration period (1 minute, approximately), the micrometer is slowly screwed up until its tip again contacts the base of P and the galvanometer needle is seen to oscillate. The micrometer reading indicates the resulting catheter lengthening.

Instead of the method for measuring lengthenings described, any other method related to measure length, like displacement transducers, differential transformers, etc., can be used.

By measuring a sufficient number of lengthenings corresponding to different loads, we obtain a set of experimental points $(F, \Delta L)$ from which the points $(F/S, \Delta L/L)$ may be transformed on taking into account catheter length and cross-section.

Subsequent linear fitting of $(\Delta L/L) = f(F/S)$ by the least-squares fit method yields a regression straight line where the independent term should be very small; the inverse of the slope in turn provides Young's modulus for the catheter material. If the students carefully perform these measurements straight lines with correlation coefficients in the order of 0.995 may be obtained; this being sufficient given the characteristics of the materials employed (Fig. 4).

The above experiment may be performed using different thickness catheters and materials. Conclusions may center on comparison of the EI products obtained and their relation to the maximum values permitted regarding the risk of thrombogenesis [3].

The exercise may be extended by deriving the elastic hysteresis cycle of the catheter material: this simply requires the simultaneous graphic representation of the points $(F/S, \Delta L/L)$ above and the set of points obtained from the progressive unloading of weights in P. Figure 5 shows the elastic hysteresis cycle of a silicon catheter.

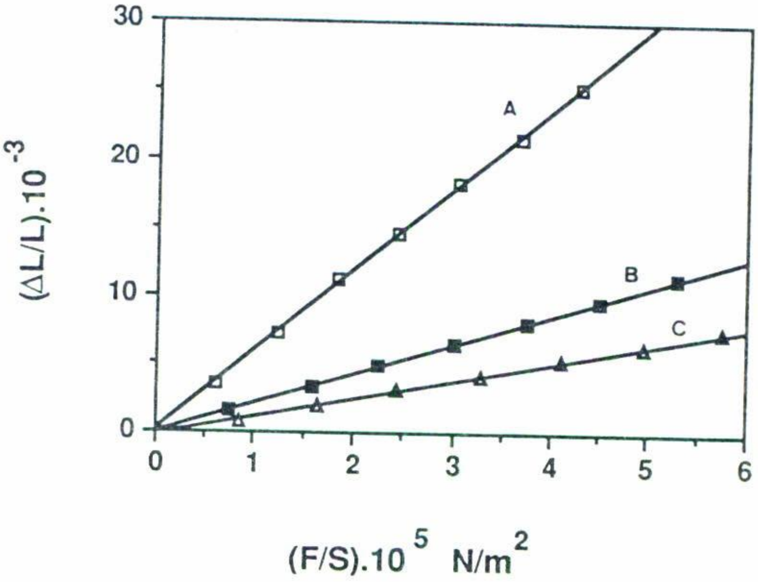

FIGURE 4. Relative deformation as a function of the forces applied to three different catheters: (A) silicon; (B) PVC; and (C) polyurethane.

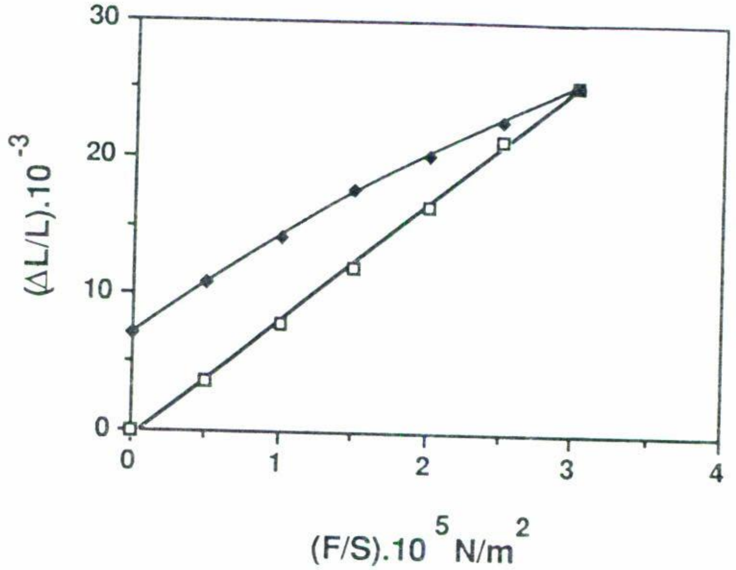

FIGURE 5. Elastic hysteresis cycle corresponding to a silicon catheter.

About Fig. 2 we must point out that, although in this kind of thermoplastic materials the non-lineal deformation occurs when the load is increased and the deformation is lineal in the unloading, in our case, deformations were so small than we can consider a lineal behaviour in both cases, *i.e.*, we are within the elastic limits of the material. Logically due to the characteristics of this kind of materials, the results shown would be modified when the waiting time between load and measurements was different from the one used to obtain Fig. 5 (1 min).

The fact that the loading-unloading curves do not coincide and that catheter length does not fully recover allows the teacher to comments on the irreversibility of the deformation process —which will be all the more important the greater the area enclosed by the hysteresis cycle.

Finally, our aims is to offer an exercise of interest to the physics student in his or her first year university studies in the health sciences (pharmacy, medicine, etc.), where in our opinion the role of the physics teacher is to emphasize those points of interest and greatest use to such students.

ACKNOWLEDGEMENTS

We wish to thank Dr. J. Pellicer (Department of Thermodynamics, Valencia University) for his suggestions regarding the irreversibility of plastic deformation.

REFERENCES

1. M. Cervera, M. Dolz, R. Belda, J.V. Herraez, M. Fernández y A. Romar. *Med. Int.* **12** (1988) 380.
2. G.S. Pisarenko, A.P. Yakolev and V. Matveev, *Manual de Resístencia de Materiales*, Ed. Mir. Moscow (1979), p. 143.
3. M. Cervera, M. Dolz, J.V. Herraez y R. Belda, *Phys. Med. Biol.* **34** (1989) 177.
4. O. Stenqvist, I. Curelaru, E. Linder and B. Gustavsson, *Acta Anaesthesiol. Scand.* **27** (1983) 153.
5. K. Bennegård, I. Curelaru, B. Gustavsson, E Linder and R. Zachrisson, *Acta Anaesthesiol. Scan.* **28** (1982) 204.