

An *In vitro* Evaluation of Epidural Catheters: Tensile Strength and Resistance to Kinking

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Abstract

The tensile strengths of 12 commercially available brands of epidural catheters were assessed using an Instron material testing device. The mean values of the tensile strengths ranged from 1.89 to 3.74 kilogram force. The extent of catheter occlusion due to kinking was also studied using an in vitro apparatus designed to simulate drug delivery at various degrees of flow restriction. It was determined that reinforced catheters were less likely to be occluded secondary to kinking.

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Introduction

In the current era of increasing economic and medico-legal pressures, it is imperative that equipment-related limitations and complications be reduced to a minimum. Epidural catheter breakage can result in the inconvenience of surgical extraction of catheter fragments,¹⁻⁵ while kinking can lead to impairment or failure of drug delivery to the patient.^{6,7} The aim of this study was to determine the tensile (breaking) strengths as well as the kink-resistance properties of some commercially available brands of epidural catheters in routine use.

Materials and Methods

The various brands of epidural catheters studied were: Becton-Dickinson (BD) Ribflex 19G and 20G (model 6333), BD Ribflex 20G (model 7033), BD polyamide 19G and 20G, Portex catheters for 16G needles (2 variants), Portex catheters for the 18G and 19G (paediatric) needles, Braun Perifix polyamide 20G, Sherwood Medical Sensi-Touch Direc-Trol 18G, Kendall Safe-Trak 20G, Abbott nylon polyamide 20G and the Arrow FlexTip Plus 19G. The BD Ribflex 20G (model 7033) and the Arrow catheters were not available for tensile strength testing.

The tensile strengths of the epidural catheters were tested using the Instron 8500 cyclic torsion compression device (Fig. 1). This is a servo-hydraulic material testing system which was used to determine the linear force

expressed in kilogram force (kgf) required to stretch and ultimately break the epidural catheter which was secured to it. The device is accurate to 0.0001 kgf and can graphically depict the stretch characteristics of the various catheters in real time.

Three equal 10-cm lengths were cut from each catheter and mounted between the clamps of the Instron 8500 for the testing procedure. The 10-cm lengths were obtained from the first 10 cm, between 20 to 30 cm and between 40 to 50 cm, as measured from the distal end, respectively.

An axial sinusoidal force was applied to the sample lengths and that force required to break the catheter samples was measured by a calibrated electronic strain-gauge incorporated in the Instron 8500. Data were sampled at a frequency of 1 kHz and captured by a dedicated computer system. The average (mean) of three force determinations for each test catheter was recorded.

In order to test the kink-resistance properties of the epidural catheters, a "Terumo" syringe pump set to deliver distilled water at a rate of 15 ml/h through each of the test catheters was used. The proximal end of each catheter was connected to a 50 ml infusing syringe by its dedicated catheter adapter. The distal end was inserted into a 10 ml syringe for the collection of water. The mass of water which was collected within the syringe after exactly 10 min was measured using a "Sartorius" weighing scale, accurate to within 0.1 g. The mass determinations were made before bending the catheter

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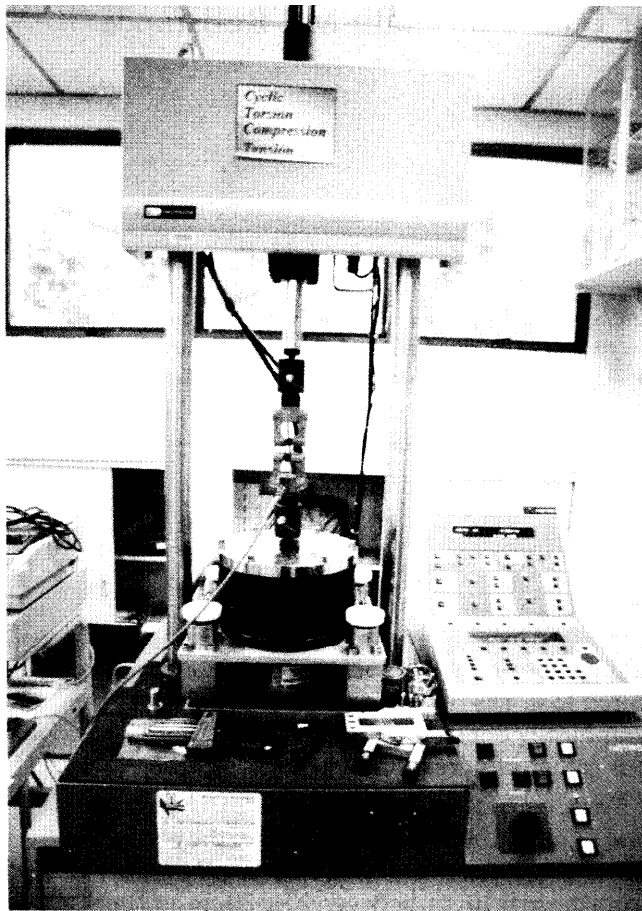


Fig. 1. The Instron 8500 cyclic torsion compression tension device.

and with increasing degrees of bending. Incremental bending was accomplished by sequentially inserting a loop of the catheter into paediatric endotracheal tubes with internal diameters of 4.5, 4.0, 3.5, 3.0, 2.5 and 2.0 mm, respectively (Fig. 2). The distance at which each catheter was inserted into the tubes was the same for all catheters tested. The average of two mass value readings for each catheter-endotracheal tube pairing was recorded. The same syringe pump was used for all the determinations and its accuracy was ascertained beforehand. Each catheter was pre-flushed with 2 ml of distilled water to ensure its lumen was patent before each assessment.

Results

The applied force was graphically represented as a function of the catheter length stretched (Fig. 3). The mean breaking forces (tensile strengths) of the epidural catheters tested ranged from 1.89 to 3.74 kgf (Fig. 4). With respect to kink-resistant testing, water flowed through the three BD Ribflex ribbed-lumen catheters and the Arrow FlexTip Plus catheter with minimal or no restriction, even on extreme bending (Table I). The rest of the catheters exhibited obvious restriction of flow

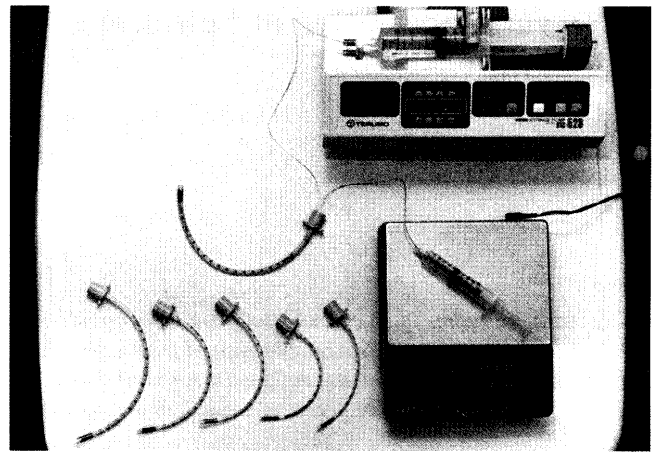


Fig. 2. In vitro apparatus used to determine the kink-resistant properties of epidural catheters.

with progressive bending. The trend of flow for each catheter through progressively smaller endotracheal tubes is graphically depicted (Fig. 5).

Discussion

Continuous epidural anaesthesia is a technique in widespread use; however, complications such as the inability to remove the catheter intact as well as restriction of drug delivery due to kinking have been reported.¹⁻⁷ Catheter breakage can result from application of a sudden force during removal, lodging within the vertebral column and removal from other than the flexed lateral position.^{8,9} Kinking of the catheter can occur within the epidural space (usually due to excessive depth of insertion) or outside the body (invariably due to changes in patient positioning and improper taping).⁵⁻⁷ Epidural catheters that resist breakage and kinking would thus offer an important clinical advantage. Blum and Sosis¹⁰ studied the tensile strength of five different types of 19G epidural catheters whereby the test catheters were wound in a figure-of-eight manner and an axial force was applied manually, whereas we utilised the Instron device, which is an industrial testing standard. They found that the tensile strengths varied from 2.53 to 3.65 kgf, somewhat analogous to our results. Hutchison¹¹ assessed the ease with which 18G catheters were severed by the bevel of an epidural needle but did not measure actual tensile strength. Ley and Jones¹² evaluated the tensile strength of five commercially available continuous spinal catheters against one brand of 20G epidural catheter and concluded that the tensile strength of spinal catheters was one-third to one-half of that for a typical epidural catheter. In contrast, our study compared several different brands as well as various sizes of epidural catheters.

The stretch characteristics of a test catheter (applied force over length stretched) is represented by a curve that rises steeply, to be followed by a gentler increase in

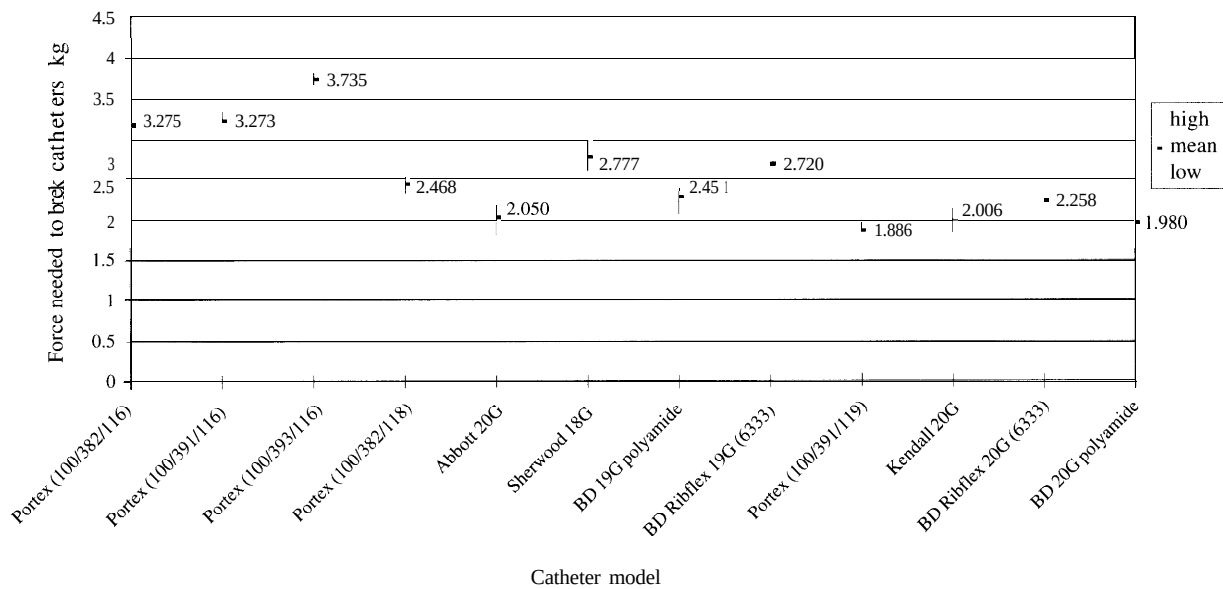


Fig. 4. Tensile strength of epidural catheters.

the slope until the breakpoint where the force abruptly drops to zero (Fig. 3). The initial steep part of the curve represents the “elastic” phase denoting that the catheter is able to return to its former configuration without deformation when the applied force is released. The more gradual part of the curve represents the “plastic” phase in which the catheter undergoes permanent elongation and a decrease in its diameter (“necking-down”) until the breakpoint is reached. A catheter which exhibits greater plasticity (i.e., can undergo considerable stretching before breaking) is desirable because “necking-down” can serve as a warning sign as well as facilitate removal should the catheter become difficult to dislodge.

Theoretically, if the catheters are constructed with the same material and are of a similar configuration, the magnitude of the tensile strength would be directly related to the size. This stands to reason because tensile strength is a function of the cross-sectional area of the catheter, which in turn is a function of the square of its radius. This size-strength relationship held true for our study samples of the same brand and configuration.

Blum and Sosis¹³ studied the kink-resistant properties of epidural catheters with an *in vitro* apparatus which measured the flow of water through the catheters at various degrees of bending under constant hydrostatic pressure conditions. Of the five brands studied, they

TABLE I: THE MASS (g) OF DISTILLED WATER COLLECTED FROM THE EPIDURAL CATHETERS OVER 10 MIN BEFORE (CONTROL) AND AFTER A LOOP OF THE CATHETER WAS INSERTED SEQUENTIALLY INTO PROGRESSIVELY SMALLER-SIZED PAEDIATRIC ENDOTRACHEAL TUBES (ETT)

Catheter brand	Internal diameter of ETT						
	None (Control)	4.5 mm	4.0 mm	3.5 mm	3.0 mm	2.5 mm	2.0 mm
BD 19G polyamide	2.5	2.4	1.2	0.3	0.1	0	0
BD 20G polyamide	2.3	2.3	0.1	0.1	0	0	0
Portex for 16G needle (100/382/1 16)	2.7	2.6	1.8	0.9	0.1	0	0
Portex for 16G needle (100/393/1 16)	2.6	2.6	0.2	0.2	0	0	0
Portex for 18G needle (100/382/1 18)	2.4	2.4	2.4	2.4	0.6	0	0
Braun Perfifix 20G polyamide	2.4	2.4	2.4	2.3	2.3	0.2	0
Sherwood Medical Sensi-Touch 18G Direc-Trol	2.5	2.2	1.2	0.2	0.1	0	0
Kendall Safe-Trak 20G	2.4	2.4	2.4	2.4	2.4	0.1	0
Abbot 20G nylon polyamide (1177 1)	2.4	2.4	2.4	2.2	2.2	1.6	0
Portex for 19G paediatric needle (100/39 1/0 19)	2.6	2.4	2.4	2.4	2.3	2.0	1.0
BD Ribflex 19G (6333)	2.4	2.4	2.3	2.4	2.3	2.3	2.3
BD Ribflex 20G (6333)	2.3	2.3	2.3	2.3	2.3	2.3	2.2
BD Ribflex 20G (7033)	2.4	2.4	2.4	2.3	2.4	2.4	2.5
Arrow FlexTip Plus 19G	2.4	2.6	2.5	2.5	2.4	2.5	2.4

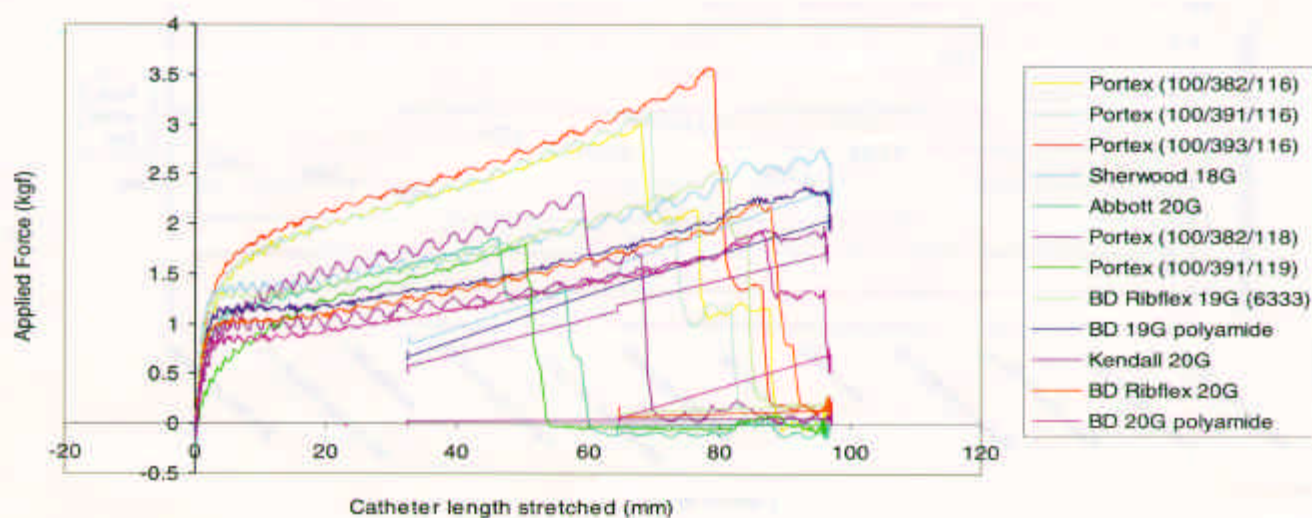


Fig. 3. Stretch characteristics of epidural catheters.

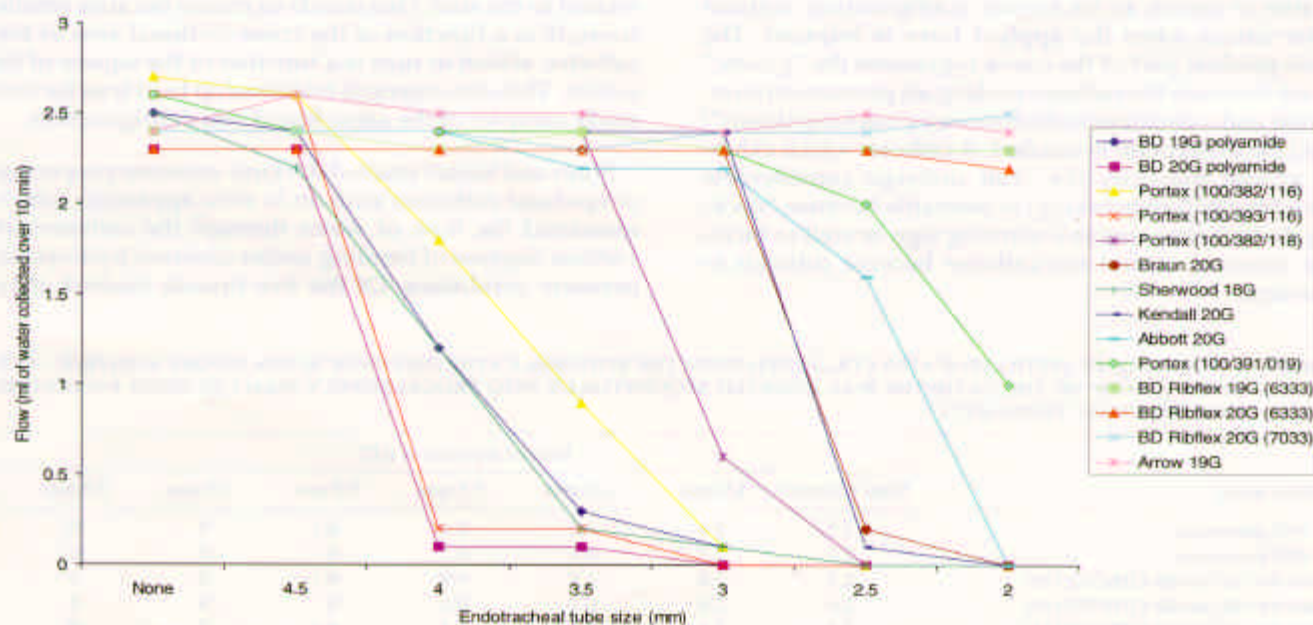


Fig. 5. Kink-resistant characteristics of epidural catheters.

found that the Arrow FlexTip Plus catheter was the most kink-resistant. Their methodology was in contrast to our constant flow technique which simulates the drug delivery process of a continuous epidural infusion. We set the syringe pump delivery rate at 15 ml/h because it represents the conventionally adopted maximum rate of epidural drug infusion in the labouring parturient.

Another reason was that we wanted to collect a reasonable quantity of fluid that would magnify the differences among the catheters during the sequential bending tests. Although the weighing scale used was not very sensitive in that mass differentials of only 0.1g could be measured, the results obtained revealed that this relatively lack of sensitivity did not hinder differentiation of the kink-resistance properties of the various catheters studied. Slight discrepancies in mass values were also evident despite recalibration of the weighing scale before each new determination. This could be due to the differing amounts of water contained within each catheter after pre-flushing, as well as the elapsed time between stopping the stopwatch and switching off the syringe pump. The authors acknowledge that testing more samples of a particular brand of catheter would be more rigorous; however, this option was logistically and economically prohibitive as most of the brands were not available in our local hospitals. Since some of these catheters were very limited in number, we chose to encompass a broader scope by incorporating the newer and more innovatively designed catheters, rather than be limited to only a few brands, as has been the case in previous studies.

Shiau et al¹⁴ offered various strategies to minimise or prevent catheter kinking. Becton-Dickinson has introduced the Ribflex catheter that is reinforced by internal longitudinal ribs running throughout its length.¹⁵ The underlying concept is that the gear-shaped catheter (in transverse section) may prove more resistant to flow obstruction, even at the extremes of flexion. Compared to the older 6333 model, the newer Ribflex 7033 model has a slightly enlarged outer diameter and a thinner wall, ostensibly to achieve better flow characteristics. The Arrow FlexTip Plus catheter has a wire coil-reinforced design engineered to resist kinking and collapsing, thereby maintaining patency. Our results showed that these "reinforced" catheters indeed had better kink-resistant properties. Future studies should address *in vivo* catheter characteristics such as ease of insertion, maintenance and removal, incidence of paresthesiae and vascular cannulation, as well as testing under body temperature conditions.

Conclusion

The authors have shown in this *in vitro* investigation of epidural catheters that larger-sized catheters of the same brand and configuration had higher tensile strengths and "reinforced" catheters are more kink-resistant. Because of the serious nature of sequelae secondary to breakage and kinking, epidural catheters which are both breakage and kink-resistant should prove advantageous in the clinical setting.

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