Anesthesiology
59:549–553, 1983

Mechanical Aspects of Epidural Catheter Insertion—Prevention of Catheter Buckling by Means of a Needle Hub Insert

Alfred C. Pinchak, Ph.D., P.E., M.D.,* Halina M. Podlipsky, M.D.,† Joan F. Hagen, B. A.‡

Six commercially available epidural catheters were tested in a special apparatus designed to simulate epidural catheter insertion and quantitatively measure the buckling strength of these catheters. The experimental apparatus utilized a modified Tuohy needle and a specially calibrated force transducer. Catheters were inserted through the Tuohy needle in a manner similar to that employed clinically, and the maximum forces developed against the surface of the force transducer were recorded electronically. In addition, a custom-designed "needle hub insert" was tested for its ability to prevent catheter buckling during insertion of an epidural catheter through a Tuohy needle. Catheter buckling forces were measured with new catheters and also with catheters that had been damaged by previous insertion attempts. Both the new and damaged catheters were tested with and without the presence of a needle hub insert. Each combination of experimental conditions was replicated four times. The results showed a marked difference in the effective buckling strength of the catheters tested. Buckling strengths ranged from a minimum of 201 ± 21 g (SD) to 418 ± 15 g of force. The largest forces were obtained with a Deseret type catheter that had an internal plastic stylet. When comparing only new catheters without stylets, the buckling forces ranged from 201 to 285 g. All catheters, whether new or damaged showed an increase in the maximum buckling force with the use of the needle hub insert. The percentage increase in force (needle hub insert *vs.* no insert) ranged from a low of 23% to a maximum of 108%. Statistical comparisons between the individual experimental conditions demonstrated that a very soft catheter can produce a larger buckling force than a stiff catheter when the former is utilized with the needle hub insert and the latter is unassisted. Increases in the buckling forces, produced by use of the hub insert, did not correspond to those theoretically predicted by the simple Euler theory of column buckling. The use of a needle hub insert during epidural catheter placement is desirable in that it provides extra strength for the catheter in the region where it commonly fails while simultaneously leaving the distal tip of the catheter unchanged in strength. In general, less rigid catheters demonstrate a larger percentage increase in buckling force when the needle hub insert is utilized. (Key words: Anesthetic techniques: epidural. Equipment: needles, catheters, epidural.)

IN MANY APPLICATIONS the occurrence of catheter buckling or kinking often prevents the successful insertion of a catheter through a needle into a desired location such as a vessel lumen or the epidural space. In most cases where resistance is encountered, the catheter buckles inside the hub of the needle because there is no support for the catheter in this region. Catheter stiffness or buckling resistance determines the maximum force that may be developed by an epidural catheter during its insertion through a Tuohy needle. A stiffer catheter usually is easier to thread into the epidural space. However, as stiffness increases the probability of dural and/or blood vessel puncture also increases.

A review of the literature revealed a number of references related to catheter buckling but no measurements of buckling strength, *per se*, were reported. Verniquet investigated the incidence of blood vessel puncture with epidural catheters.[1] In comparing his results with those of Bromage,[2] Verniquet speculated that "the different rigidities of the catheters and the different shapes of the tips may account for some difference in the incidence of vessel puncture." However, Verniquet presented no evidence for the suspected difference in "rigidity" between his catheters and those of Bromage.

Ravindran, Albrecht and McKay[3] discussed the delayed, intravascular migration of epidural catheters, while Kim and Mazza[4] reported subarachnoid migration of an epidural catheter. Neither of the above groups presented data concerning the effect of catheter stiffness on migration tendency. Intuitively one would anticipate an increased incidence of migration as stiffness increased. Other epidural catheter complications also are related to stiffness or buckling resistance. The tendency to form a knot in the catheter[5,6] is dependent upon the catheter "curling back" upon itself in the epidural space.

Because we could find no prior measurements of catheter buckling in our review of the literature, we devised a series of experiments to evaluate the stiffness of several epidural catheters in current, clinical use. The experiments were designed to closely simulate the actual clinical insertion of catheters through a Tuohy needle. Data presented here will assist the clinician in evaluating the tradeoff between ease of catheter insertion and decreased risk of tissue injury.

Catheter support inside the hub of a needle may be provided by an internal stylet or by utilization of an annular insert within the hub. External support is thus provided in this critical hub region and higher insertion forces may be developed during catheter placement. A literature

* Assistant Professor of Anesthesiology, Departments of Anesthesiology and Mechanical-Aerospace Engineering.

† Research Fellow, Department of Anesthesiology.

‡ Research Associate, Department of Anesthesiology.

Received from the Departments of Anesthesiology and Mechanical–Aerospace Engineering, Case Western Reserve University, Cuyahoga County Hospitals, Cleveland, Ohio 44109. Accepted for publication June 22, 1983. Supported by funds from the Department of Anesthesiology, Cuyahoga County Hospitals, Lee S. Shepard, M.D., Director.

Address reprint requests to Dr. Pinchak: Department of Anesthesiology, Cleveland Metropolitan General Hospital, 3395 Scranton Road, Cleveland, Ohio 44109.

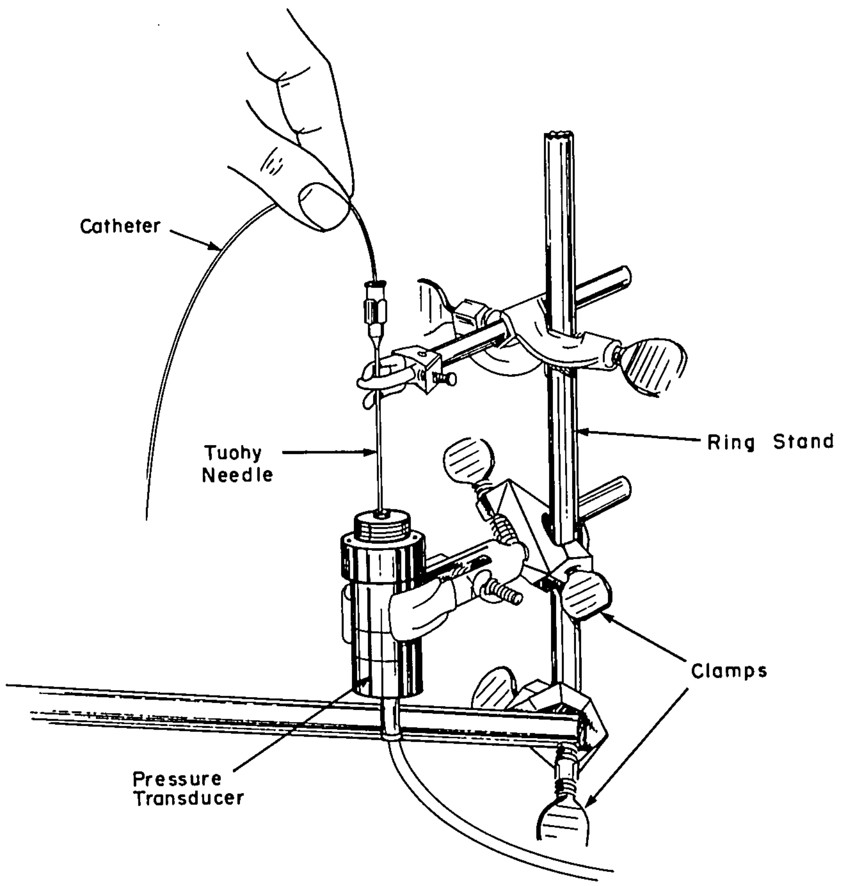

FIG. 1. Sketch of experimental apparatus for measurement of catheter buckling force.

review found no previous references to this concept.§ Consequently, this work constitutes a fundamental investigation of hub inserts and their effect on catheter buckling. Although only epidural catheters were tested, the general results concerning a hub insert may be applied to *any* catheter-through-needle system.

Methods

When testing the catheters, we wished to simulate, as closely as possible, the clinical conditions that occur during catheter insertion. Thus, the maximum forces were developed by an anesthetist's hand forcing the catheter through the Tuohy needle.

The curved tip of a conventional, 17-gauge, Tuohy (epidural) needle was cut off squarely and all burrs smoothed. An epidural catheter was passed, in the usual manner, through the needle. As the catheter exited the needle it impinged perpendicularly against the face of a conventional pressure transducer (Statham Model P23-AC). Vertical position and alignment of both the needle and transducer were maintained fixed during the experiments by means of a special jig with appropriate clamps (fig. 1). Instantaneous values of the forces exerted by the catheter were displayed on an oscilloscope (Datascope 861 with Type 2 Pressure Module) and recorded with a Gould 220 Recorder.

Calibration of the pressure transducer as a force measuring device was achieved by placing 50-, 100-, 200-, 300-, 400-, and 500-g weights on the head of a modified stylet that passed through the Tuohy needle. Calibrations were carried out periodically during the course of the experiments. Linearity of the transducer system was good. A linear regression line through the cumulative calibration data gave a slope of 0.1002 chart divisions/g, a zero force intercept of −0.186 chart divisions and an r^2 value of 0.9997. The *maximum deviation* for *all* calibration data points from the ideal straight line was only 10 g over the 100 to 500 g range.

Six different catheters were tested. They were manufactured by Deseret®, Pharmaseal®, Portex®, and Trav-

§ After completion of our experiments, we learned of a patent granted for a needle hub insert, U. S. Patent No. 4,349,023 by James R. Gross assigned to Abbott Laboratories. However, no experimental data were presented concerning the performance of the needle hub insert.

¶ Use of manufacturers' trade names is for identification purposes only. Such use does not constitute approval or endorsement of these products by the authors or the ASA.

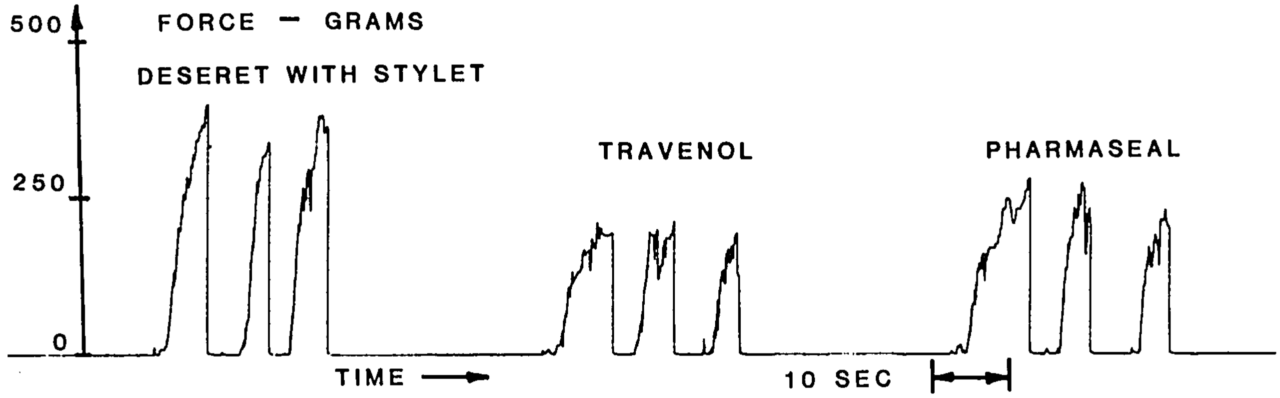

FIG. 2. Recording of forces developed during buckling experiment.

enol®.¶ Because the Deseret catheter is supplied with a full-length plastic stylet, we tested this catheter both with and without the stylet. Two different Portex catheters were included in this study. Portex "A" catheter is model type 380040 with an opaque wall, a closed end, three side holes, and a fixed syringe connector on one end. Portex "B" is a transparent, nylon catheter with an end hole and no side ports. For each given catheter three attempts were made to produce a maximum force. The largest magnitude of the three attempts was recorded for data analysis. An example of the recorded force data is seen in figure 2. In most cases, the occurrence of buckling limited the maximum force that could be developed. Occasionally finger slippage along the catheter was the limiting factor. When true buckling occurred, an irreversible deformity or "kink" would develop in the catheter. Subsequent attempts, with the "kink" in place, invariably resulted in reduced, maximum forces.

Four new sections of each catheter type were tested as described above. Thus, four values of the maximum force (for each catheter) were entered into the data analysis. The order of catheter test was randomized and all tests were conducted by only one of us (J.H.). (Earlier tests had demonstrated a small but significant difference in the average buckling forces achieved by each of us.)

In addition to the standard buckling tests, these experiments also measured the buckling force associated with the presence of a hub insert within the hub of a Tuohy needle. The hub insert was fabricated from stainless steel tubing that was identical to that which formed the shaft of the Tuohy needle. This hub insert was designed and positioned so as to provide complete, external support of the catheter from the entrance of the needle shaft, through the needle hub, to the fingertips of the anesthetist gripping the catheter. A sketch of the insert may be seen in figure 3. An epoxy material fills the annular region between the needle shaft portion of the hub insert and wall of the needle hub. This insures concentric alignment of the bore of the Tuohy needle and the tubing of the needle hub insert. Our earlier research tested five different types of custom-designed inserts.** Because no significant differences were found between the various inserts, only one of the five inserts was utilized in this series of tests.

Six different epidural catheters were tested with a simulated clinical protocol. Each new catheter was inserted through the Tuohy needle and three attempts were made to achieve a maximum force without a hub insert in position. (The largest force produced in the three attempts was the quantity *recorded* for data analysis.) The occurrence of buckling within the needle hub usually limited the maximum force that could be developed. A needle hub insert then was slipped over the proximal end of this "used" catheter and seated into the needle hub. Three more attempts then were made to develop a maximum force. A new catheter then was taken and tested with the hub insert in place. A fourth simulation of clinical conditions also was tested. New catheters were tested three times without a needle hub insert (these data were *not* included in the analysis). This produced a new series of catheters designated as "used" or "damaged." The "used" catheters then were tested again *without* a needle hub insert in place. Thus, the four clinically simulated conditions were new catheter with no hub insert, "used" catheter with no hub insert, new catheter with hub insert, and "used" catheter with hub insert. The order of catheter selection, for each of the above tests, was randomized. Each test combination was replicated four times for each catheter type.

The resulting data were analyzed with a three-way analysis of variance (ANOVA) using a Hewlett-Packard 9815A programmable calculator. This program also pro-

** Pinchak AC, Podlipsky HM: Prevention of Catheter Buckling by Means of a Needle Hub Insert. December, 1981, 7 pps, 6 illustrations, unpublished manuscript.

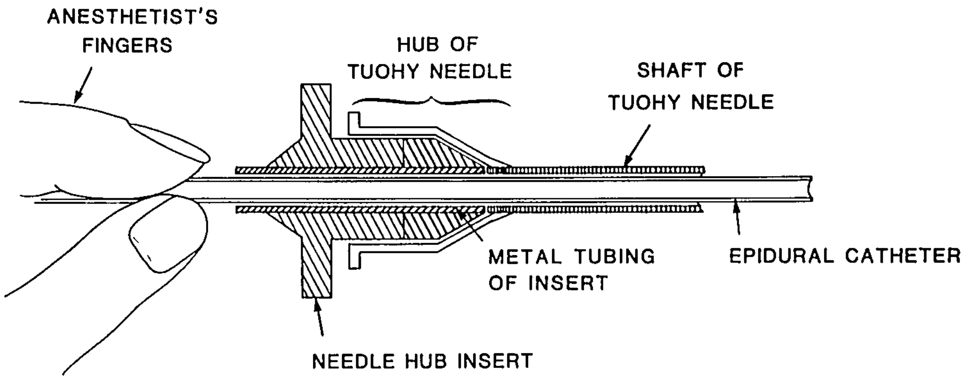

FIG. 3. Sketch of typical Needle Hub Insert providing external support for epidural catheter.

vides contrasts for combinations of the factor means. A P value of less than 0.05 was considered significant. Contrasts between the means of the individual cells in the ANOVA array were evaluated by means of the Studentized range test as described by Dixon and Massey.[7]

Results and Discussion

New Catheter Tests

Mean catheter buckling forces along with the associated standard deviations (SD) are shown in table 1. The effect of an internal stylet (Deseret catheter) is impressive, and the total range of the average forces for all catheters (201 to 418 g) is also notable. Forming contrasts between the means (taken in pairs) shows that not all of the catheters are distinctly different from each other in terms of their maximum buckling forces. The Deseret catheter with stylet differs from all the other catheters which form a nonhomogeneous group.

It is important to note that optimum resistance to buckling is a subjective consideration for anesthesiologists. On our clinical staff we have proponents for both the stiffest and softest catheters. Each anesthesiologist must make his own decision concerning the trade-off between ease of catheter insertion, tendency of knot formation, and the potential for tissue injury (*e.g.*, dural puncture). In most clinical cases if some resistance to catheter insertion is encountered, the catheter will buckle within the hub of the Tuohy needle. A stiffer catheter will have less of a tendency to buckle within the hub. An alternate approach would be to use a soft catheter with a central stylet or to utilize a Needle Hub Insert to externally support the catheter within the hub.

Hub Insert Tests

Table 1 also shows the mean forces and the associated standard deviation for all hub insert tests. A three-way analysis of variance formed the basis for a statistical evaluation of the results. Contrasts between the columns and rows of table 1 indicate that the hub insert effectively does increase the maximum catheter force and that the catheters still differ in effective stiffness even with the hub insert in place. Individual entries in table 1 may be compared with each other by means of the Studentized range or q statistic. In addition, row and column means also may be compared simultaneously without affecting the α probability level.†† As shown in the NAPS deposition, the critical value of the range is 68 g. Individual cell means that differ from each other by more than this value are considered different at the $P = 0.05$ level.

Inspection of table 2 reveals that various catheters show a larger increase in buckling force when used with the needle hub insert. For example, the Travenol catheter shows a 52% increase in force (new catheter + insert *vs.* new catheter alone). In contrast, the Deseret catheter with stylet shows only a 23% increase for the same comparison. The largest increase in force is found with the Portex B catheter, which showed a 108% increase when the "damaged" catheter was tested with an insert.

From comparisons (contrasts) between the cell means of table 1, it is seen that a "softer" catheter (Travenol) when used with the insert (306 g) becomes stronger (for buckling purposes) than a stiffer catheter (Deseret without stylet, 285 g). Now a "softer" catheter still retains its decreased probability of dural puncture as it is inserted. Buckling at the catheter tip where it impacts on tissue is unchanged by the presence of the hub insert. It is only

†† See NAPS Document No. 04128 for 15 pages of supplementary material from ASIS/NAPS, Microfiche Publications, P. O. Box 3513, Grand Central Station, New York, New York 10163. Remit in advance $4.00 for microfiche copy or for photocopy, $7.75 up to 20 pages plus $.30 for each additional page. All orders must be prepaid. Institutions and organizations may order by purchase order. However, there is a billing and handling charge for this service of $15. Foreign orders add $4.50 for postage and handling for the first 20 pages and $1.00 for every additional 10 pages of material. $1.50 for postage of any microfiche orders.

TABLE 1. Mean Values of the Experimental Buckling Forces (grams)

Catheters	Deseret (with stylet)	Deseret (without stylet)	Pharmaseal	Portex B	Portex A	Travenol	Row Mean ± SD
New catheter no insert	418* ± 15	285 ± 40	232 ± 16	216 ± 17	216 ± 38	201 ± 21	261 ± 82
New catheter with insert	514 ± 46	384 ± 12	382 ± 24	379 ± 21	390 ± 36	306 ± 24	393 ± 67
Damaged catheter no insert	323 ± 25	220 ± 18	182 ± 18	182 ± 11	178 ± 22	145 ± 7	205 ± 63
Damaged catheter with insert	444 ± 45	362 ± 38	375 ± 11	379 ± 30	362 ± 22	293 ± 25	369 ± 48
Column mean ± SD	425 ± 79	313 ± 75	293 ± 101	289 ± 104	287 ± 105	236 ± 77	

* Cell mean ± SD. Observations/cell = 4 for all cells.

TABLE 2. Increase in Buckling Forces Due to Use of Hub Insert with New and Damaged Catheters (Mean Force Ratio/Per cent Increase)

Catheters	Deseret (with stylet)	Deseret (without stylet)	Pharmaseal	Portex B	Portex A	Travenol
New catheter (insert/no insert)	1.23 (23%)	1.35 (35%)	1.65 (65%)	1.75 (75%)	1.81 (81%)	1.52 (52%)
Damaged catheter (insert/no insert)	1.37 (37%)	1.65 (65%)	2.06 (106%)	2.08 (108%)	2.03 (103%)	2.02 (102%)

buckling in the hub region that is avoided. This situation is equivalent to a catheter with an internal stylet that constantly is withdrawn, as the catheter is inserted, so as to keep the stylet from passing beyond the tip of the Tuohy needle. We contend that the use of a hub insert is more convenient than the aforementioned procedure with intermittent stylet withdrawal. The hub insert should find applicability in many other areas related to catheter insertion such as neurosurgery, where extremely soft catheters are used. These soft catheters often are inserted with the assistance of forceps so as to grasp the catheter within the hub region and thus decrease the length of catheter, which is unsupported.

Conclusions

1) The average buckling force for the catheters tested here ranged from a low of 201 g (Travenol) to a high of 418 g (Deseret with stylet).

2) Catheters fall into several groups on the basis of their maximum buckling forces. Deseret with stylet (the stiffest catheter) differed from all others. Deseret catheter without stylet was similar to Pharmaseal but differed from Portex A, Portex B, and Travenol. Although the Travenol catheter was the softest of all tested, it could not be considered different from Portex A, Portex B, or Pharmaseal.

3) Use of a needle hub insert can increase the maximum buckling force for a given catheter by 25 to 100%.

4) With the aid of a needle hub insert, a less rigid catheter can become more resistant to buckling within the needle hub than a stiffer catheter used without the hub insert.

5) The hub insert only affects buckling without the needle hub and does not alter the buckling properties of the catheter at its distal tip, where it interacts with tissues in the epidural space.

6) Less rigid catheters demonstrate larger percentage increases in buckling force when a needle hub insert is utilized.

Donald Hancock, A.E., assisted with instrumentation problems for this article. Frances Hall processed the manuscript and assisted with preparation of the figures.

References

1. Verniquet AJW: Vessel puncture with epidural catheters. Anaesthesia 35:660–662, 1980
2. Bromage PR: Epidural Analgesia. Philadelphia, WB Saunders, 1978
3. Ravindran R, Albrecht W, McKay M: Apparent intravascular migration of epidural catheter. Anesth Analg 58:252–253, 1979
4. Kim YI, Mazza NM: Massive spinal block with hemicranial palsy after a test dose for extradural analgesia. ANESTHESIOLOGY 43:370–372, 1975
5. Browne RA, Politi VL: Knotting of an epidural catheter: A case report. Can Anaesth Soc J 26:142–144, 1979
6. Blass N, Roberts R, Wiley J: The case of the errant epidural catheter. ANESTHESIOLOGY 54:419–421, 1981
7. Dixon JW, Massey FJ: Introduction to Statistical Analysis. New York, McGraw-Hill, 1957, p 170