Evaluation of different methods of securing intravenous catheters: measurement of forces during simulated accidental pullout

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The purpose of the study was to compare the relative effectiveness of several combinations of tapes and taping methods with respect to the force required to pull out intravenous catheters. A simulated forearm model consisting of a section of firm PVC pipe was used for the first and second series of experiments. In the third experiment, one method of taping catheters was compared in the PVC model and in volunteers. Pull-out forces were measured with a force transducer and recorded on paper. In the first experiment, catheters secured with Curity tape resisted pullout to a greater extent than those with Transpore tape and provided approximately twice the force advantage ($P < 0.05$). In the second experiment using Curity tape, minimum forces to dislodge the catheters were (means $\pm$ SD) 53 ± 13 , 82 ± 13 , 113 ± 29 , 124 ± 24 , 176 ± 29 and 141 ± 46 N, for methods 1–6, respectively. In the third series, the minimum pullout forces were higher for Curity than with Transpore tape for both the human and simulated PVC forearm surfaces (63 ± 11 and 55 ± 12 N vs 52 ± 7 and 44 ± 12 N, $P < 0.01$), and the pullout forces were higher for the simulated vs the human skin surface for both tape types ($P <$

0.01). Compared with Curity tape, Transpore tape was more likely to fail by tape fracture in both the simulated and human skin surfaces ($P < 0.05$). The data suggest that there are important differences in pullout forces and mechanisms of dislodgement depending on taping method and tape type. Curity tape, using method 5 or 6, was superior to Transpore tape and the other taping methods in resisting pullout.

Cette étude vise à comparer l'efficacité relative de différentes combinaisons de ruban adhésif et méthodes de fixation par rapport à la force requise pour extraire une canule intraveineuse. Un modèle factice d'avant-bras composé d'une section de tube en CPV est utilisé pour la première et la deuxième série d'expériences. Pour la troisième série, la comparaison de la méthode de fixation de la canule se fait entre le modèle en CPV et des volontaires. La force nécessaire pour l'extraction est mesurée avec une jauge de contrainte et enregistrée sur papier. Au cours de la première expérience, les canules fixées avec du ruban Curity résistent environ deux fois mieux à l'extraction que celles qui sont fixées avec le ruban Transpore ($P < 0,05$). Au cours de la deuxième expérience avec le ruban Curity appliqué à la surface du membre factice, les forces minimales requises pour déplacer la canule sont respectivement de (moyenne $\pm$ SD) 53 ± 13 , 82 ± 13 , 113 ± 29 , 124 ± 24 , 176 ± 29 et de 141 ± 46 N avec les méthodes 1 à 6. Dans la troisième série, les forces minimales d'extraction sont plus élevées pour le ruban Curity que pour le Transpore tant sur la peau humaine que sur le membre factice (63 ± 11 et 55 ± 12 N vs 52 ± 7 et 44 ± 12 N, $P < 0,01$); avec les deux rubans, la force d'extraction est plus élevée sur le bras factice que sur la peau humaine ($P < 0,01$). Comparativement au ruban Curity, le ruban Transpore est plus susceptible de se briser tant sur le bras factice que sur la peau humaine ($P < 0,05$). Ces données suggèrent que les méthodes de fixation et les types de ruban adhésif sont des facteurs déterminants sur les forces d'extraction et les mécanismes de déplacements des canules. Avec les méthodes 5 et 6, le ruban Curity résiste mieux à l'extraction que le ruban Transpore et que les autres méthodes.

Key words

EQUIPMENT: catheters, intravenous.

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Secure intravascular access is essential in the perioperative management of anaesthetized patients. Loss of vascular access due to dislodgements of an inadequately secured catheter, or to sudden pulling forces as may occur during patient positioning or transport can be devastating. The optimal method of securing *iv* catheters to prevent or minimize the risk of dislodgement has not been determined. No standard taping method exists, and anaesthesia residents are often required to satisfy each individual staff anaesthetist in terms of peculiarities of tape brands and taping techniques. A variety of tape brands manufactured by several companies are available for intraoperative use. Although these brands may have been manufacturer-tested for tensile strength, adhesion to steel, and elongation at break, little or no work has been done on the forces required to dislodge *iv* catheters secured with these brands using current taping techniques. At our institution, many individuals prefer Transpore tape instead of Curity tape for short-term perioperative use because of ease of handling, reduced patient skin sensitivity and lack of residual adhesive marks. However, these purported advantages of Transpore tape over Curity tape have not been established, and it is the authors' clinical impression that securing *iv* and arterial catheters (as well as endotracheal tubes) to skin using Transpore tape is unsatisfactory because of a high incidence of tape splitting and fracture as well as separation of tape from skin, despite the use of extra reinforcing strips. The purpose of the study was to evaluate the relative effect of different tape types and conventional taping methods on the force required to pull out intravenous cannulae in a simulated forearm model that would withstand repeat testing. Additional tests evaluated the validity of the simulated forearm model by reproducing the results of a single taping method in two human volunteers.

Methods

The study was approved by the Institutional Review Board and consent for the third series of experiments was obtained from the volunteers. The forearm model consisted of a section of hard PVC pipe (8.8 cm outer diameter, 3 mm thick) in place of a patient's arm. A 2-mm hole was drilled through the hollow PVC pipe at an angle of 20°. The angle was chosen to simulate the orientation of an *iv* catheter inserted percutaneously. The *iv* catheter (14 gauge two-inch catheter without the needle, Becton Dickinson Vascular Access, Sandy, UT) was inserted into the hole in the PVC pipe up to its hub and a Luer lock extension tubing was attached to the catheter. The catheter and extension tubing (Baxter Interlink System, 2C6519S) was then taped to the PVC pipe in a manner similar to that utilized to secure *iv* catheters with patients in the operating room. A piezo-

FIGURE 1 Experimental procedure. A constant pullout force was applied in the longitudinal direction until the catheter was pulled out of the simulated forearm, or until there was dislodgement of the catheter-hub tubing connection due to tape fracture or disconnection.

FIGURE 2 Taping method 1. Single chevron using 1.25 × 10 cm Curity adhesive tape.

electric force transducer (0–225 N range) was utilized to measure the pullout forces which were recorded on a two-channel strip chart recorder. The force transducer was calibrated prior to each experiment. The experimental procedure is shown in Figure 1. The pullout forces were generated by hand so as to simulate the clinical situation in which an *iv* catheter is pulled out accidentally with a large force of short duration. The mechanism of dislodgement (tape fracture, hub disconnection, catheter disconnection with and without intact tape) was recorded for each pullout test.

In the first series of 48 pullout tests, two individuals (CES, ACP) tested two tape types commonly used at our institution – opaque adhesive tape (Curity standard porous tape, Kendall Healthcare Products Co., Mansfield, MA) and plastic translucent tape (Transpore surgical tape, 3M Health Care, St Paul, MN). Four taping methods were tested: Method 1. Single 1.25 by 10 cm wide piece of tape inserted under the catheter hub sticky side up, with each side folded across the hub and taped to opposite sides (single chevron, Figure 2); Method 2. Double 1.25 by 10 cm chevron (Figure 3); Method 3. As in method two plus a third piece of 2.5 × 10 cm tape at a right angle to the catheter axis covering the catheter hub but not the *iv* tubing connection (Figure 4); Method 4. As in method three, plus a 2.5 × 10 cm tape over the catheter hub and connector, parallel to the catheter axis, with a fifth piece of 2.5 × 10 cm tape over the

FIGURE 3 Taping method 2. Double chevron using 1.25×10 cm Curity adhesive tape.

FIGURE 4 Taping method 3. Reinforcement of double chevron with 2.5×10 cm Curity adhesive tape.

catheter hub perpendicular to the catheter axis. Although methods 1 and 2 are rarely used clinically, they were included to determine the relative contribution of each piece of tape to the overall force required to pull out the iv with methods 3 and 4.

In the second series of experiments, two popular taping methods in the operating room and surgical intensive care unit (methods 5 and 6) were evaluated by two individuals (NP, DEH) in addition to the first three described in the first series. Method 4a was a modification of method 4 from the first series, and consisted of reinforcing a double chevron with 2 strips of 2.5×10 -cm tape at right angles to each other, covering the catheter hub, but not the iv tubing connection (Figure 5). Method 5 was as in method two, plus two strips of 2.5×10 cm tapes at right angles to the catheter covering the hub-tubing connection (Figure 6). Method 6 had a single 2.5×10

FIGURE 5 Taping method 4a. Reinforcement of double chevron with 2 strips of 2.5×10 cm Curity adhesive tape at right angles to each other, covering the catheter hub but not the iv tubing connection.

FIGURE 6 Taping method 5, anaesthetist-preferred. Reinforcement of double chevron with two strips of Curity adhesive tape across the catheter hub-iv tubing connection increased the force required to dislodge the catheter.

cm tape divided up to $\frac{3}{4}$ length, with the undivided portion inserted under the hub-tubing connection sticky side up, while the divided two portions acted as chevrons, plus two 2.5×10 cm tapes at right angles to the catheter covering the hub-tubing connection (Figure 7). Only Curity tape was tested in the second series because data from the first series suggested that this was the strongest tape type. A randomized 2×6 factorial design was utilized, with each condition replicated six times (72 pull out tests). The surface area of the tape-PVC pipe contact was determined by placing the dislodged assembly onto 1 mm $\times$ 1 mm graph paper and counting the area covered by the tape.

In the third series of experiments, one method of taping

FIGURE 7 Taping method 6, SICU-preferred. Alternate single chevron technique using a divided 2.5×10 cm Curity adhesive tape and two 2.5×10 cm strips across the catheter hub-iv tubing connection.

iv catheters with Curity and Transpore tape was compared between the PVC pipe surface and the anterior surface of two human forearms (NP, DEH). The taping method consisted of a 2.5×10 cm piece of tape with its sticky surface facing the underside of the iv catheter hub with the tape folded upon itself, but not crossing the hub. Two pieces of 2.5×10 cm tape reinforced this arrangement (Figure 8). This taping method was chosen instead of the strongest methods from the second series of experiments in order to provide an intermediate force that could be tolerated and easily replicated during multiple pullouts in volunteers. A randomized $2 \times 2 \times 2$ factorial design was utilized, with each condition replicated ten times (80 pullout tests).

Data were analyzed using the general linear model procedure (GLM, SAS software) with the Tukey method for multiple comparisons. Mechanism of dislodgement data was analyzed by Chi Square and Fisher's Exact test. A P value < 0.05 was considered significant.

Results

In the first series of experiments (simulated PVC forearm model), for the dependent variable force, the GLM procedure was run with the independent variables taping method, tape type, taper, and their interactions, taper*method and taper*tape. The F values of these three independent variables and their interactions were 35, 126, 5.7, 1.9 and 0.33, respectively. The P values associated with these F values were 0.0001, 0.0001, 0.02, 0.15 and 0.57, respectively, implying effects of both taping method and tape type, a slight effect of taper, and no interaction between taper and method or between taper and tape. Compared with Transpore tape, catheters secured with

FIGURE 8 Taping method used in the third series of experiments to compare forces and mechanism of dislodgement for human volunteers and the simulated forearm model. Curity adhesive tape was used in this example.

TABLE I Minimum pullout force (mean $\pm$ SD) to dislodge iv catheters in the first series of tests comparing four taping methods and two tape types. The force ratio (Curity/Transpore) and incremental percent increase with additional Transpore and Curity tape is shown

Method	Force (N)		Force ratio	Incremental % increase	
	Transpore (n = 24)	Curity (n = 24)		Transpore	Curity
1	25.3 (4.5)	51.1 (12.9)	2.02	—	—
2	36.5 (9.8)	80.5 (25.3)*	2.21	44	57
3	38.7 (5.3)	82.6 (8.4)*	2.14	6	3
4	65.8 (11.6)	119 (20)*	1.80	70	44

* $P < 0.01$ vs Transpore tape.

Curity tape resisted pull out to a greater extent, and provided approximately twice the force advantage (Table I). The incremental percent increase in dislodgement force of one method over another was calculated as follows: $(F_{i+1} - F_i) / F_i \times 100$, where F = force, and i represents the various taping methods. Adding a second chevron gave a 44 to 57% increase in pullout force for both tapes ($\{F_2 - F_1\} / F_1 \times 100$), whereas adding a third piece of tape crosswise only added a 3–6% increase ($\{F_3 - F_2\} / F_2 \times 100$, Table I). During pullout, Transpore tape was more likely to fracture and break off from the catheter and from the simulated forearm, whereas Curity tape was more likely to stay firmly fixed to the simulated forearm such that either the catheter would be pulled out while the tape remained behind, or for the more secure taping methods, the catheter, tape and iv tubing would be pulled out together ($P < 0.01$, Table II).

TABLE II Mechanism of dislodgement (frequency of occurrence) in the first series of tests for all four taping methods

	Transpore Tape (n = 24)	Curity Tape (n = 24)
Tape remained but catheter pulled off	7	12*
Tape fractured	16	1*
Tape and catheter came off as a unit	0	6*
Tape and catheter remained, but iv tubing pulled out	1	5*

* $P < 0.05$ vs Transpore tape.

In the second series of tests using the simulated forearm model and the strongest tape type (Curity), method 5 resisted pullout to the greatest extent, followed by methods 6, 4, 3, 2 and 1 (Table III). In general, force required to dislodge the taped catheter was greater when the surface area of contact between the tape and the simulated forearm was increased (Figure 9). However, this relationship was more influenced by taping method than by surface area. For example, method 4a, which consisted of applying strips of tape at right angles to each other (one along the catheter axis and one across the axis) was much less secure than method 5, which had two strips of tape applied across the catheter axis, despite the almost identical taped surface area between these two methods (Figure 9, Table III). The mechanism of dislodgement (tape remained but catheter pulled off and tape and catheter came off as a unit) was independent of taping method ($P > 0.2$, Table III), although the iv tubing was very unlikely to become disconnected from the catheter hub connection with methods 5 and 6 (tape and catheter remained but tubing pulled out, $P = 0.02$ vs other four methods, Table III).

The data in the third series of experiments were analyzed using the GLM procedure, for the dependent variable, force. The independent variables were tape type, taped surface (skin or PVC), and type*surface. The F values for these two independent variables and their interaction were 22, 33 and 0.49, respectively. The P values associated with these F values were 0.0001, 0.0001, and 0.5, respectively, implying effects of both tape type and taped surface. In this third series, Curity tape resisted pull out to a greater degree with less tape fracture compared with Transpore tape (Tables IV and V), as was the case in the first series of tests. Compared with human skin, both Curity and Transpore tape resisted pullout to a greater extent in the simulated PVC model (Table IV). As well, Curity tape was more likely to remain on the volunteer's skin, whereas both the tape and catheter were more likely to be pulled out together in the simulated PVC model ($P = 0.02$, Table V).

TABLE III Results of the second series of tests comparing six taping methods using Curity tape. Data are means ($\pm$ SD) for pullout force

Method	Pullout force (N)	Surface area (cm ²)	Mechanism of dislodgement* (frequency)	
1	52.9 (11.5)	0.98	a - 2	c - 7
			b - 0	d - 3
2	81.8 (13.3)	1.38	a - 2	c - 8
			b - 0	d - 2
3	112.5 (28.9)§	2.95	a - 2	c - 5
			b - 2	d - 3
4	124 (24)†	4.25	a - 2	c - 5
			b - 0	d - 5
5	175.6 (28.9)†	4.30	a - 1	c - 9
			b - 1	d - 1¶
6	141.3 (46)‡	5.45	a - 5	c - 6
			b - 1	d - 0¶

*Legend for mechanism of dislodgement - a - tape remained but catheter pulled off; b - tape fractured; c - tape and catheter came off as a unit; d - tape and catheter remained, but tubing pulled out.

† $P < 0.05$ vs all other methods.

‡ $P < 0.05$ vs methods 1 and 2.

§ $P < 0.05$ vs method 1.

¶ $P < 0.05$ vs methods 1-4.

FIGURE 9 Scattergram of pullout forces versus surface area in the second series of experiments evaluating six different taping methods using Curity tape. Z - method 1; Y - method 2; X - method 3; + - method 4; * - method 5; - - method 6.

TABLE IV Minimum pullout force (mean $\pm$ SD) to dislodge angiocatheters in the third series of tests

Surface	Force (N)	
	Transpore tape	Curity tape
Simulated PVC model	52 (7.1)†	63.1 (11.1)*†
Human	43.6 (12)	54.7 (11.6)*

* $P < 0.05$ vs Transpore plastic tape.

† $P < 0.05$ vs human.

TABLE V Mechanism of dislodgement (frequency of occurrence) in the third series of tests

	Transpore tape		Curity tape	
	Simulated model	Human forearm	Simulated model	Human† forearm
Tape remained but catheter pulled off*	0	1	0	6
Tape fractured*	14	9	0	0
Tape and catheter came off as a unit*	6	10	20	14

* $P < 0.05$ vs Transpore vs Curity tape.† $P < 0.05$ vs Simulated model (Curity tape).

Discussion

Intravenous cannulae and other dwelling devices necessary for patient care are often subjected to substantial degrees of tugging and pulling that may result in accidental dislodgement. Although the exact incidence and morbidity associated with accidental dislodgement of indwelling devices is unknown, Mirro *et al.* found that the most frequent cause of Hickman/Broviac catheter failure was accidental dislodgement (20 of 286, or 7% of central venous catheter placements).¹ Similarly, dislodgement of central venous catheters in critically ill neonates has been reported to occur in 53% of cases (17 catheter insertions in 13 neonates for a median duration of 32 days per cannula).² Dislodgement or displacement of other devices such as nasogastric tubes, feeding jejunostomies, urinary bladder catheters, arterial lines, epidural catheters and endotracheal tubes have all been reported to occur.^{3,4} Methods of preventing accidental dislodgement include suturing the device into place, subcutaneous tunnelling of the device underneath the skin, application of liquid adhesives to improve tape or bandage stickiness, and a wide assortment of bandages, tape and taping methods.⁵⁻⁹ That no one method is uniformly employed suggests that the optimal method of securing intravascular devices has not been determined.

The present study indicated that it is possible to measure the force required to dislodge *iv* catheters in a consistent and reproducible fashion using a force transducer. Different taping methods as well as different tape types may substantially alter the degree to which *iv* cannulae resist being pulled out. Increasing the surface area of the tape adhering to the catheter and forearm, especially at the catheter-hub connection appeared to provide additional resistive forces. The taping methods evaluated in the second series of experiments were chosen based on their utilization at our institution. Indeed, the two most popular methods of taping *iv* catheters at our institution (method 5 – anaesthetist preferred and method 6 – intensive care unit preferred) were also found to resist

pull out to the greatest extent. The taping method used in the third experiment was chosen for evaluation of the PVC model because the surface area of skin contact and pull out forces were smaller, making this method more tolerable for human volunteers. The simulated PVC forearm model was utilized in the present study because of its ability to provide a uniform surface that would withstand repeated testing with higher pullout forces. However, care must be taken when extrapolating results from smooth PVC pipe to patients. Human skin, with its uneven surface, skin oils, hair, and differing textures, is very different from the PVC model. Moreover, the pullout forces generated in the simulated PVC forearm model were greater than those generated in normal intact human forearm skin, although the effect of Transpore vs Curity tape was the same for both maximum force generated before pullout occurred and for mechanism of dislodgement (tape fracture vs other methods of tape failure). Thus, the forces generated using the simulated PVC model may be slightly higher than those encountered clinically, but the relative effects of tape type and taping method were similar.

Tapes are manufactured by several companies and of various materials. Most have been bench tested by the manufacturer for certain characteristics such as tensile strength at break and adhesion to steel. For Curity tape, manufacturer reported tensile strength at break was $23 \text{ kg} \cdot 2.5 \text{ cm}^{-1}$ ($225 \text{ N} \cdot 2.5 \text{ cm}^{-1}$), about ten times that of Transpore tape $2.5 \text{ kg} \cdot 2.5 \text{ cm}^{-1}$ ($25 \text{ N} \cdot 2.5 \text{ cm}^{-1}$). Based on the tensile strength at break, it could be expected that Curity would be unlikely to break at forces below 255 N, and that Transpore would begin to fracture at forces greater than 23 N. These expected observations were indeed documented in the present study. Other tapes that may be encountered in the operating room setting are Leukopor and Leukosilk (BDF Beiersdorf Inc, Norwalk, CT) and Hy-tape (Hy-tape Surgical Products Corp., New York, NY). Tensile strength of these tapes ($\text{N} \cdot 2.5 \text{ cm}^{-1}$) were reported by the manufacturers as fol-

lows: Leukopor – 45, Leukosilk – 99, Hy-tape – 52. Manufacture reported adhesion to steel for Leukopor, Leukosilk, and Curity tapes was between 500–550 g · 2.5 cm⁻¹ (and not available for Transpore tape). It would be anticipated that tapes with higher tensile breaking strength and higher adhesion to steel might resist pull out to a greater extent in the clinical setting. However, the present study showed that despite a nearly ten-fold difference in the tensile strength of Curity over Transpore, there was only a two-fold difference between these tapes in terms of minimum force to dislodge the catheters. Thus, extrapolation of manufacturer bench tests to the clinical setting could lead to incorrect conclusions.

Hand force was applied to pull the catheter out in the experiments. This type of force was chosen to simulate more closely the force versus time profile that might be encountered in clinical situations in which an *iv* catheter is accidentally pulled or tugged on in a jerky fashion, or if the patient intentionally or accidentally attempted to remove the catheter with a large force of short duration. Manual generation of pullout force was preferred over standard laboratory test machines because many machines are not capable of rapidly increasing the applied force so as to simulate a sudden jerk or tug, and spring-loaded testing devices would increase the pullout force too rapidly. The main disadvantage of manual force generation is larger variation in the measured forces. The increased variability can be overcome by increasing the number of replications of each experimental condition, as was done in the present study, and by demonstrating that there was little difference in pullout force regardless of who did the pulling and who did the taping. It should be noted that the study only evaluated forces generated along the longitudinal axis. This axis was chosen because it was our clinical impression that the majority of catheter pullouts occurred after sudden distal pulls along this axis (e.g., when transferring the patient to or from the operating room table and during patient transport). This type of pulling force may also be encountered during patient positioning (e.g., – supine to prone), and from backwards pulls where the *iv* tubing caught on something during patient transfer. Other factors that may be important in reducing the risk of accidental dislodgement include taping a portion of the *iv* tubing in a direction opposite to the catheter, avoiding extraneous loops that may be subjected to pulls, removing skin hair to insure a dry smooth skin surface, minimizing movement of the area in which the *iv* is secured (e.g., armboards, restraints) and vigilance, especially during patient positioning, transfer and transport.

In summary, securing *iv* catheters using Curity tape and method 5 or 6 resisted pullout to the greatest extent in this simulated patient forearm model, the most im-

portant determinant being separate adhesion of an adequate surface area of tape to the catheter hub-*iv* tubing connection. Overall, Curity tape was stronger than Transpore tape in preventing catheter dislodgement. There were differences in dislodgement force and mechanism of dislodgement of secured *iv* catheters between human and simulated PVC forearm surfaces, although the effect of taping material was similar between the two surfaces.

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References

- 1 Mirro J, Rao BN, Stokes DC, et al. A prospective study of Hickman/Broviac catheters and implantable ports in pediatric oncology patients. *J Clin Oncol* 1989; 7: 214–22.
- 2 Hruszkewycz V, Holtrop PC, Batton DG, Morden RS, Gibson P, Band JD. Complications associated with central venous catheters inserted in critically ill neonates. *Infect Control Hosp Epidemiol* 1991; 12: 544–8.
- 3 Blebea J, King TA. Intraperitoneal infusion as a complication of needle catheter feeding jejunostomy. *JPEN J Parenter Enteral Nutr* 1985; 9: 758–9.
- 4 Metheny NA, Spies M, Eisenberg P. Frequency of nasoenteral tube displacement and associated risk factors. *Res Nurs Health* 1986; 9: 241–7.
- 5 Mikhail GR, Selak L, Salo S. Reinforcement of surgical adhesive strips. *J Dermatol Surg Oncol* 1986; 12: 904–6.
- 6 Samelson SL, Robin AP, Merlotti GL, Lange DA, Barrett JA. A new method of rapid fluid resuscitation during thoracotomy performed in the emergency room. *Surg Gynecol Obstet* 1987; 165: 175–6.
- 7 Schulmeister L. Needle dislodgement from implanted venous access devices: inpatient and outpatient experiences. *Journal of Intravenous Nursing* 1989; 12: 90–2.
- 8 Graham DR, Kelderman MM, Klemm LW, Semenza NJ, Shafer ML. Infectious complications among patients receiving home intravenous therapy with peripheral, central, or peripherally placed central venous catheters. *Am J Med* 1991; 91(supp 3B): 95S–100S.
- 9 Patel N, Smith CE, Pinchak AC, Hancock DE. The influence of tape type and of skin preparation on the force required to dislodge angiocatheters. *Can J Anaesth* 1994; 41: 738–41.