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Comparison of Penetration Force and Catheter Tip Damage of Intravenous Catheters among Different Catheter Tip Designs

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Summary

Purpose: We compared the penetration force of eight brands of 18-gauge intravenous catheters using an original experimental device. Differences in penetration force were examined for 20 catheters for each brand.

Method: The inner needles of the intravenous catheters were inserted into a 0.08-mm polyethylene film at a 30- or 45-degree penetration angle by a push-pull gauge moved by a motor at 4.5 mm/sec. until the outer catheter penetrated the film. Each intravenous catheter consisted of an inner needle and an outer catheter. Inner needles were divided into two groups according to tip grinding method: Lancet or Backcut. Catheter tips were classified in two designs: acute- and obtuse-tapering. We studied the impact of these inner needle grinding methods and catheter tip designs on penetration forces, and catheter damage was observed under an electron microscope.

Result: At a 45-degree penetration angle, the penetration force of inner needles ranged from 25 to 45 grams, while the penetration force of catheters ranged from 35 to 58 grams, with no obvious influence of inner needle tip grinding method or catheter tip design on penetration force. At a 30-degree penetration angle, penetration force was lower in catheters with an obtuse-tapering design; the penetration force was significantly higher (120 g) in Surflo® catheters with acute-tapering design. All six Surflo® catheters had visible tip damage under the electron microscope. The seven other brands of catheters showed no tip damage regardless of inner needle grinding method.

Conclusion: In clinical practice, the insertion angle for peripheral venipuncture is 30 degrees or less. Our results show that catheters with an obtuse-tapering tip design were better than those with an acute-tapering tip design. If an intravenous catheter with an acute-tapering tip is inserted into a vein at an obtuse angle, the catheter tip will be damaged, resulting in insertion failures.

Key words: intravenous catheter, catheter structure, catheter damage, Lancet, Backcut

Introduction

When inserting an intravenous catheter into a peripheral vein, the handiness of a device depends on the physician's skill and experience and is thus difficult to evaluate. Several factors may influence the handiness of the device. These factors are needle shape, bevel size, level difference between the inner needle and the outer catheter, catheter tip shape, catheter structure, and catheter material. We compared the penetration force of eight brands of 18-gauge intravenous catheters using an original experimental device.

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Structure of intravenous catheters

Intravenous catheters consist of an inner needle and an outer catheter. The inner needle is divided into the needle tip, bevel, and needle tube. The picture on the left in Figure 1 shows the smooth bevel of an inner needle ground by the Lancet method. The picture on the right shows the bevel of an inner needle ground by the Backcut method. This bevel is smaller than that of the Lancet inner needle and the bevel tip is sharper, with two cutting edges behind the bevel. Intravenous catheters differ from brand to brand in the length between the bevel and tip of the outer catheter, the size and shape of the bevel, the level differences between the inner needle and the outer catheter, and catheter structure.

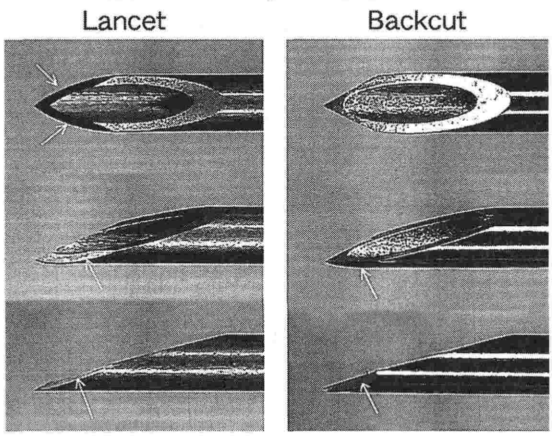


Fig. 1　Structure of intravenous catheter

Insertion site shapes of intravenous catheters

Insertion site shapes of intravenous catheters vary with inner needle tip grinding method. Lancet inner needles create oval insertion site shapes, whereas Backcut inner needles create V-shaped insertion site shapes (Fig. 2).

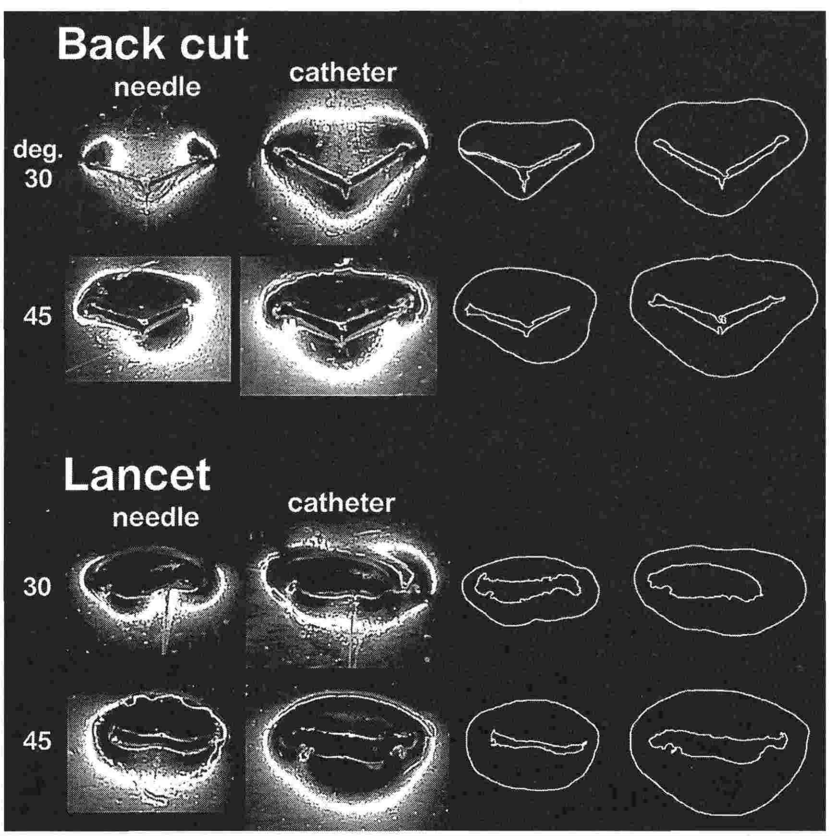


Fig. 2　Shape of Insertion Site

Materials and methods

Eight brands of 18-gauge intravenous catheters were used. They were divided into two groups according to inner needle tip grinding methods, either Lancet or Backcut. The Lancet group comprised Angiocath®, Insyte®, Surflo®, and Supercath®, while the Backcut group comprised Jelco®, Vitaflon Plus®, Introcan Certo®, and Vasculon®. Catheter tips were classified in two designs, acute- and obtuse-tapering designs. Only Surflo® had the acute-tapering design. The seven other brands had the obtuse-tapering design (Fig. 3). Twenty intravenous catheters were used for each brand after the integrity of each catheter was verified under the microscope.

Changes in penetration force were examined when a catheter was attached to the push-pull gauge and moved by a motor at 4.5 mm/sec, inserting the inner needle into a 0.08-mm polyethylene film at a 30- or 45- degree angle until its outer catheter penetrated the film (Fig. 4). The highest penetration force was determined for each inner needle and outer catheter. All measurements are presented as mean ± SD. Student's t-test was used for statistical analysis, and p values of less than 0.05 were considered to indicate statistical significance.

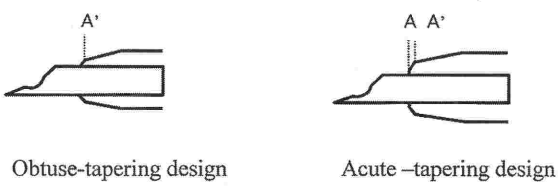


Fig. 3 Classification of catheter tip tapering designs

Results

(1) Penetration forces

1) Lancet group

Figure 5 presents the penetration force of an inner needle and an outer catheter of each intravenous catheter in the Lancet group. The black and gray bars indicate the highest penetration force of inner needles at 45- and 30-degree insertion angles, respectively. The striped and checkered bars indicate the highest penetration force of outer catheters at 45- and 30-degree penetration angles, respectively. The data with either a single or a double asterisk show a significant difference in the penetration force of inner needles and outer catheters at a 45-degree angle from that of a

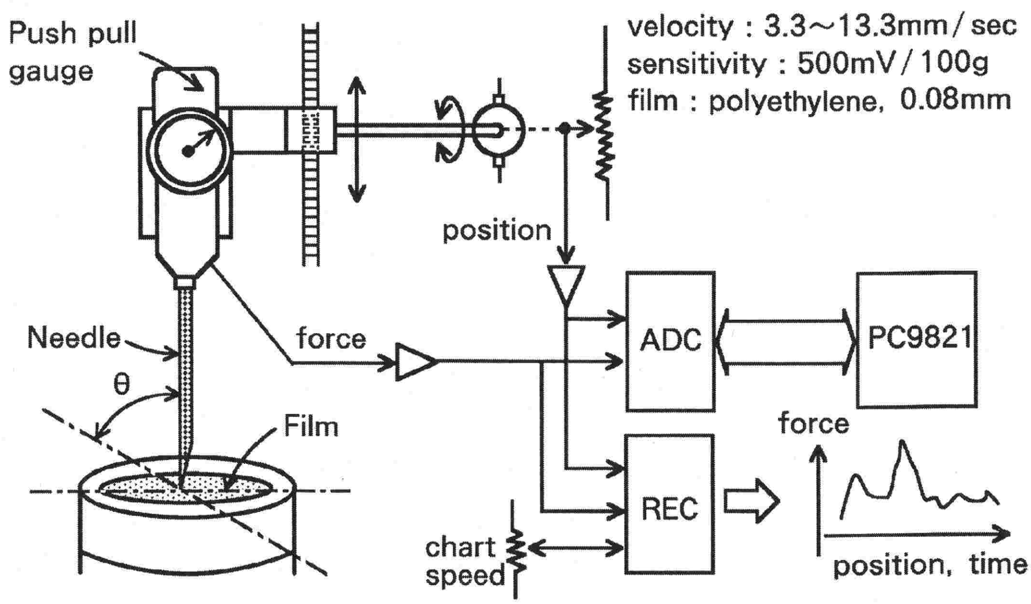


Fig. 4 Experimental device

30-degree angle, respectively ($p<0.05$). The lowest penetration force of an outer catheter was Surflo®, which was significantly higher at 30 degrees than at 45 degrees. No significant differences between the brands were found in outer catheter penetration forces at a 45-degree angle. At a 30-degree angle, the outer catheter penetration force was 2.5 to 3.0 times higher in Surflo® than for the other brands. For all the brands studied, the outer catheter penetration force was 1.1 to 2.5 times higher at a 30-degree penetration angle than at a 45-degree penetration angle.

2) Backcut group

Figure 6 shows the highest penetration force in inner needles and outer catheters for each intravenous catheter in the Backcut group (four brands). The inner needle penetration force was significantly higher at the 45-degree penetration angle than at the 30-degree penetration angle, whereas the outer catheter penetration force was 1.1 to 1.3 times lower at the 30-degree penetration angle than at the 45-degree penetration angle.

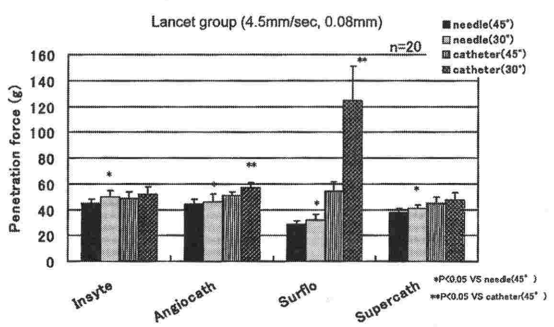


Fig. 5 Penetration force for the Lancet group

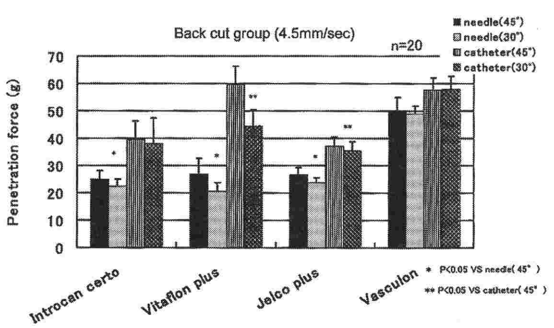


Fig. 6 Penetration force for the Backcut group

angle.

(2) Catheter tip shape changes

1) Catheter damage

Six catheters for each brand were observed under a scanning electron microscope after penetrating the polyethylene film at a 30-degree angle. Photomicrographs, which were taken at RAN of 15 KV and magnification of 50 times, show designs, shapes, and catheter tip damage. As for Surflo®, which has an acute-tapering catheter tip design, showed tip damage. The seven other brands of catheters with obtuse-tapering design showed no damage, regardless of inner needle tip grinding method .

2) Damage of six catheters of Surflo®,

Fig 7 shows six photomicrographs of Surflo® after penetrating the polyethylene film at a 30-degree /angle. All six Surflo® catheters showed tip damage.

(3) Measurement of inner needle diameter and level differences between inner needle and outer catheter

Inner needle diameter (A), level difference between inner needle and catheter (B), and bevel angle (C) were determined for each brand using projection charts. The outer diameter of the inner needle was longest in Vitaflon Plus® and shortest in Angiocath®, with a difference of 0.1 mm. The level difference between the inner needle and its catheter was smaller in the Lancet group than in the Backcut group, although Surflo® had a different catheter tip design. The level difference was smallest for Insyte®. The bevel angle was less acute in the Backcut group than in the Lancet group (Fig.8).

Discussion

The force necessary to insert an intravenous catheter into a peripheral vein is related to the physician's skill, the quality and intensity of venipuncture pain, the severity of venous damage, and the frequency of catheter-related phlebitis. Therefore, penetration force is a critical factor in assessing intravenous catheters with different designs. We previously evaluated the handiness of the needles experimentally and clinically[1]. Our previous studies demonstrated that the

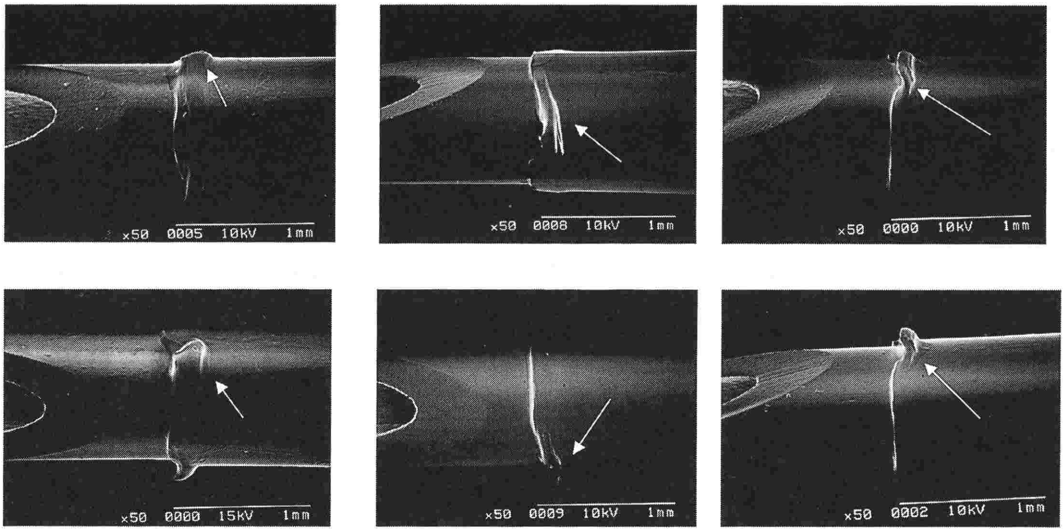
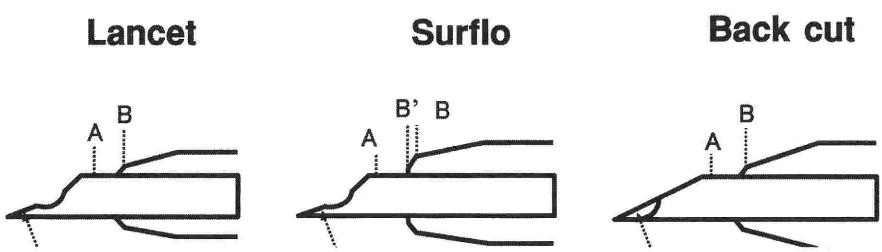


Fig. 7 Damage of six catheterrs of Surflo®, All six Surflo® catheters showed tip damage.



n=5 mean±SD

		A(mm)	B(mm)	C(°)
Lancet group	Insyte	0.88±0.01	0.06±0.01	14.4±0.1
	Angiocath	0.81±0.01	0.10±0.01	14.4±0.1
	Supercath	0.92±0.01	0.07±0.01	16.2±0.1
	Surflo	0.90±0.01	*0.10±0.01	14.9±0.3
Backcut group	Introcan certo	0.91±0.01	0.19±0.01	18.0±0.1
	Jeluco plus	0.91±0.01	0.10±0.01	17.9±0.3
	Vitaflon	0.92±0.01	0.11±0.02	17.2±0.1
	Vasculon	0.85±0.01	0.18±0.01	17.0±0.1

A: Diameter
B: Level difference between inner needle and outer catheter
C: Bevel angle

Fig. 8 Measurement of inner needle diameter and level differences between inner needle and outer catheter

penetration force of intravenous catheters varied with the brand and also that the penetration force pattern depended on the inner needle tip grinding method and catheter structure[2].

Venipuncture failures are classified into two types: the inner needle is inserted into a vein deeply enough to penetrate through the vessel; and the outer catheter cannot be inserted into a vein. In most of these cases, the catheter is still outside of the vein after the backflow of blood is observed and the catheter is advanced. This is because no attention is paid to high penetration force, large bevel, or the length between the inner needle tip and its outer catheter (lie distance, i.e., the actual length of backflow running to the catheter tip). Venipuncture failures also seem to be associated with penetration speed. We have thus advised beginners to advance the catheter slowly by several millimeters after backflow is observed, until the catheter is inserted into the vein.

On the basis of these findings, useful intravenous catheters should have a lower penetration force of both the inner needle and its catheter, a smaller bevel, and a shorter lie distance, for easy insertion[2]. Kinast shows that venipuncture pain is related to *in vivo* penetration force and that intravenous catheters with a smaller penetration force are desirable to reduce pain[3]. Stability of intravenous catheters after insertion is another important factor for useful needles. Needle materials that are unlikely to cause phlebitis have been studied[4~6]. The incidence of phlebitis is reported to exceed 50% when an intravenous catheter dwells in a vein for 4 days or longer[4]. The incidence of phlebitis is 1.3 times higher for Teflon (polytetrafluorethylene) intravenous catheters than for polyurethane catheters[5]. However, intravenous catheters are often removed in 1 to 2 days. Needles with a structure that helps even beginners succeed in insertion should be clinically and economically good devices.

In some cases, an intravenous catheter cannot be inserted into a vein by advancing the inner needle by several millimeters after the backflow of blood is observed. This problem seems to be associated with needle structure, especially inner needle tip grinding methods and the shape of the catheter tip. Inner needle tip grinding methods determine the shape of insertion site. The shape of the hole created by outer catheter insertion depends on the shape of the catheter tip, the volume of lubricant, and the level difference between the inner needle and its catheter. If an outer catheter with a large diameter is inserted into a small hole created by the inner needle, the penetration force could be increased causing damage to the catheter tip.

An inner needle tip ground by the Lancet method makes a oval insertion site, and then the catheter passes through this small entry, enlarging it. If the catheter tip has an acute-tapering design (e.g., Surflo®), the penetration force of the outer catheter could be increased, with a higher risk of catheter tip damage. In our study, all six Surflo® catheters showed tip damage. This suggests that the damage may occur even if a catheter can be inserted into a vein successfully.

An inner needle tip ground by the Backcut method makes a V-shaped insertion site. Although this looks like a small entry, the tricuspid shape makes a larger opening than the opening made by Lancet inner needles, resulting in a lower penetration force. Backcut inner needles have three cutting edges, and the two edges behind the bevel have a large impact on penetration force. If the penetration angle is obtuse, the opening will be larger and this makes peripheral venipuncture . In the use of Backcut inner needles, catheter damage is unlikely to occur and less attention should be paid to catheter tip shape, catheter tip tapering design, or level difference between the inner needle and its outer catheter, compared to Lancet inner needles. Measurements of level differences between the inner needle and the outer catheter indicate that no catheter damage occurred in spite of the larger level difference in the Backcut group. In the Lancet group, all catheters except for Surflo® showed no damage. This is probably because of the obtuse-tapering design and a smaller level difference between the inner needle and its catheter (e.g., Insyte®). All these findings were obtained from in vivo studies, and penetration forces at the skin or venous walls may be higher in clinical practice. Ideal intravenous catheters should have a Backcut inner needle, a small level difference between the inner needle and the outer catheter, and an obtuse-tapering design for the catheter tip. Development of Backcut inner needles with a smaller bevel, as well as polyurethane catheters with a small level difference between the inner needle and the catheter, like Insyte®, is needed. In addition, ideal lie distance should be established on the basis of the average penetration speed.

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