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Differences in Penetration Force of Intravenous Catheters: Effect of Grinding Methods on Inner Needles of Intravenous Catheters

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Objectives: To compare penetration forces of intravenous catheters based on two grinding methods used for the inner needle tip.

Method: Forty intravenous catheters were divided into two groups according to two inner needle grinding methods: Lancet and Backcut. To compare the characteristics of inner needles, 18 gauge Surflo® outer catheters, were attached to all inner needles. We measured penetration forces by attaching a "Push-Pull-Gauge" to the chamber of intravenous catheters, then we penetrated intravenous catheters through a 0.04-mm thick polyethylene film. The penetration velocity was 3.3 mm/sec. we measured penetration forces at 30- and 45-degree penetration angles.

Results: There was no significant difference in the penetration forces of inner needle and outer catheter between the two groups at the 45-degree penetration angle. Penetration forces of the inner needle and the outer catheter in the Backcut group was significantly lower than those of the Lancet group at the 30-degree penetration angle. The penetration force of the outer catheter was reduced from 0.3 N to 0.18 N, a 40 % reduction at 30-degree penetration angle. Computerized measurements of penetration holes indicate that the Y-shaped incision mark of the Backcut leaves larger incision hole than the actual puncture size. We hypothesize that the Y-shaped incision mark creates more efficient path for the outer catheter to advance. Therefore, lower penetration force was indicated compared to the other group.

Conclusion: Backcut shows less penetration force of inner needles of peripheral intravenous catheters than lancet.

Key words : Intravenous catheter, Penetration force, Grinding method

INTRODUCTION

Recently, various user-friendly intravenous catheters have been on the market. During typical medical applications, there are a few differences in style and manner of usage of intravenous catheters between individuals. Therefore, it is difficult to compare individual differences in practice objectively due to personal preferences and habits that have not been questioned scientifically. A typical intravenous catheter consists of an inner needle and an outer catheter. Current intravenous catheters on the market vary in

terms of the shape of the inner needle bevel, the bevel-face size, the gap between the outer catheter and the inner needle, the shape of the outer catheter, the tapering method, and the material composition. These features create the difference of penetration force. When intravenous catheters require greater penetration force, practitioners may push the wall of the blood vessel ineffectively, resulting in unsuccessful catheterization. Consequently, we have investigated how two grinding methods create differences in outer catheter penetration forces to understand factors.

SUBJECTS AND METHODS

Intravenous catheters were divided into two groups. 1) Lancet group with lancet-grind inner needles, 2) Backcut group with Backcut-grind inner needles. All inner needles had an outer diameter of 0.09 mm, and all the outer catheters were 18-gauge Surflo®. For the Lancet group, Surflo® inner needles were used. For the Backcut group, Vitaflon® inner needles were used. Bevel angles measured by a projector for the Lancet (Surflo®) needle was 15.3 degree, and the Backcut (Vitaflon™) needle was 17.0 degrees, respectively.

Among commercially available intravenous catheters, inner needles ground by the Lancet method are Angiocath (BD), Insyte (BD), Supercath (Medikit), and Surflo (Terumo). Inner needles ground by the

Backcut method are Vasculon (BD), Jelco (J&J), Jelco Plus (J&J), Introcan (BB), Introcan Certo (BB). It is estimated that the market share of Lancet needle is 84.3 % and that of Backcut needle is 15.7 % in Japan [6].

An inner needle of intravenous catheter is composed of a tip, a beveled face, and a main needle tube. The needle shown in upper part of figure 1 is a needle where the front half of the bevel face is ground by the Lancet method. Its bevel face is gently sloping. The bottom needle in figure 1 is a needle ground by the Backcut method. The bevel face of the backcut needle is smaller than that of the Lancet needle. The tip of the bevel is sharply angled, and it has an edge behind the bevel. The biggest part of bevel diameter is closer to the tip than in the case of the Lancet bevel.

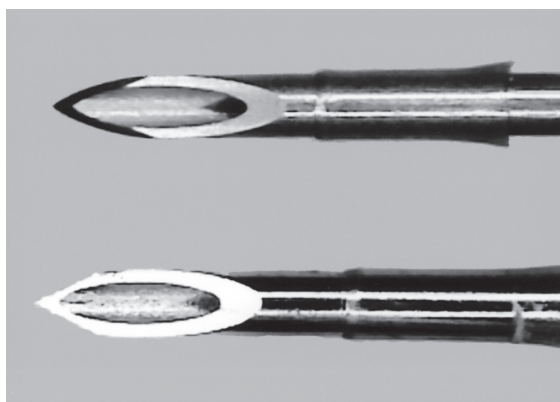


Fig. 1 Configurations of the Lancet and Backcut venous catheter needle tips.
Upper: Lancet needle tip. Lower: Backcut needle tip.
The outer catheters are the same for all samples. (18-gauge Surflo® outer catheter)

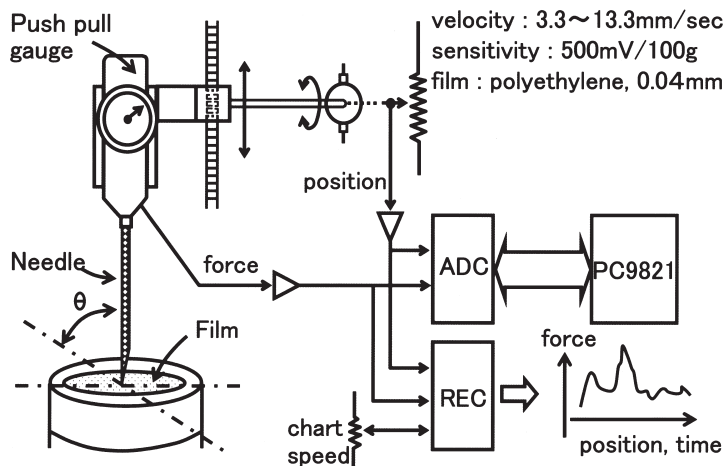


Fig. 2 Diagram of the experimental apparatus.

Measurement of penetration forces

Penetration forces required for catheters to penetrate a 0.04-mm thick polyethylene film at 3.3 mm/sec velocity at both 30- and 45-degree penetration angles were measured by a motor push-pull gauge (fig. 2). Intravenous catheters were attached to the gauge, and real-time changes in penetration force were measured from initiation of penetration at the tip of the inner needle until outer catheter penetration. Each group of catheters was allocated 20 samples.

Measurement of penetration holes

Penetration holes on the polyethylene film were created by inner needle and outer catheter penetration was magnified 80 times, and sizes of penetration were compared and examined. These images were also scanned into a computer (300 dpi; Apple Macintosh), and an image-authoring software (Photoshop, Adobe Systems Inc.) was used to reduce noise and sharpen the edges. Next, manual outlines of the damaged areas and holes were scanned into the computer. These abstract lines were recorded into software that measured analyzed the images (NIH Image

1.62, National Institute of Health). Two penetration holes made by the Backcut needle, 1.4 mm (at 30 degrees) and 1.2 mm (at 45 degrees), were used for calibration (approximately 208 pixels/mm). The pixels surrounding the borderlines were automatically abstracted and counted, and then the size of the holes and the damaged areas were calculated with a coefficient obtained through the calibration (Unit: mm²).

In all analyses, unpaired-t-tests were used ($p < 0.05$), with results expressed in mean \pm standard deviation.

RESULTS

(1) Comparison of penetration force patterns.

1) Lancet group

The left half of figure 3 shows the construction and penetration force pattern of Lancet needles with catheter. The penetration force pattern for the Lancet group with film at 45-degree angle and the velocity of 3.3 mm/sec is shown below (the horizontal axis shows time, and the vertical axis shows penetration force). As shown on Fig. 3, the penetration force increases immediately

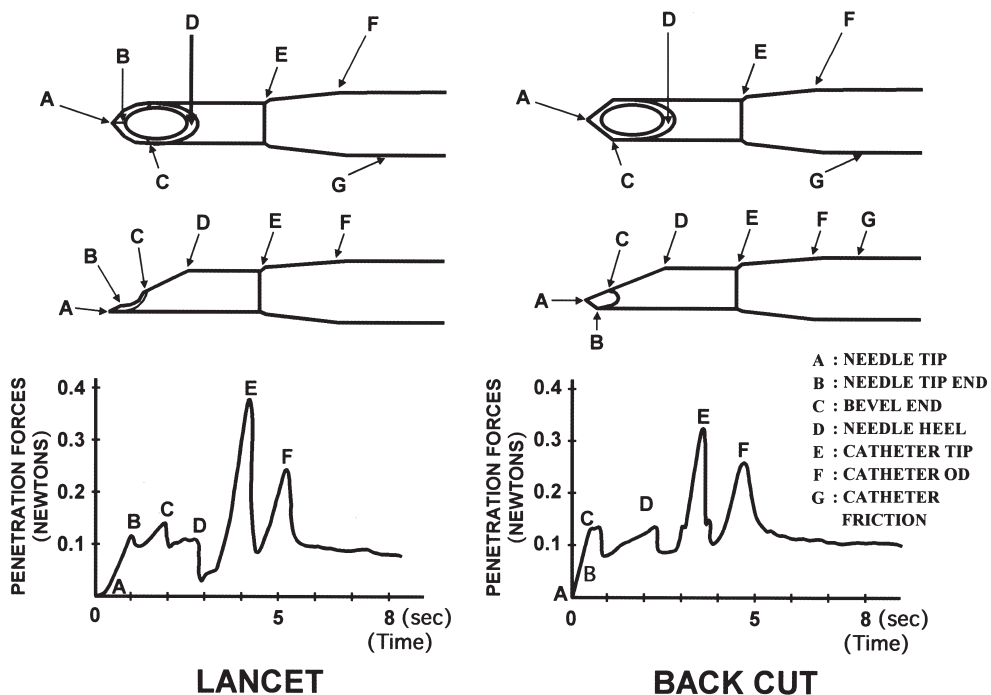


Fig. 3 Typical patterns of the change in penetration force over time for Lancet Group (left), and Backcut Group (right). The catheter configurations, with letters indicating different positions, are shown above each of the graphs.

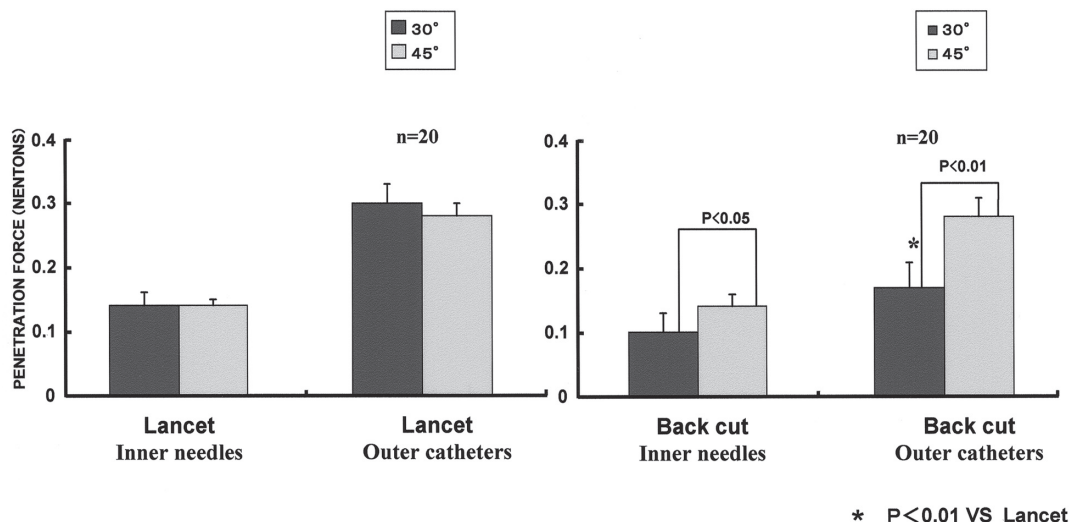


Fig. 4 Comparison of the highest penetration force measured for each of the intravenous catheter. In all analyses, unpaired-t-tests were used ($p<0.05$), results are expressed in mean \pm standard deviation.

after the needle tip (A) penetrates the film. After the needle tip (B) pierces the film, the penetration force slightly decreases. Then the penetration force gradually increases as the needle heel (D) passes through the film, and decreases afterwards. Subsequently, a sudden increase in force is observed when the catheter tip (E) reaches the film and then rapidly decreases after point (E) passes through the film. After the bevel end (E) passes through the film, and penetration forces rapidly decrease. When the catheter outer diameter (OD) (F) reaches the film, the penetration force increases and shows a small peak.

2) Backcut group

The right half of figure 3 shows the construction and penetration force pattern of the Backcut group with catheter. Penetration force gradually increases immediately after the needle tip (A) penetrates the film until the needle tip end (B) passes through the film. Subsequently, the penetration force abruptly increases as the bevel end (C) reaches the film. After point C, force decreases once, and gradually increases again until the needle heel (D) reaches the film. The penetration force pattern after point E (catheter tip) is similar to that of the Lancet group.

(2) Comparison of penetration forces.

Figure 4 shows the highest penetration forces of both groups.

The graph on the left shows the highest

penetration forces of Lancet group, while the graph on the right shows those of the Backcut group. Penetration forces at the 30-angle and at the 45 angle are shown in black and gray, respectively.

In the lancet Group, there were no significant differences in penetration forces of both inner needle and outer catheters at both 30 and 45-degree insertion angle. At 30-degree insertion angle, penetration forces of the both inner needle and the outer catheter in the Backcut group show significantly lower force compared to those of the 45-degree. Furthermore, the data shows penetration forces of the outer catheter in the Backcut group were significantly lower compared to the lancet group, about 40 % reduction in penetration force, reduced the force from 0.3 N to 0.18 N.

(3) Comparison of shapes and sizes of penetration holes

1) Shape of the penetration holes

Photomicrographs of penetration holes in the polyethylene film are shown in figure 5. The holes by Lancet needles are oval in shape. At a 30-degree angle, a bigger tear-like hole is visible. On the other hand, backcut needles create a Y-shaped hole, which is obviously different from the holes created by the Lancet group needles.

2) Measurement of the penetration holes

Table 1 shows a computerized image of

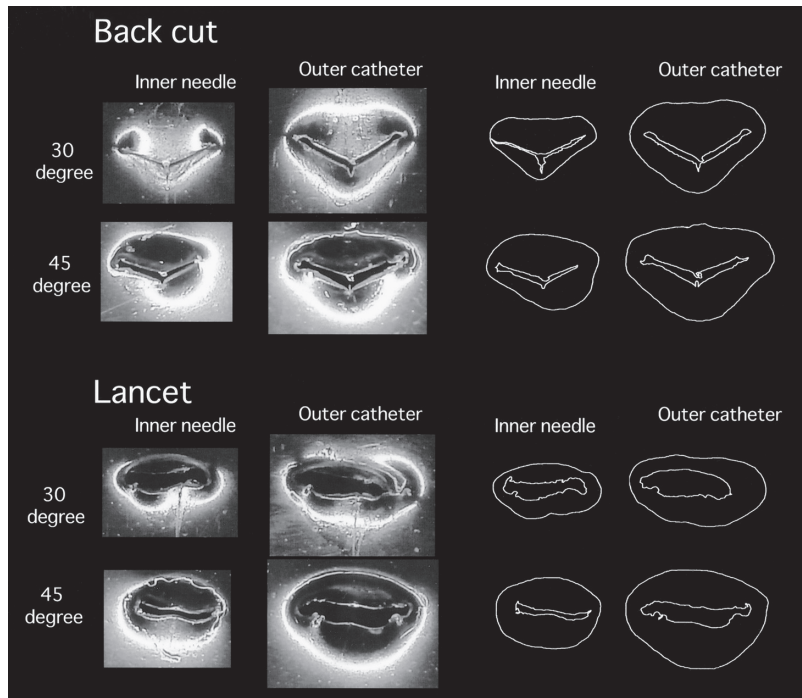


Fig. 5 Photomicrographs of typical holes made in polyethylene film by the different groups of catheters.

Table 1 Areas surrounding the penetration holes (mm²) for each group of catheters at penetration angles of 30- and 45-degrees.

	Inner needle		Outer catheter		Inner needle		Outer catheter	
	30°		30°		45°		45°	
	hole	damage	hole	damage	hole	damage	hole	damage
Back Cut(n=2)	0.05	0.98	0.13	1.98	0.08	1.40	0.17	2.29
triangle BS*(n=2)	0.36		0.52		0.26		0.41	
Lancet (n=2)	0.25	1.09	0.44	1.81	0.18	1.40	0.36	2.53
Average	0.15	1.03	0.28	1.90	0.13	1.40	0.26	2.40
S.D.	0.10	0.09	0.18	0.10	0.08	0.27	0.11	0.14

* The triangular area is not included in the averages and standard deviations.

the area surrounding the penetration holes. With the same penetration angles, size of damaged areas made by inner needles are similar for both types of needles because the same outer catheters were used with both types of needles.

The Lancet group shows little difference in penetration hole sizes at both 30-

and 45-degree angles. The Backcut group revealed the lower penetration force for the outer catheter penetration, although the inner needle hole is relatively small.

DISCUSSION

The penetration force of an intravenous catheter is affected by factors including the penetration angle [7-9], the penetration velocity, and structural features of the needle such as size, tip configuration, and outer catheter surfactant [2, 7, 9]. In addition, several factors vary from patient to patient, including not only gender and age, but also the thickness and hardness of the subcutaneous tissue, and compliance of the blood vessel wall.

Eriksson *et al.* investigated the force necessary to penetrate the dorsal vein in various groups [2]. According to that study, necessary penetration forces are higher for men than for women due to differences in the thickness of the skin and the vein wall. The situation for infants and children, however, is complicated by variations in the weakness of the vessel walls, the thickness of the subcutaneous tissue, and differences in elasticity [3]. For elderly individuals, the penetration force is lower because of senile deterioration of the skin [2]. For craftsmen and other repetitive hand-use laborers, the penetration force is higher because of the thicker skin and developed hand veins [2].

In *in vitro* experiments, materials such as latex [2], polyethylene [5, 7, 8], polyvinyl chloride, lamb's leather [2], heat-treated pig skin, and the skin of a corpse have been used to substitute for human skin [1].

In clinical, two common scenarios involving insertion failure include puncturing the back wall of the vein as a result of advancing the inner needle too deeply and an inability to advance the outer catheter [7]. The reasons for these failures are high penetration speed, inadequate estimation of the gap between the outer catheter and the inner needle, and high resistance to outer catheter insertion.

Based on the above penetration patterns, it appears that the vessel wall is pressed and deformed as the inner needle penetrates the vessel, and after the tip of the inner needle passes through the wall, the vessel attempts to return to its original shape. Next, however, when the outer catheter penetrates the wall, the vessel is pressed again. Therefore, it can be assumed that low penetration forces for both the inner needle and the outer catheter are desirable due to reduced pressure and

consequently a more patent lumen with resultant easier catheterization.

Furthermore, it has been reported that lower penetration force leads to less pain [3].

Kinast *et al.* reported that the level of pain for penetration of the intravenous catheter *in vivo* correlates with the force required to penetrate a 0.4 mm thick polyvinyl chloride film [4]. The study also showed that the penetration patterns differ with variable configurations of the inner needle tips [7, 8].

There was little difference in inner needle penetration forces between the Lancet group and the Backcut group at both 30- and 45-degree penetration angles.

However, with regard to outer catheter penetration, the force is greatly affected by the penetration angle. We found that outer catheter penetration force required by the Lancet group was 1.1- to 1.2-times larger at the 30-degree penetration angle than at the 45-degree penetration angle.

A possible explanation for low penetration forces in Backcut needles inserted at a 30-degree angle is that the inner needle creates a Y-shaped hole, which functions like a tricuspid valve [7, 9]. That is, the triangular area (BS*), defined by lines connecting the three apexes of the Y-shaped penetration hole, is bigger than the holes created by the Lancet group needles. The Y-shaped hole allows the outer catheter to be inserted smoothly. The size of the triangular area (BS*) at the 45-degree penetration angle is smaller than that at the 30-degree penetration angle. We hypothesize that the reason for this outcome can be explained by the fact that, at the 45-degree penetration angle, the shape of the hole is more V-shaped than Y-shaped. In general, the penetration force required for catheter insertion increases inversely to the size of the hole created by the inner needle. Therefore, outer catheter insertion is easier at the 30-degree penetration angle where a larger hole is made. Our data supports this owing to the fact that the observed penetration force of the Backcut catheter was about 40 % less at the 30-degree penetration angle than at the 45-degree angle.

Another important factor in reducing penetration forces is related to the unique edge on the back of the Backcut bevel face (Lancet needles have only two edges, while Backcut needles have three edges). This difference appears to be important in reducing the

penetration force needed to insert the outer catheter at a 30-degree penetration angle. This tendency was similar to that found in an experiment that used a polyethylene film of 0.1 mm.

In summary, it is clear from this study that penetration forces and patterns of intravenous catheters differ by tip configuration, unevenness between the inner needle and outer catheter, the tapering of the outer catheter, and other factors [2, 7, 8]. Consequently, penetration forces and their patterns are expected to differ with each product type [1, 9]. Considering these various patterns, it is possible to choose the appropriate catheter for specific purposes such as peripheral venous insertions, central venous insertions, and arterial punctures. Finally, because a peripheral venous insertion is usually performed with a penetration angle of about 30 degrees or less, it can be concluded that Backcut needles are better suited to peripheral venous catheter insertions than are Lancet needles when the same outer catheter is used.

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