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ORIGINAL ARTICLE

Shaping the tip of microcatheters for superselective catheterization: steam vs. manual methods

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PURPOSE
We aimed to evaluate and compare the shapeability and stability of five microcatheters commonly used in interventional radiology after steam shaping and manual shaping.

METHODS
Steam shaping was performed using three mandrels of different angles: L(S) shape (90°), U(S) shape (180°), and O(S) shape (360°). Three manual shapes—L(M), U(M), and O(M)—were made to have a similar angle to their steam-shaped counterparts. The stability of the microcatheters was evaluated by passing them through a 5 F catheter and inserting microguidewires. The tip angles of the microcatheters and the angle change rates were compared between groups.

RESULTS
The mean angle of the microcatheters after steam shaping was 42.4°–54.1° for L(S) shape, 80.2°–96.7° for U(S) shape, and 130.7°–150.8° for O(S) shape. Five microcatheters showed significantly different mean angle reductions after passing through the 5 F catheter (17.4%–30.3%) and inserting microguidewires (24.1%–61.2%). Different microguidewires also caused significantly different mean angle reductions (34.6%–50.8%). The reduced angle caused by the guidewire was almost completely recovered after withdrawing it (93.2%–101.6%). Although manual-shaped microcatheters showed a 4.2%–6.3% greater angle reduction than steam-shaped microcatheters after passing through the 5 F catheter, the final tip angle was not significantly different between the two groups and was within 10%.

CONCLUSION
The tip angle of the microcatheters after steam shaping using mandrels may differ depending on the shape of the mandrel and the type of microcatheter used, and the stability varies depending on the type of microcatheter. The manual shaping of microcatheters can be a good alternative to steam shaping.

Transarterial chemoembolization (TACE) has become a widely accepted treatment option in patients with hepatocellular carcinoma since it was reported by Yamada et al. (1). Among a variety of TACE techniques, superselective TACE, in which the embolization is performed at the distal part of fine tumor feeding arteries is regarded as a standard technique for localized hepatocellular carcinomas in many institutions in East Asia to minimize collateral damage to the adjacent normal liver parenchyma (2–4). In addition, superselective embolization in patients with gastrointestinal bleeding may have several advantages including the reduction of the area to be embolized and the chance of rebleeding from collateral routes (5–8). However, in some cases, it may be challenging to catheterize a target vessel that is very small, tortuous, or arising from a relatively large vessel with an acute angle. The inability to catheterize the target vessel because of difficult anatomy was one of the most common causes of technical failure (9).

Several novel techniques have been developed to overcome these anatomic challenges including the shaping of the microcatheter tip (10, 11), the creation of a side hole or a cleft at the distal segment of the larger catheter (12–14), the shepherd's hook technique (15, 16), a tri-axial microcatheter system (17), and a steerable microcatheter (18, 19). Among these techniques, along with the shepherd's hook technique, shaping the tip of microcatheter can

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easily be tried in clinical practice without the need for additional specialized devices. However, the shaping procedure, which is usually performed by steam heating, can be time consuming and is limited by variation in shapeability and stability among microcatheters. Several studies have evaluated characteristics, including shapeability and stability, of various steam-shaped microcatheters, all of which are popular for cerebral aneurysm coiling (20–23). However, to the best of our knowledge, no reports have described the impact of different tip-shaping methods, including steam shaping and manual shaping, on various microcatheters, particularly those that are commonly used in visceral arterial intervention.

The purpose of this study is to evaluate and compare the shapeability and stability of five microcatheters commonly used in interventional radiology after steam shaping and manual shaping.

Methods

The study protocol conformed to the ethical guidelines of the Declaration of Helsinki. The Institutional Review Board approval was waived because this experimental study did not involve human subjects. The following five commercially available microcatheters were tested: Progreat lambda 1.7 F (Terumo), Progreat alpha 2.0 F (Terumo), Veloute 1.7 F (Asahi Intecc), Radiostar 1.9 F (Taewoong Medical), and Carnelian 1.8 F (Tokai). Progreat alpha 2.0 F is a coil-reinforced microcatheter while the others are the braid-reinforced type.

Steam shaping using mandrels

Shapeability

Before steaming, one of the three preshaped mandrels was inserted into the distal portion of the microcatheter and the catheter tip was located at a specific point of the mandrel. Consequently, the following three shapes were made: 1) L(S) shape (a mandrel with a 90 degree angle, and the tip was located 5 mm beyond the bending point of the mandrel), 2) U(S) shape (a U-shaped mandrel with 5 mm outer curve width, and the tip was located 5 mm beyond the U-turn point), and 3) O(S) shape (a circular looped mandrel with 5 mm outer diameter, and the tip was located at the endpoint of the loop). Four samples per each product were tested for each shape. Thereafter, they were steamed for 60 seconds (80°C) and then placed in water at room temperature for 20 seconds (24°C).

Following the mandrel removal, the microcatheter tip was placed on the stage and captured by a digital camera (Dino Lite edge USB microscope camera; AnMo electronics corporation). The image data were transferred to a personal computer, where the angle of the microcatheter tip was measured using image analysis software (Leopard ix; Zootos). The tip angle was defined as the angle measured between the longest line that is parallel to the shaft and the longest line that is parallel to the distal end of the tip of the microcatheter (Fig. 1). After tentatively delineating the outline of the microcatheter, the software automatically detected the edge of the microcatheter using the difference in intensity of the pixels within the region of interest and calculated the angle. The mandrel shapes, the positions of the microcatheter tip on the mandrel, and representative cases of the microcatheter tip after steaming are presented in Fig. 2.

Stability

The impact of the straightening forces that are frequently encountered in clinical practice on the tip angle was evaluated as follows. First, the tip angle was measured after the insertion of each steam-shaped microcatheter through a 5 F catheter (Davis, Cook). The reduction of the tip angle after passing through the 5 F catheter was expressed as a percentage of the initial angle after steam shaping. Second, a microguidewire was subsequently advanced into the microcatheter until the tip of the guidewire was located 1 cm beyond the tip of the microcatheter, and this was followed by the angle measurement. Four types of microguidewires—0.014-inch Streaming (Asahi Intecc), 0.016-inch Meister (Asahi Intecc), 0.016-inch GT (Terumo), and 0.014-inch Transend (Boston Scientific)—were used in the evaluation. For each shape, four different microguidewires were paired with four samples of each product for the experiment. The microguidewires remained in the microcatheter for 60 seconds. Thereafter, the microguidewires were withdrawn, and the tip angle was measured again. The reduction and recovery rate after introducing and withdrawing the guidewire are expressed as a percentage of the tip angle measured immediately after passage through the 5 F catheter. Because no deformity or flexure was found on microguidewires after the withdrawal, four microguidewires (one for each product) were repeatedly used for the stability test. Consequently, a total of 60 microcatheters (12 microcatheters per product) and four microguidewires were used for the steam shaping experiment.

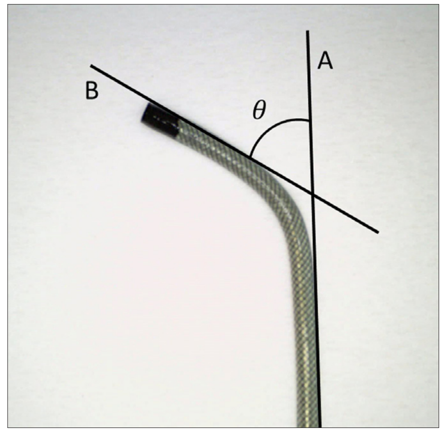

Figure 1. Measurement of the tip angle of the microcatheter. We measured the angle made by the longest line that is parallel to the shaft (line A) and the longest line that is parallel to the distal portion (line B) of the microcatheter.

Manual shaping

Shapeability

First, for each product and each shape, we selected a reference microcatheter from the previously steam-shaped microcatheters. The reference microcatheter had the angle closest to the mean angle of the same product and shape , i.e., L(S), U(S), or O(S). Consequently, a total of 15 microcatheters were selected as reference microcatheters for manual shaping. One researcher shaped microcatheter with hands to have a similar tip angle to the reference microcatheter. A shaping device with diameter of 1.25 mm, which was enclosed to 0.016-inch Meister microguidewire (Asahi Intecc), was used for the manual shaping process (Fig. 3a). First, the shaping device held in the right hand was placed on the inner side of intend-

Main points

- Shaping the tip of microcatheter can be used to catheterize the target vessel that is difficult to access using either steaming or manual method.
- The tip angle of microcatheters after steam shaping differs depending on the shape of the mandrel and the type of microcatheter.
- The various tip angles of microcatheters made by steam shaping can be reproduced successfully by manual shaping without the need for additional steam processing or equipment.

ed curve of microcatheter and the thumb was placed on the opposite side. Then, the thumb and shaping device were slowly moved to the distal portion of microcatheter while gently pressing the thumb against the shaping device (Fig. 3b). This step was repeated with gentle force to avoid kinking or breaking of the microcatheter until its shape was made similar to that of the reference microcatheter (Fig. 3c). The shape was reassessed 10 seconds later and additional shaping was performed if the tip shape was not maintained. For each reference microcatheter, three samples were manually shaped.

The three manual shapes were named L(M), U(M), and O(M), which represent the shaping according to the reference shapes of L(S), U(S), and O(S), respectively. Thereafter, the initial tip angle of manual-shaped microcatheter was measured using the same method as that used for steam-shaped ones. The initial tip angles of the manual-shaped microcatheters were compared with those of the steam-shaped ones.

Stability

The stability of the manual-shaped microcatheters was evaluated using the same method that was used to test the steam-shaped ones, except that only Transend guidewire was used for the microguidewire test. A total of 45 microcatheters (9 microcatheters per product) and one microguidewire were used for the manual shaping experiment. A comparison of the stability between steam-shaped and manual-shaped microcatheters was performed. The stability of the manual-shaped microcatheters after microguidewire insertion and removal was compared to that of a subgroup of steam-shaped ones examined with Transend guidewire.

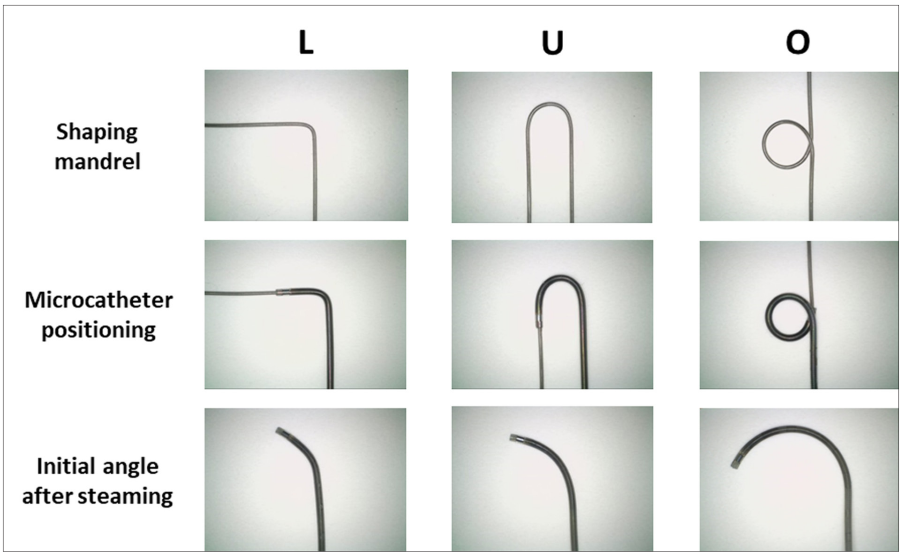

Figure 2. The shaping mandrel and the position of the microcatheter used for the L(S), U(S), and O(S) shapes and representative cases of steam-shaped microcatheters.

Statistical analysis

The SPSS 25.0 software package (IBM Corp.) was used for the statistical analyses performed in this study. Comparison between groups was performed using the independent t-test, Mann-Whitney U test, analysis of variance (ANOVA), or Kruskall-Wallis test as appropriate according to the number and size of groups and the result of the Kolmogorov-Smirnov test. The Bonferroni and Dunn-Bonferroni methods were used as post hoc tests after the ANOVA and the Kruskall-Wallis test, respectively. A *P* value of <0.05 indicated a statistically significant difference.

Results

Fig. 4 shows representative examples of microcatheter tip shapes after steam shaping. The mean angle of different microcatheters after steam shaping ranged from 42.4° to 54.1° for the L(S) shape, from 80.2° to 96.7° for the U(S) shape, and from 130.7° to 150.8° for the O(S) shape (Table 1). None of the five microcatheters showed consistently higher shapeability than the others for all shapes.

The results of the stability tests after steam shaping for the three different shapes are presented in Table 2 and Supplementary Table 1. When averaged across the tested microcatheters, the group with the

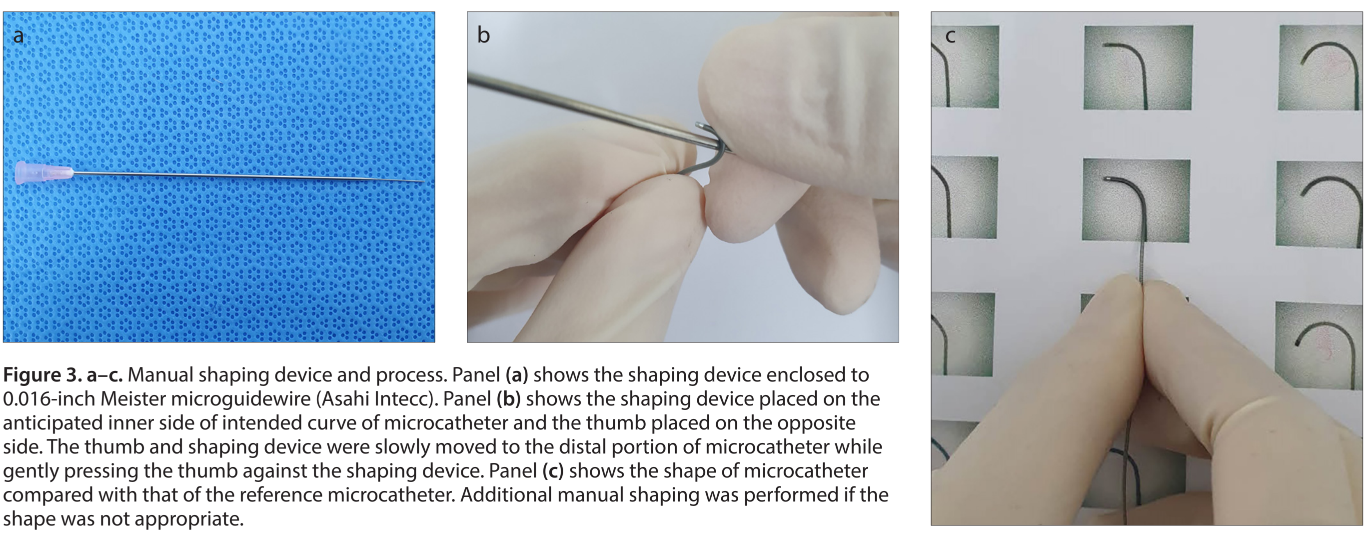

Figure 3. a–c. Manual shaping device and process. Panel **(a)** shows the shaping device enclosed to 0.016-inch Meister microguidewire (Asahi Intecc). Panel **(b)** shows the shaping device placed on the anticipated inner side of intended curve of microcatheter and the thumb placed on the opposite side. The thumb and shaping device were slowly moved to the distal portion of microcatheter while gently pressing the thumb against the shaping device. Panel **(c)** shows the shape of microcatheter compared with that of the reference microcatheter. Additional manual shaping was performed if the shape was not appropriate.

Table 1. The initial tip angle of microcatheters measured after shaping

	Steam shaping			Manual shaping		
Microcatheter	L(S)	U(S)	O(S)	L(M)	U(M)	O(M)
No. of microcatheters*	20 (4)	20 (4)	20 (4)	15 (3)	15 (3)	15 (3)
Progreat 1.7 F	44.0±12.6	87.0±5.3	143.7±12.9	46.9±2.7	90.1±3.4	142.3±2.1
Progreat 2.0 F	48.4±3.8	80.2±6.9	139.3±8.7	51.2±4.1	74.2±5.7	130.8±1.0
Veloute	54.1±7.1	96.7±6.0	130.7±4.4	54.9±1.8	97.9±0.7	139.0±7.5
Radiostar	51.2±6.1	88.5±5.0	146.6±19.1	62.3±3.7	87.8±6.1	133.3±6.1
Carnelian	42.4±4.7	81.1±0.8	150.8±10.2	52.9±4.9	81.4±8.1	148.0±13.9
Total	48.0±8.1	86.7±7.7	142.2±12.9	53.6±6.1	86.3±9.5	138.6±9.1

Data are presented as mean ± standard deviation (degree).
*Number of microcatheters per product in parentheses.

Table 2. Comparison of the stability of steam-shaped and manual-shaped microcatheters

	Initial angle		5 F catheter passage		Guidewire insertion			Guidewire removal	
Shape	n	Degree	Degree	Reduction rate (%)	n*	Degree	Reduction rate (%)	Degree	Recovery rate (%)
L(S)	20	48.0±8.1	38.8±7.0	18.8±7.8	5	18.5±8.4	51.5±16.6	36.6±5.5	98.9±7.6
L(M)	15	53.6±6.1	40.5±6.3	24.6±5.4	15	19.7±8.3	51.5±20.8	38.9±7.1	95.7±8.0
P		0.030	0.452	0.019		0.735	1.000	0.612	0.567
U(S)	20	86.7±7.7	65.2±11.2	25.0±8.3	5	31.5±5.6	52.3±14.7	64.5±10.7	94.7±6.3
U(M)	15	86.3±9.5	59.8±12.1	31.3±7.6	15	28.8±6.3	50.7±12.7	58.3±13.0	97.3±5.7
P		0.883	0.176	0.030		0.297	0.612	0.266	0.542
O(S)	20	142.2±12.9	100.5±11.6	29.2±6.8	5	48.3±8.3	48.7±12.0	90.5±11.0	95.0±7.3
O(M)	15	138.6±9.1	92.3±12.1	33.4±7.7	15	47.3±5.3	47.8±9.6	90.0±10.0	97.8±5.0
P		0.368	0.052	0.098		0.800	1.000	0.933	0.173

*The stability of manual-shaped microcatheters after guidewire insertion and removal was compared to that of the steam-shaped subgroup examined with Transend.

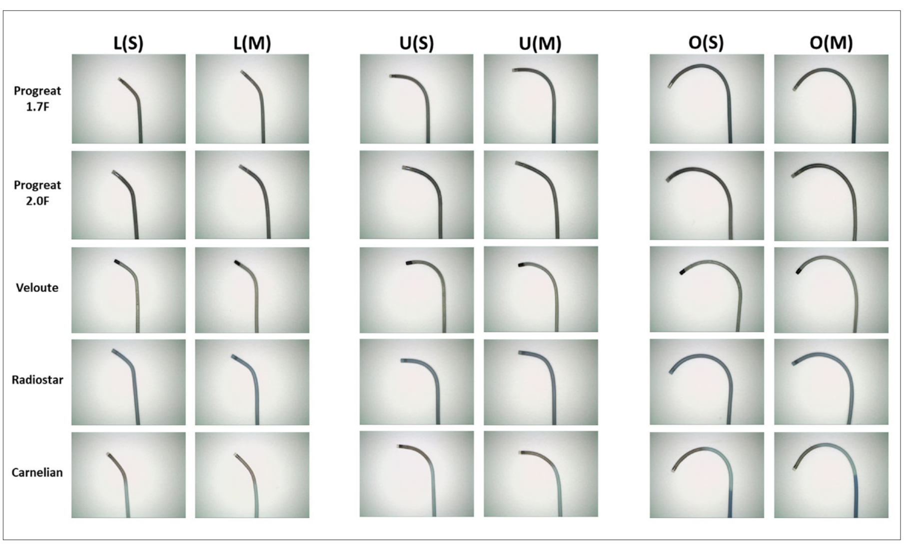

Figure 4. Steam-shaped reference catheters and representative cases of manual-shaped microcatheters.

larger initial angle showed a greater angle reduction after passage through a 5 F catheter (18.8%±7.8% for the L(S), 25.0%±8.3% for the U(S), and 29.2%±6.8% for the O(S), $P < 0.001$, post hoc test: L(S) < U(S), O(S)). However, the initial angles did not influence the angle reduction rate after guidewire insertion. The mean angle reduction of the L(S), U(S), and O(S) shapes after guidewire insertion were 43.8%±19.6%, 44.1%±15.6%, and 41.9%±12.0%, respectively ($P = 0.899$).

The stability of the five tested microcatheters after steam shaping is summarized in Table 3 and Fig. 5. When averaged across the three tested shapes, the angle reduction rate after passage through the 5 F catheter and guidewire insertion differed significantly among the five tested microcatheters ($P < 0.001$). The most stable microcatheter after passing through the 5 F catheter was Veloute (mean angle reduction rate: 17.4%±3.9%), followed by Progreat 1.7 F (21.3%±9.0%), Carnelian (24.8%±7.0%), Radiostar (28.1%±6.9%), and Progreat 2.0 F (30.3%±9.6%). The most stable microcatheter during guidewire insertion was Progreat 2.0 F (mean angle reduction rate: 24.1%±7.8%), followed by Radiostar (36.8%±7.6%), Veloute (44.6%±11.7%), Carnelian (49.7%±10.8%), and Progreat 1.7 F (61.2%±11.2%). The reduced angle due to the insertion of the guidewire was almost completely recovered after withdrawing it in all microcatheters (93.2%–101.6%). However, the recovery rate was significantly different among the five microcatheters ($P = 0.009$). The recovery rate of Progreat 1.7 F (93.2%±6.6%) was the lowest, and it was significantly lower than that of Progreat 2.0 F (101.6%±6.9%) and Veloute (99.6%±3.5%) in the post hoc test.

Table 4 demonstrates the significant variation in angle reductions caused by the four guidewires ($P = 0.033$). When averaged across the types of microcatheter, the stiffest microguidewires causing the largest angle reduction was Transend (50.8%±13.6%), followed by GT (46.0%±18.2%), Meister (41.7%±14.1%), and Streaming (34.6%±13.7%).

Fig. 4 shows representative examples of tip angles for manual-shaped microcatheters. The mean angles of the various microcatheters after manual shaping ranged from 46.9° to 62.3° for the L(M) shape, from 74.2° to 97.9° for the U(M) shape, and from 130.8° to 148.0° for the O(M) shape (Table 1). The mean initial angles of the microcatheters of the L(M) shape were slightly larger than those of the L(S) shape (53.6°±6.1° vs. 48.0°±8.1°, $P = 0.03$). No significant difference was noted in the initial angle between the U(M) and U(S) shapes (86.3°±9.5° vs. 86.7°±7.7°, $P = 0.883$), and between the O(M) and O(S) shapes (138.6°±9.1° vs. 142.2°±12.9°, $P = 0.368$) (Table 2).

The stability of the three manual shapes is presented in Table 2, Supplementary Table 2 and Fig. 6. Compared to steam-shaped microcatheters, manual-shaped ones demonstrated a slightly greater angle reduction after passing through the 5 F catheter. The mean angle reduction rate was 24.6%±5.4% vs. 18.8%±7.8% for L(M) vs. L(S) ($P = 0.019$), 31.3%±7.6% vs. 25.0%±8.3% for U(M) vs. U(S) ($P = 0.030$), and 33.4%±7.7% vs. 29.2%±6.8% for O(M) vs. O(S) ($P = 0.098$). However, the stability after guidewire insertion was not significantly different between the manual-shaped microcatheters and the steam-shaped subgroups examined with Transend guidewire. The mean angle reduction rate was 51.5%±20.8% vs. 51.5%±16.6% for L(M) vs. L(S) ($P = 1.000$),

Table 3. Comparison of the stability of various microcatheters

Microcatheter	n	Reduction rate (%) 5 F catheter passage	Reduction rate (%) Guidewire insertion	Recovery rate (%) Guidewire removal
Steam shaping				
Progreat 1.7 F	12	21.3±9.0	61.2±11.2	93.2±6.6
Progreat 2.0 F	12	30.3±9.6	24.1±7.8	101.6±6.9
Veloute	12	17.4±3.9	44.6±11.7	99.6±3.5
Radiostar	12	28.1±6.9	36.8±7.6	97.6±4.5
Carnelian	12	24.8±7.0	49.7±10.8	96.1±5.6
P		< 0.001	< 0.001	0.009
Post hoc test		c < b, d	b < a, c, e d < a	a < b, c
Manual shaping				
Progreat 1.7 F	9	28.6±6.8	65.7±10.7	92.9±5.9
Progreat 2.0 F	9	36.4±8.6	28.2±7.8	100.5±5.6
Veloute	9	22.8±4.2	54.6±8.4	99.4±5.7
Radiostar	9	29.1±7.3	46.6±2.7	97.8±4.1
Carnelian	9	31.9±5.9	54.9±9.2	94.3±7.2
P		0.006	< 0.001	0.028
Post hoc test		c < b	b < a, c, e d < a	-

P values were calculated using the Kruskall-Wallis test, and the Dunn-Bonferroni method was used as a post hoc test. a = Progreat 1.7 F, b = Progreat 2.0 F, c = Veloute, d = Radiostar, e = Carnelian.

Table 4. Comparison of the stiffness of microguidewires

Guidewire	No. of tested microcatheters	Reduction rate after guidewire insertion (%) L(S)	U(S)	O(S)	Total	*P*	Post hoc test
Streaming	15	35.7±18.3	36.3±16.4	31.9±6.2	34.6±13.7	0.033	Streaming < Transend
Meister	15	37.8±18.5	41.2±15.6	46.0±8.5	41.7±14.1		
GT	15	50.1±25.0	46.8±16.0	41.1±15.1	46.0±18.2		
Transend	15	51.4±16.6	52.3±14.7	48.7±12.0	50.8±13.6		

P values were calculated using the Kruskall-Wallis test, and the Dunn-Bonferroni method was used as a post hoc test.

50.7%±12.7% vs. 52.3%±14.7% for U(M) vs. U(S) (P = 0.612), and 47.8%±9.6% vs. 48.7%±12.0% for O(M) vs. O(S) (P = 1.000). In addition, no significant difference was observed in the recovery rate between steam-shaped and manual-shaped microcatheters for all shapes (P > 0.05). The final tip angle after passage through the 5 F catheter and the guidewire insertion and removal was 38.9°±7.1° vs. 36.6°±5.5° for L(M) vs. L(S) (P = 0.612), 58.3°±13.0° vs. 64.5°±10.7° for U(M) vs. U(S) (P = 0.266), and 90.0°±10.0° vs. 90.5°±11.0° for O(M) vs. O(S) (P = 0.933).

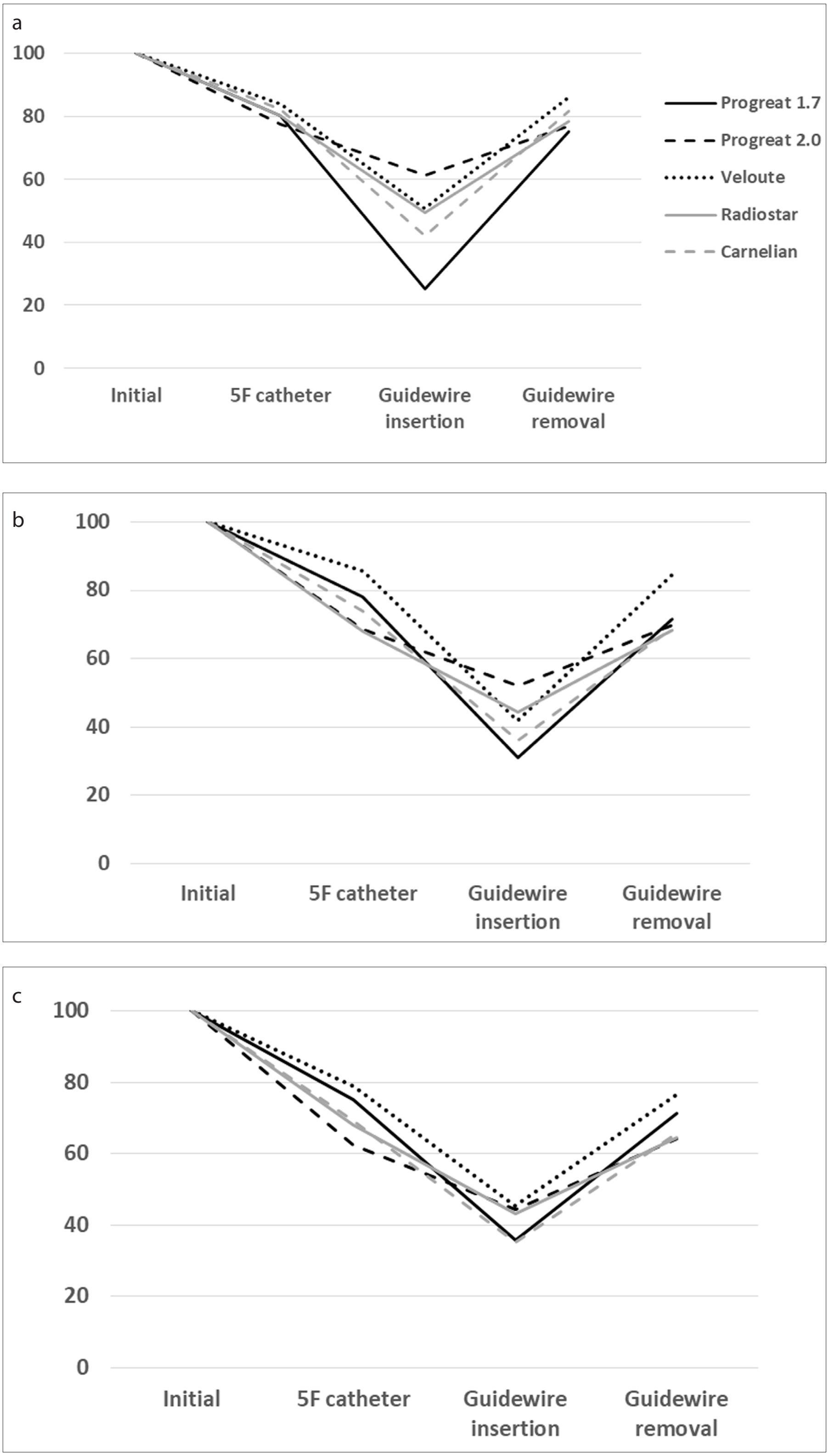

Figure 5. a–c. Comparison of the stability of different microcatheters in the L(S) shape (**a**), U(S) shape (**b**), and O(S) shape (**c**).

Regarding the variation in stability among the five microcatheter models after 5 F catheter passage and during guidewire insertion, the results for the manual-shaped microcatheters were similar to those for the steam-shaped ones (Table 3). The most stable microcatheter after passing through the 5 F catheter was Veloute (mean angle reduction: 22.8%±4.2%), followed by Progreat 1.7 F (28.6%±6.8%), Radiostar (29.1%±7.3%), Carnelian (31.9%±5.9%), and Progreat 2.0 F (36.4%±8.6%). The most stable microcatheter during guidewire insertion was Progreat 2.0 F (mean angle reduction: 28.2%±7.8%), followed by Radiostar (46.6%±2.7%), Veloute (54.6%±8.4%), Carnelian (54.9%±9.2%), and Progreat 1.7 F (65.7%±10.7%). Similar to the result of the steam-shaped microcatheters, the recovery rate after withdrawing the guidewires varied significantly depending on the type of microcatheter (P = 0.028), with Progreat 1.7 F showing the lowest recovery rate (92.9%±5.9%). However, the post hoc test did not show statistically significant results.

Discussion

The results of our study demonstrated that the tip angle of microcatheters after steam shaping may differ depending on the shape of the mandrel and the type of microcatheter. However, no microcatheter showed consistently higher shapeability than the others for all shapes. For example, the mean angle of Veloute after shaping was larger than the other microcatheters for the L(S) and U(S) shape, whereas it was the lowest for the O(S) shape. Nevertheless, the results of this study may help interventional radiologists to determine the appropriate shaping mandrel and microcatheter to produce a specific tip angle required for the selection of the target vessel.

We evaluated the stability by using two types of straightening force that are frequently encountered in clinical practice. First, while passing through the 5 F catheter, the wall of the catheter applies a strong force on the microcatheter and almost completely straightens the angle. The angle was measured only after the distal angular portion of microcatheter was passed completely through the 5 F catheter to remove the straightening stress on the angle of microcatheter. In contrast, the insertion of a guidewire is considered to apply a relatively weak straightening force. The tip angle was measured while the straightening stress was being applied. The most stable microcatheter after passing through the 5 F catheter was Veloute (mean angle reduction: 17.4%), while Progreat 2.0 F showed the lowest stability (30.3%). In contrast, Progreat 2.0 F was the most stable microcatheter in response to guidewire insertion (mean angle reduction: 24.1%). We speculate that the stability observed after passage through the 5 F catheter is associated with the resilience of the microcatheter, whereas the stability observed during guidewire insertion reflects its stiffness. The variation in the stability of Progreat 2.0 F in response to the two types of straightening force may be explained by the relatively low resilience and high stiffness associated with being the only microcatheter of the coiled type and having the largest distal outer diameter among the tested products. In contrast, Progreat 1.7 F showed the lowest stability during guidewire insertion. Progreat 1.7 F had the smallest outer diameter of the tested microcatheters, along with Veloute, which is advantageous when selecting fine arteries. However, to confirm our speculation regarding the resilience and stiffness of the microcatheter, a further experiment is required to directly measure its mechanical properties.

In this study, manual-shaped catheters were shaped to have a similar tip angle to their steam-shaped counterparts, and this required different amounts of time and effort according to the specific microcatheters. We could not evaluate the difficulty of the manual shaping of different microcatheters because of the lack of objective criteria. The standardization of the manual-shaping method and the development of objective criteria are required to clarify the difficulty of manual shaping for different microcatheters. Nevertheless, the result of our experiment is meaningful in that various tip angles of microcatheters made by steam shaping can be reproduced successfully by manual shaping.

However, after passage through the 5 F catheter, the angle reduction of manual-shaped microcatheters was slightly higher than that of the steam-shaped ones, depending on the shape (mean angle reduction: 24.6% vs. 18.8% for the L(M) vs.

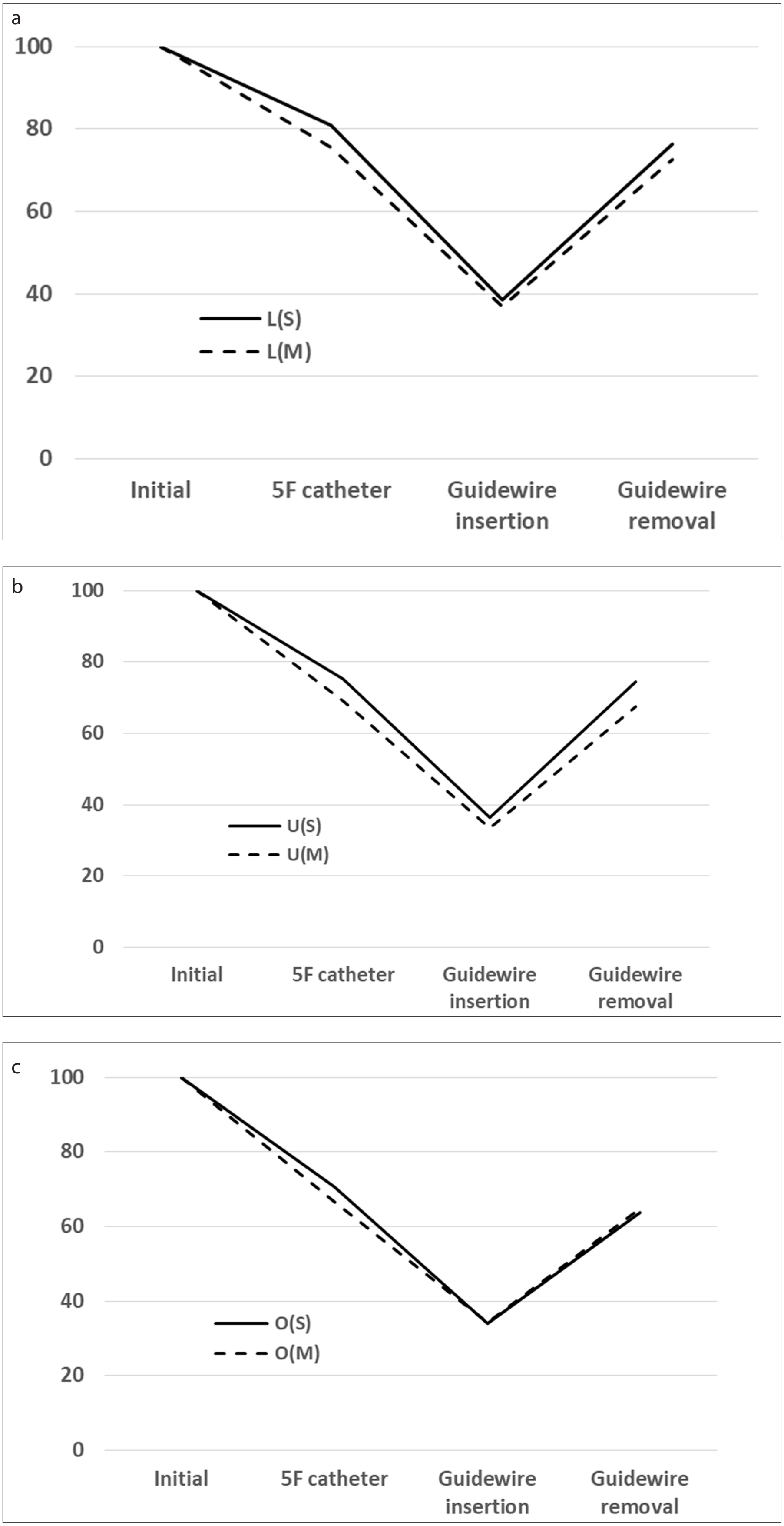

Figure 6. a–c. Comparison of the stability of steam- and manual-shaped microcatheters. The stability of the L(S) vs. L(M) shape **(a)**, U(S) vs. U(M) shape **(b)**, and O(S) vs. O(M) shape **(c)** is presented.

L(S), 31.3% vs. 25.0% for U(M) vs. U(S), and 33.4% vs. 29.2% for O(M) vs. O(S)). The insertion and withdrawal of the microguidewire caused a similar angle change in the steam- and manual-shaped microcatheters. The difference in the final mean tip angle of the steam- and manual-shaped microcatheters after passing through the 5 F catheter and inserting and removing the guidewire was less than 10%, which was not statistically significant. Therefore, considering the advantage of there being no additional steam processing or equipment, manual shaping is a good alternative to steam shaping in clinical practice.

This study has several limitations. First, the power of the statistical methods used was limited in this experimental study because it included a relatively small number of microcatheters. Nevertheless, the statistical analysis demonstrated several significant results, including the difference in stability between steam- and manual-shaped microcatheters after passing through the 5 F catheter and the difference in stability among the five tested microcatheters. Second, because we tested five microcatheters that are commonly used in interventional radiology in our institution, microcatheters of the non-braided type were not included in our study, and there have been several previous studies reporting their higher shapeability and stability (20, 22, 23). In addition, microcatheters that are popular in interventional radiology may vary depending on the region and institution. Other microcatheters used in TACE, especially those with diameter larger than 2.2 F, were not evaluated.

In conclusion, the tip angle of microcatheters after steam shaping using mandrels may differ according to the shape of the mandrels and the type of microcatheters, and its stability varies according to the type of microcatheter used. The manual shaping of microcatheters can be a good alternative to steam shaping.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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Supplementary Table 1. The shapeability and stability of steam-shaped microcatheters

Shape	n	Initial angle (degree)	5 F catheter passage (degree)	Change rate (%)	Guidewire insertion (degree)	Change rate (%)	Guidewire removal (degree)	Recovery rate (%)
L(S) shape								
Prograt 1.7 F	4	44.0±12.6	35.3±8.6	17.7±13.5	11.1±6.0	70.6±11.4	33.1±8.9	93.4±11.8
Prograt 2.0 F	4	48.4±3.8	37.5±5.7	22.5±10.9	29.7±2.5	20.0±7.0	37.2±3.6	100.4±10.4
Veloute	4	54.1±7.1	45.3 ±7.0	16.4±2.9	27.4±9.8	40.4±13.9	46.5±6.8	102.8±1.2
Radiostar	4	51.2±6.1	41.0±6.1	20.1±2.5	25.3±6.5	39.0±10.0	40.1±6.7	97.6±3.1
Carnelian	4	42.4±4.7	34.9±3.8	17.5±5.7	17.8±4.7	48.8±13.0	34.7±3.0	99.7±7.0
Total	20	48.0±8.1	38.8±7.0	18.8±7.8	22.3 ±9.0	43.8±19.6	38.3±7.4	98.8±7.7
U(S) shape								
Prograt 1.7 F	4	87.0±5.3	68.0±7.1	21.7±7.9	26.9±2.3	60.2±4.7	62.2±5.5	91.6±3.5
Prograt 2.0 F	4	80.2±6.9	55.1±5.4	31.1±6.4	41.8±3.6	23.6±9.4	56.1±7.8	101.7±7.0
Veloute	4	96.7±6.0	82.7±6.4	14.5±2.1	40.4±7.9	51.3±7.1	81.8±6.6	98.8±3.3
Radiostar	4	88.5±5.0	60.2±6.2	32.0±4.5	39.3±3.9	34.3±7.5	60.5±4.8	100.7±2.6
Carnelian	4	81.1±0.8	60.0±3.5	26.0±4.8	29.2±6.8	51.1±12.8	55.9±2.6	93.4±5.0
Total	20	86.7±7.7	65.2±11.2	25.0±8.3	35.5±7.9	44.1±15.6	63.3±11.0	97.2±5.8
O(S) shape								
Prograt 1.7 F	4	143.7±12.9	108.2±8.0	24.6±4.4	51.4±12.3	52.7±9.5	102.3±7.0	94.6±1.6
Prograt 2.0 F	4	139.3±8.7	87.1± 5.1	37.3±5.5	61.9±2.3	28.6±6.0	89.4±6.1	102.7±3.5
Veloute	4	130.7±4.4	102.9±5.8	21.2±3.3	59.3±10.4	41.9±12.8	99.9±5.1	97.2±3.2
Radiostar	4	146.6±19.1	99.9±18.3	32.1±4.5	63.2±15.3	37.2±6.3	94.6±17.9	94.6±5.9
Carnelian	4	150.8±10.2	104.2±6.4	30.9±1.0	52.9±10.1	49.2±9.7	99.2±8.7	95.1±3.6
Total	20	142.2±12.9	100.5±11.6	29.2±6.8	57.7±10.9	41.9±12.0	97.1±10.1	96.8±4.6

Data are presented as mean ± standard deviation.

Supplementary Table 2. The shapeability and stability of manual-shaped microcatheters

Shape	n	Initial angle (degree)	5 F catheter passage (degree)	Change rate (%)	Guidewire insertion (degree)	Change rate (%)	Guidewire removal (degree)	Recovery rate (%)
L(M) shape								
Prograt 1.7 F	3	46.9±2.7	35.3±3.9	24.5±9.8	8.1±4.1	76.8±12.1	30.9±1.8	88.1±6.5
Prograt 2.0 F	3	51.2±4.1	38.0±4.7	25.9±5.1	29.1±1.3	22.4±12.6	37.5±3.8	99.0±7.5
Veloute	3	54.9±1.8	42.1±3.8	23.5±4.4	16.6±6.0	61.2±11.8	41.3±5.3	97.9±4.2
Radiostar	3	62.3±3.7	48.8±4.3	21.7±3.0	25.3±2.3	48.2±0.2	48.6±2.3	99.8±4.7
Carnelian	3	52.9±4.9	38.4±6.3	27.6±5.0	19.5±4.4	48.8±13.3	36.0±6.4	93.9 ±12.7
Total	15	53.6±6.1	40.5±6.3	24.6±5.4	19.7±8.3	51.5±20.8	38.9±7.1	95.7±8.0
U(M) shape								
Prograt 1.7 F	3	90.1±3.4	60.7±4.9	32.6±4.5	23.5±1.0	61.1±2.8	57.7±6.2	94.9±3.3
Prograt 2.0 F	3	74.2±5.7	44.2±4.3	40.5±2.5	31.1±3.5	29.7±1.4	43.7±5.3	98.8±2.3
Veloute	3	97.9±0.7	76.7±5.4	21.6±5.1	35.6±1.2	53.4±4.5	78.9±2.9	103.2 ±8.6
Radiostar	3	87.8±6.1	61.2±7.3	30.2±7.2	32.7±3.8	46.5±3.8	58.9±6.0	96.5±5.8
Carnelian	3	81.4±8.1	55.9±8.7	31.5±5.7	21.0±4.2	62.6±3.0	52.0±6.9	93.2±3.4
Total	15	86.3±9.5	59.8±12.1	31.3±7.6	28.8±6.3	50.7±12.7	58.3±13.0	97.3±5.7
O(M) shape								
Prograt 1.7 F	3	142.3±2.1	101.3±5.8	28.8±4.1	41.2±2.7	59.2±4.3	96.7±3.6	95.6±5.6
Prograt 2.0 F	3	130.8±1.0	74.7±4.3	42.9±3.3	50.4±2.5	32.5±1.4	77.3±4.6	103.7±6.5
Veloute	3	139.0±7.5	106.2±0.9	23.4±4.8	54.0±3.2	49.2±3.5	103.1±2.7	97.1±2.2
Radiostar	3	133.3±6.1	86.1± 4.9	35.4±2.5	47.2±3.1	45.1±2.8	83.4±3.9	97.0±1.1
Carnelian	3	148.0±13.9	93.3±2.6	36.7±4.4	43.6±1.8	53.3±1.6	89.2±2.3	95.7±5.1
Total	15	138.6±9.1	92.3±12.1	33.4±7.7	47.3±5.3	47.8±9.6	90.0±10.0	97.8±5.0

Data are presented as mean ± standard deviation.