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Retrospective Study

The Quadrant Localization Technique for Percutaneous Balloon Compression Surgery is Beneficial for Patients with Classic Trigeminal Neuralgia: A Retrospective Study

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Background: The Hartel anterior approach is a commonly used puncture method in percutaneous balloon compression (PBC) surgery. However, anatomical variations along the puncture path, and visual errors on x-ray 2-dimensional imaging, may increase the difficulty of a successful first attempt. Our clinical practice has shown that employing the quadrant localization technique to plan puncture points and angles can enhance the puncture success rate.

Objectives: We will demonstrate that the quadrant localization technique increases the success rate of the first puncture of the foramen ovale and the initial placement of the balloon catheter, thereby improving the efficiency of PBC surgery.

Study Design: Retrospective study.

Setting: A single center, tertiary general hospital.

Methods: This study included a total of 371 patients with classic trigeminal neuralgia who underwent PBC surgery from January 2019 through May 2023. All patients received general anesthesia and underwent PBC surgery under radiographic guidance. In total, 170 patients underwent a puncture using the quadrant localization technique (Group Q), and 201 underwent a puncture using the conventional Hartel anterior approach (Group P).

Results: Group Q demonstrated higher success rates for the first puncture and insertion of the balloon catheter, along with a lower total radiographic radiation dose, shorter surgical duration, and shorter hospital stay ($P < 0.05$). However, there were no significant differences in PBC success rates or the incidence of puncture-related side effects and complications between the 2 groups ($P > 0.05$).

Limitations: This study lacked information on long-term complications and pain recurrence rates. Also, single-center results may be influenced by institution-specific practices and physician-related biases.

Conclusion: In PBC surgery, the quadrant localization technique improves efficiency and reduces hospital stay compared with the conventional Hartel anterior approach, without increasing the risk of complications.

Key words: Classic trigeminal neuralgia, percutaneous balloon compression, puncture, quadrant localization technique, surgical side effects, surgical complications, retrospective study, balloon catheter, Hartel anterior approach

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Classic trigeminal neuralgia (TN) affects both middle-aged and elderly individuals (1). It is typically triggered by innocuous facial stimuli, and manifests as paroxysmal or severe pain. This condition significantly affects patients' psychological, physiological, and daily social activities (2). As the disease progresses, drug therapy may lead to drug resistance and adverse reactions, leading to decreased patient compliance (3). Approximately 50% of patients eventually require surgical intervention to alleviate pain (4); therefore, the treatment of classic trigeminal pain is challenging.

Radiofrequency ablation is one of the minimally invasive treatment options for TN. Compared to invasive treatments like microvascular decompression, radiofrequency ablation offers similar pain relief effects with lower costs and fewer side effects (5). However, it may cause nonselective damage to nerves, leading to the loss of motor and autonomic function (6).

Percutaneous balloon compression (PBC) is a primary minimally invasive surgical method for elderly patients who have severe underlying conditions and who refuse microvascular decompression. It is more suitable for patients with trigeminal neuralgia involving the ophthalmic branch because it minimally affects corneal sensation (7-10). Compared to radiofrequency ablation, PBC requires relatively less specialized surgical equipment and provides higher perioperative comfort for patients under general anesthesia. Therefore, with desirable therapeutic effects, PBC is more widely used in minimally invasive treatment of TN.

PBC typically employs the classic Hartel anterior approach, which sets the puncture point based on anatomy and completes the puncture of the foramen ovale and placement of the balloon catheter into Meckel's cave under x-ray imaging guidance. However, anatomical variations in the foramen ovale and Meckel's cave, along with visual errors introduced by 2-dimensional imaging, can require repeated adjustments to the puncture angle, eventually damaging the nerves and blood vessels around the foramen ovale and Meckel's cave. Improving the puncture method for PBC, increasing the success rate of the first puncture, and reducing puncture-related complications has become a pressing clinical issue.

Currently, some reports claim that the use of more advanced 3-dimensional computed tomography guidance or neuronavigation techniques can improve the success rate of foramen ovale puncture (11,12). However, advanced technology entails higher learning costs for surgeons and increased surgical expense for patients; however, the same objectives can be achieved using x-ray guidance, which has a lower cost.

Meckel's cave is located posterior to the inner aspect of the foramen ovale. Based on the spatial relationship between these 2 structures, a quadrant localization method was developed to plan the puncture point and angle. This method divides the foramen ovale image in the axial plane into 4 quadrants, with punctures from the outer upper quadrant to the inner lower quadrant. Real-time x-ray fluoroscopy guides fine adjustments to the puncture angle. Our study retrospectively compared cases in our hospital of PBC using the quadrant localization technique with the classic Hartel anterior puncture method. We aimed to demonstrate that, under fluoroscopic guidance, the quadrant localization technique can increase the success rate of the first puncture of the foramen ovale and the first placement of the balloon catheter, reduce puncture-related injuries, improve surgical efficiency, and provide further evidence for the clinical promotion of quadrant positioning-guided puncture.

Methods

Patients

Patients who underwent PBC surgery from January 2019 through May 2023 were included in this study. The inclusion criteria, in accordance with the diagnostic criteria for classic TN (Table 1 [2,13]), were men or women aged 18-85. The exclusion criteria were previous trigeminal procedures such as microvascular decompression or PBC, a history of surgery that could affect the anatomy relevant to PBC surgery, ipsilateral facial numbness, masseter weakness, abnormal corneal reflex, presurgery diplopia, incomplete pain Numeric Rating Scale (NRS-11) data, and surgery without the assistance of a mobile C-arm x-ray fluoroscope.

Grouping was based on the puncture method used. The quadrant localization technique was assigned to Group Q, while the conventional Hartel method was assigned to Group P. All patients provided written, informed consent. Ethical approval for this study was provided by the Ethics Committee of our institution (Ethics Number: (2023) Clinical Research No. K052).

Surgical Procedure and Postoperative Management

Patients were required to fast for 8 hours presurgery. Peripheral intravenous access was established, and intravenous antibiotic prophylaxis was administered at

30 minutes presurgery. Patients were instructed to lie supine with a thin pillow placed under the neck and the head slightly tilted backward. General anesthesia was administered intravenously; backup medications, including atropine and nitroglycerin, were also available. During surgery, heart rate, blood oxygen saturation, and invasive radial artery pressure were continuously monitored.

A mobile C-arm fluoroscope was used for skull base axial projection (typically with a 15° rotation toward the affected side and a 30° head-to-foot tilt) to confirm the foramen ovale.

In Group P, using the conventional Hartel anterior approach, the puncture point was located at the intersection of a vertical line drawn from the outer edge of the affected-side orbit, and a horizontal line drawn from the ipsilateral oral cleft, approximately 2–3 cm away from the oral cleft. The puncture needle was inserted with its coronal plane facing the direction of the pupil on the same side, and the sagittal plane directed toward the midpoint of the zygomatic arch on the same side. Under fluoroscopic guidance, the entry direction was adjusted to the external opening of the foramen ovale.

In Group Q, using the quadrant localization technique, the foramen ovale image in the axial plane was divided into 4 quadrants. The puncture point was localized within the upper outer quadrant, and the puncture needle was directed toward the lower inner quadrant (Figs. 1A, 1B, and 1C). Under fluoroscopic guidance, the direction was fine-tuned to allow entry into the external opening of the foramen ovale.

Both groups continued to undergo puncture under the guidance of lateral fluoroscopy. The puncture was stopped when the needle tip extended approximately 5 mm beyond the internal opening of the foramen ovale and was directed toward the petrous bone slope. Next, the needle core was removed and a probing needle was used to create a passage into Meckel's cave. A balloon catheter was introduced into Meckel's cave through a blunt-tipped puncture needle, with its tip extending approximately one cm beyond the needle (approximately 17–20 mm from the foramen ovale).

Following the withdrawal of the guidewire, 0.1–0.3 mL of a nonionic contrast agent was injected into the balloon catheter. Under the guidance of lateral fluoroscopic imaging, the balloon expanded into a "pear-shaped" configuration, confirming precise placement (Fig. 1D). After maintaining compression for 2.5–3 minutes, the balloon was deflated and withdrawn along with the puncture needle. Hemostasis was achieved by applying pressure to the puncture site for 5 minutes, followed by dressing with sterile material.

Postprocedure, patients were transferred to the postanesthesia care unit until they were fully awake, capable of following commands, coughing, and demonstrating purposeful limb movements. They were then transferred back to the ward for monitoring of vital signs and pain assessment. Patients were discharged upon meeting the following criteria: stable vital signs with clear consciousness; significant pain relief (pain NRS-11 ≤ 3); absence of dizziness, nausea, or vomiting; and normal walking ability.

Observation Parameters

Preoperative data included age, gender, disease duration, pain location (left/right), and preoperative pain NRS-11 scores. The primary outcomes included the success rate of the first puncture of the foramen ovale, the success rate of the balloon catheter insertion on the

Table 1. *Classification and characteristic of trigeminal neuralgia (TN) (2,13).*

	Classic Trigeminal Neuralgia	Secondary Trigeminal Neuralgia
Etiology	• Idiopathic TN: no apparent cause • Classic TN: Trigeminal nerve root atrophy and/or displacement due to vascular compression	Multiple sclerosis or space occupying lesion
Onset age	Over 40 years old	Less than 40 years old
Pain characteristics	• Trigger point exists • Triggered by innocuous sensory stimuli to the affected side of the face • Unilateral • Stabbing pain or electric shock-like pain • Paroxysmal pain • Lasts for a few seconds to a few minutes each time • Usually without neurological deficits and extratrigeminal symptoms	• No trigger point • Unilateral or bilateral • With long duration pain • Prolonged background pain in the affected area may exist • Neurological deficits and extratrigeminal symptoms are more frequent
Imaging examination	• Idiopathic TN: no apparently abnormal imaging features • Classic TN: with neurovascular compression	Occupying lesion of related sites

first attempt, total intraoperative x-ray radiation dosage, operation time (from localization to completion of balloon inflation), and hospital stay. Secondary outcomes included the surgical success rate (pain NRS-11 ≤ 3 on the day of surgery) and incidence of surgical side effects (masseter weakness and facial numbness) and

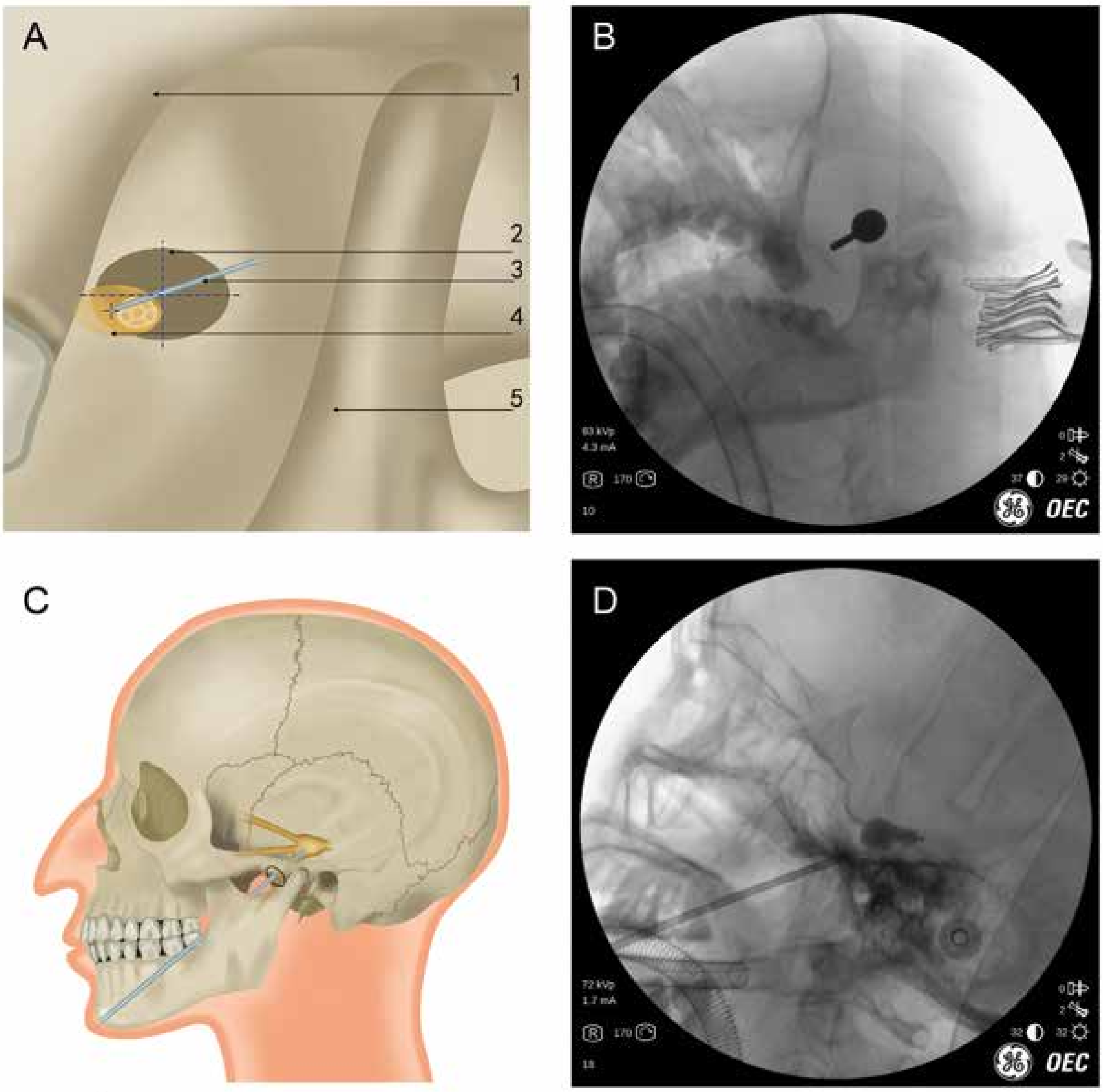

Fig. 1. *Illustration of the quadrant localization technique in left-sided percutaneous balloon compression surgery*
A. The foramen ovale image in the axial plane was divided into four quadrants. The puncture point was located in the upper outer quadrant, with the needle directed towards the lower inner quadrant. 1 represents the maxilla, 2 the foramen ovale, 3 the puncture needle, 4 Meckel's cave, and 5 the mandible.
B. Puncture of quadrant localization technique with the guidance of a C-arm x-ray machine.
C. The needle tip was advanced about 5 mm beyond the internal opening of the foramen ovale, directed towards the petrous bone slope. The inner stylet was then removed, and a probing needle was utilized to create a channel into Meckel's cave, followed by the insertion of a balloon catheter through the channel.
D. Contrast was injected into the balloon catheter; when the balloon inflates into a pear-shaped expansion, precise positioning is confirmed.

complications (herpes labialis, facial hematoma, arterial bleeding, arteriovenous fistula, decreased corneal reflex, and diplopia).

Statistical Analysis

Counting data are presented as percentages and were analyzed using the χ^2 test or Fisher's exact test. Rate differences and 95% CIs were used to describe intergroup differences. Continuous variables were recorded as mean ± SD, or as median(Q1,Q3), depending on their distribution. Normally distributed data were analyzed using Student's t test, and mean differences and their 95% CIs, were reported to describe intergroup differences. Nonnormally distributed data were analyzed using the Mann–Whitney U test, and median differences along with their 95% CIs were estimated using the Hodges–Lehmann method to describe intergroup differences. Statistical analysis was performed using IBM SPSS Statistics 25.0 (IBM Corporation). A *P* value < 0.05 was considered statistically significant.

Results

In total, the data of 371 patients were analyzed; Group P, who received the conventional Hartel anterior approach, included 201 patients; Group Q, who received the quadrant localization technique, included 170 patients. No statistically significant differences were observed in baseline information, including age, gender, disease duration, pain location, and preoperative pain NRS-11 score ($P > 0.05$; Table 2).

The success rate of foramen ovale puncture on the first attempt was 75.9% in Group Q and 66.2% in Group P, while the success rate of balloon catheter insertion on the first attempt was 75.9% in Group Q and 62.7% in Group P. These differences were statistically significant ($P < 0.05$; Table 3). The surgical duration was shorter for Group Q, with a median (IQR) of 16.8 (12.9–22.8) minutes, compared with 19.5 (14.9–26.9) minutes for Group P ($P = 0.001$; Fig. 2A). The hospital stay was also shorter for Group Q, with a median of 5 (4–6) days, compared with 6 (4–7) days for Group P ($P = 0.002$; Fig. 2B). The total intraoperative x-ray radiation dose was lower for Group Q, with a median of 2.8 (2.2–4.6) mGy, compared with 3.3 (2.4–4.9) mGy for Group P ($P = 0.019$; Fig. 2C).

The surgical success rates for Groups Q and P were not significantly different (98.8% vs 97.5%; $P > 0.05$). Regarding postoperative side effects, Group Q included 14 incidents of masseter weakness and 144 incidents of facial numbness. Group P included 19 incidents of masseter weakness and 166 incidents of facial numbness. Regarding postoperative complications, Group Q included 35 incidents of herpes labialis, one incident of decreased corneal reflex, one incident of diplopia, and no intraoperative puncture-related hematomas. Group P included 47 incidents of herpes labialis, one incidents of decreased corneal reflex, 3 incidents of diplopia, and 3 incidents of intraoperative puncture-related hematomas. No incidents of arteriovenous fistulae or arterial bleeding were observed in either group. There was no significant difference in the occurrence rate of surgery-related side effects and complications between the 2 groups ($P > 0.05$; Table 3).

Discussion

Pear-shaped balloon expansion within Meckel's cave is the key to successful PBC surgery. Inserting a needle into the foramen ovale is a prerequisite, and only by smoothly inserting the balloon catheter into the ideal position in Meckel's cave through the puncture path can the desired pear-shaped balloon expansion be achieved (14).

In clinical practice, we observed that successful puncture of the foramen ovale and smooth placement of the balloon on the first attempt are challenging; multiple punctures are common. The difficulty of the first successful puncture of the foramen ovale is related to the following factors: first, the morphology and size of the foramen ovale vary significantly among individuals. Second, the central region of the foramen ovale may have bony partitions, or nodular or spiky protrusions at its edges. Cranial base depressions or ossification of the adjacent ligaments can also lead to changes in the structure and position of the foramen ovale (15-17).

The anterior and posterior bony structures overlap in the fluoroscopic imaging. Repeated probing and adjustment of the puncture needle increases the risk of penetrating other cranial foramens and vascular or nerve injuries, as well as increasing the difficulty of sub-

Table 2. ***Demographic and Baseline Characteristics of Patients***

	Group P n = 201	Group Q n = 170	*P* value
Gender, men/women	81/120	52/118	0.052
Age, years	68 (58,75)	65 (59,73)	0.094
Pain location, left/right	82/119	73/97	0.676
Disease duration, mos	36 (12,96)	36 (12,93)	0.890
Preoperative pain NRS-11	6 (5,6)	6 (5,6)	0.998

NRS-11 = Numeric Rating Scale

sequent punctures and balloon catheter placements. Improper balloon placement may lead to an irregular shape upon inflation, compressing the adjacent structures around Meckel's cave, or creating false lumens. This can increase the challenge of reintroducing the balloon catheter into Meckel's cave.

The classic Hartel method solely includes anatomical information and designing the specific puncture

Table 3. *Primary and Secondary Outcomes*

Outcome	Group P n = 201	Group Q n = 170	Difference (95% CI)	*P* value
Primary Outcome				
Success rate of the foramen ovale puncture on the first attempt, n(%)	133 (66.2)	129 (75.9)	-9. 7(-18.9,-0.5)	0.041
Success rate of initial placement of balloon catheter, n(%)	126 (62.7)	129 (75.9)	-13.2 (-22.5,-3.9)	0.006
Radiation dosage, mGy	3.3 (2.4,4.9)	2.8 (2.2,4.6)	0.4 (0.1,0.7)	0.019
Operation time, min	19.5 (14.9,26.9)	16.8 (12.9,22.8)	2.6 (1.0,4.1)	0.001
Length of hospital stay, days	6 (4,7)	5 (4,6)	1 (0,1)	0.002
Secondary Outcome				
Surgical success rate, n(%)	196 (97.5)	168 (98.8)	-1.3 (-4.0,1.4)	0.460
Masseter weakness, n(%)	19 (9.5)	14 (8.2)	1.2 (-4.6,7.0)	0.682
Facial numbness, n(%)	166 (82.6)	144 (84.7)	-2.1 (-9.7,5.4)	0.583
Herpes labialis, n(%)	47 (23.4)	35 (20.6)	2.8 (-5.6,11.2)	0.518
Decreased corneal reflex, n(%)	1 (0.5)	1 (0.6)	-0.1 (-1.6,1.4)	1.000
Diplopia, n(%)	3 (1.5)	1 (0.6)	0.9 (-1.1,2.9)	0.628
Facial hematoma, n(%)	3 (1.5)	0 (0)	1.5 (-0.2,3.2)	0.253
Arteriovenous fistula, n(%)	0 (0)	0 (0)	-	1.000
Arterial bleeding, n(%)	0 (0)	0 (0)	-	1.000

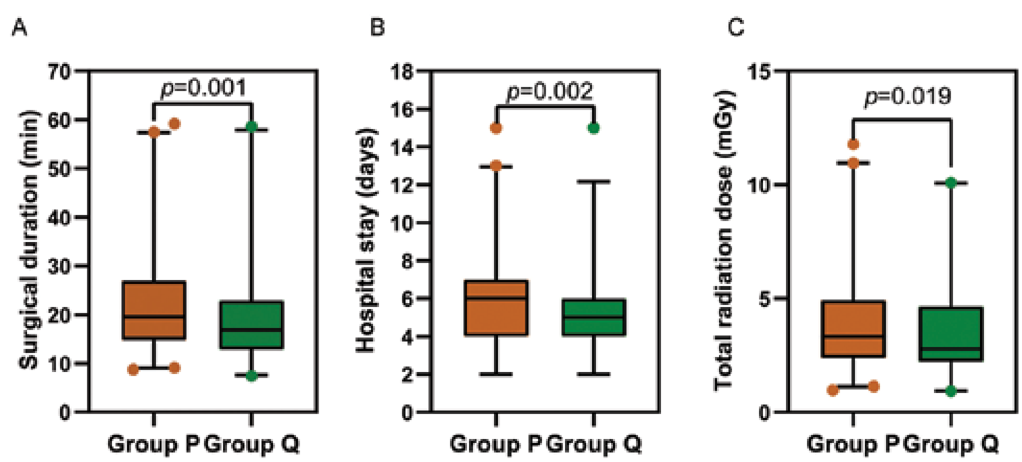

Fig. 2. *Reduction in the surgery duration, hospital stay, and total radiographic radiation dose in Group Q compared to those in Group P*
A. The surgical duration was shorter in Group Q, with a median (interquartile range) of 16.8 (12.9–22.8) minutes, compared with 19.5 (14.9–26.9) minutes in Group P (P = 0.001).
B. The length of hospital stay was also shorter in Group Q with a median (IQR) of 5 (4–6) days, compared with 6 (4–7) days in Group P (P = 0.002).
C. The intraoperative total X-ray radiation dose was lower in Group Q, with a median (IQR) of 2.8 (2.2–4.6) mGy, compared with 3.3 (2.4–4.9) mGy in Group P (P = 0.019).

path relies on intraoperative imaging. In contrast, the quadrant localization technique integrates both anatomical and imaging information and provides a specific puncture path. Considering that Meckel's cave is located posterior and medial to the foramen ovale, and the trigeminal ganglion is typically located adjacent to the bony surface at the base of the middle cranial fossa, we have provided specific information on the puncture point and puncture angle.

Images of the foramen ovale in the cranial base axis position are divided into 4 quadrants. Puncture is performed from the outer upper quadrant toward the inner lower quadrant. In the coronal plane, the needle trajectory closely overlaps with the line connecting the center points of the foramen ovale and the center points of Meckel's cave. In the sagittal plane, the needle trajectory is directed toward the bottom of Meckel's cave, with the inner lower quadrant of the foramen ovale closer to the anterior wall. Through planning and adjustment of these 2 vectors, the success rate of first-time puncture of the foramen ovale, and the initial placement of the balloon catheter, is maximized.

Therefore, compared to the classic Hartel method, the quadrant localization technique can provide surgeons with a more specific puncture path, reduce blind attempts during puncture, and improve surgical efficiency. In our study, using quadrant positioning puncture technology resulted in a higher success rate for first-time foramen ovale puncture (75.9% vs 66.2%) and initial placement of the balloon catheter (75.9% vs 62.7%). The quadrant localization technique improved the success rates of key steps in PBC surgery, not only reducing the surgical duration (16.8 minutes vs 19.5 minutes), but also decreasing the radiation exposure for both patients and surgeons (2.8 mGy vs 3.3 mGy) (18). We found that Group Q had a shorter average hospital stay than Group P did, which undoubtedly represents a dual benefit regarding both time and hospital expenses for patients.

In our study, the immediate postoperative pain relief rates were 98.8% and 97.5% in Groups Q and P, respectively. There was no significant difference in the success rates between the 2 groups, which is consistent with previous clinical reports (19). We hypothesize that this may be related to the surgeons being experienced and that senior physicians performed the procedures in both groups.

Hemorrhage is a common complication of PBC. Facial hematomas are primarily caused by damage to the main trunk and branches of the maxillary artery located within the puncture area during needle insertion (20). In our study, there were 3 incidents of facial hematomas in Group P; upon reviewing the intraoperative images of these 3 incidents, the puncture needles had been directed from the lower quadrant of the foramen ovale to the upper quadrant, potentially increasing the likelihood of contact and damage to the maxillary artery. Group Q did not experience any facial hematomas; this is because the puncture route before entering the foramen ovale was positioned slightly above and outside the cranial base axis, away from the course of the maxillary artery. Therefore, the likelihood of the needle tip coming into contact with the maxillary artery was reduced. The spinous foramen is located on the posterior lateral side of the foramen ovale, and arterial bleeding is often related to injury of the meningeal artery running through the spinous foramen (21). Following the puncture route of quadrant localization, the puncture needle tip was positioned in the lower inner quadrant of the foramen ovale, away from the structures within the upper lateral quadrant of the foramen ovale; therefore, the probability of middle meningeal artery injury was minimized. Group Q did not experience arterial bleeding.

Limitations and Prospects

The classic Hartel method is a percutaneous foramen ovale puncture method. Other minimally invasive treatments for trigeminal neuralgia, such as radiofrequency ablation, also utilize the Hartel method. Currently, our quadrant localization technique has only been attempted in balloon compression surgery. It remains unclear whether this new puncture method can be applied to other surgeries requiring percutaneous puncture of the foramen ovale and whether it offers advantages in improving puncture efficiency, reducing puncture time, and minimizing complications. More clinical trials and further research are needed to explore these possibilities.

In addition, there are some limitations to this study. First, we did not provide postdischarge information, including pain recurrence rate and postoperative long-term complications. We focused on the effect of 2 positioning techniques on surgical efficiency, and therefore mainly collected data on surgery and hospitalization. However, if patients in Group Q exhibit fewer long-term complications and a better pain recurrence rate, it would further demonstrate the advantages of the quadrant localization technique. Second, the patient cohorts originated from a single institution, thereby rendering the results susceptible to potential influence from specific institution practices and patient characteristics, thus restricting the generalizability of the technique. Moreover, the surgeries in both groups were performed by various physicians; differences in puncture techniques, image localization, and other aspects among these physicians may have introduced bias. These limitations provide guidelines for future prospective studies.

Conclusions

Our study demonstrates that, compared with the conventional Hartel anterior approach puncture method, the quadrant localization technique can assist surgeons achieve faster foramen ovale puncture and balloon catheter placement under the guidance of C-arm fluoroscopy, thereby improving the efficiency of PBC surgery and reducing intraoperative radiation dose and hospital stay. Additionally, it may reduce the risk of maxillary artery injury. This technique is easy to master, does not require additional imaging devices, and is suitable for clinical use.

Author Contributions

The study was designed by JXH and TYC.

Statistical analysis was performed by TYC.

The figures were illustrated by ZW and TYC.

All authors contributed to the preparation of the manuscript and reviewed and approved the content of the final version of the manuscript.

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