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CASE REPORT

Intravascular ultrasonography assisted carotid artery stenting for treatment of carotid stenosis: Two case reports

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Abstract

BACKGROUND

Digital subtraction angiography (DSA), the gold standard of cerebrovascular disease diagnosis, is limited in its diagnostic ability to evaluate arterial diameter. Intravascular ultrasonography (IVUS) has advantages in assessing stenosis and plaque nature and improves the evaluation and effectiveness of carotid artery sten-ting (CAS).

CASE SUMMARY

Case 1: A 65-year-old man presented with a five-year history of bilateral lower limb weakness due to stroke. Physical examination showed decreased strength (5-/5) in both lower limbs. Carotid artery ultrasound, magnetic resonance angiography, and computed tomography angiography (CTA) showed a right proximal internal carotid artery (ICA) stenosis (70%-99%), acute cerebral infarction, and severe right ICA stenosis, respectively. We performed IVUS-assisted CAS to measure the stenosis and detected a low-risk plaque at the site of stenosis prior to stent implantation. Post-stent balloon dilatation was performed and postoperative IVUS demonstrated successful expansion and adherence. CTA six months postoperatively showed no significant increase in in-stent stenosis. Case 2: A 36-year-old man was admitted with a right common carotid artery (CCA) dissection detected by ultrasound. Physical examination showed no positive neurological signs. Carotid ultrasound and CTA showed lumen dilation in the proximal CCA with an intima-like structure and bulging in the proximal segment of the right CCA with strip-like low-density shadow (dissection or carotid web). IVUS-assisted DSA confirmed right CCA dissection. CAS was performed and intraoperative IVUS suggested a large residual false lumen. Post-stent balloon dilatation was performed reducing the false lumen. DSA three months postoperatively indicated good stent expansion with mild stenosis.

CONCLUSION

IVUS aids decision-making during CAS by accurately assessing carotid artery wall lesions and plaque nature preoperatively, dissection and stenosis morphology intraoperatively, and visualizing and confirming CAS postoperatively.

Key Words: Intravascular ultrasonography; Carotid artery stenting; Carotid stenosis; Arteriosclerotic stenosis; Carotid artery dissection; Case report

Core Tip: Intravascular ultrasonography (IVUS) improves carotid artery stenting (CAS) evaluations and outcomes *vs* those of the traditional gold-standard, digital subtraction angiography (DSA). We present two cases of cerebrovascular diseases. Case 1 involves a 65-year-old patient with stroke. IVUS-assisted CAS was performed after right proximal internal carotid artery stenosis was diagnosed *via* DSA. Preoperative IVUS imaging showed a low-risk plaque and accurately measured the stenosis. Postoperative IVUS confirmed good stent expansion and adherence, and the patient had no discomfort at 4-mo follow-up. Case 2 involves a 36-year-old patient with common carotid artery dissection, confirmed *via* IVUS-assisted DSA, and CAS was performed. Intraoperative and postoperative IVUS imaging showed the size of the true and false lumen, assisted in treatment decision-making, and confirmed CAS outcomes. This paper highlights the crucial role of IVUS in decision-making during CAS. IVUS can facilitate the accurate assessment of carotid artery wall lesions and plaque nature preoperatively, measure stenosis and true and false lumen size intraoperatively, and confirm CAS effects postoperatively.

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INTRODUCTION

Intravascular ultrasonography (IVUS) is a novel method for diagnosing vascular diseases. It involves placing a miniaturized ultrasound transducer into the lumen of a vessel using catheter technology to produce a cross-sectional image of blood vessel morphology[1].

In recent years, neurologists have shown increasing interest in utilizing the advantages of IVUS for the treatment of cerebrovascular diseases. Further, by advancing research and development, the widespread application of IVUS has become increasingly urgent owing to the high incidence and disability rate of stroke[2,3]. IVUS not only provides high-resolution images of vessel walls and lumens but it can also distinguish various arterial plaque components and irregular structures in vessel walls based on differences in echo intensity[4]. IVUS has become a powerful tool for diagnosing and treating endovascular lesions (such as arterial dissection and arterial stenosis), specifically for preoperative evaluation and postoperative optimization in carotid artery stenting (CAS)[5-7]. IVUS is used to preoperatively evaluate the characteristics of carotid plaques and measure the length and diameter of diseased blood vessels to select the appropriate stent [4,8]. Postoperative examinations of plaque protrusions using IVUS have been shown to be more accurate than those of digital subtraction angiography (DSA)[9]. IVUS is used postoperatively for several reasons, including: (1) To determine whether or not the stent fully expands and tightly adheres to the wall; (2) To observe complications (*e.g.*, plaque protrusion or fragmentation)[10]; (3) To quickly manage issues to optimize postoperative results; and (4) To reduce the risk of stroke[11,12]. We present two patients who underwent IVUS-assisted CAS followed by a literature review to improve the management of CAS.

CASE PRESENTATION

Chief complaints

Case 1: The patient, a 65-year-old male, presented with prolonged bilateral weakness in the lower limbs for five years due to sequelae of a stroke that occurred in July 2022.

Case 2: In July 2022, a 36-year-old male patient was admitted due to a right common carotid artery (CCA) dissection detected by a carotid ultrasound one day previously, which also revealed an occlusion in the left CCA.

History of present illness

Case 1: Computed tomography (CT) angiography (CTA) performed 10 d prior to hospital admission showed severe right posterior cerebral artery stenosis and possible basilar artery occlusion. CT perfusion (CTP) imaging showed decreased blood perfusion and blood volume in the right anterior and middle cerebral artery territory.

Case 2: The patient felt no discomfort and was not treated with medication at that time.

History of past illness

Case 1: The patient had a history of hypertension, diabetes mellitus, and smoking for more than 10 years, and had undergone percutaneous coronary intervention two years previously for coronary heart disease.

Case 2: The patient had no previous history of chronic diseases, smoking, or drinking.

Personal and family history

Two patients' personal and family histories were unremarkable.

Physical examination

Case 1: Physical examination at admission showed decreased muscle strength in the lower extremities (5-/5) but no other abnormal neurological signs.

Case 2: Physical examination at admission showed no positive neurological signs.

Laboratory examinations

Case 1: Laboratory analyses reported that syphilis and human immunodeficiency virus antibodies were negative, serum myoglobin, creatine phosphokinase, troponin I, B-type natriuretic peptide, and D-dimer levels were within normal limits, and thyroid and coagulation function indices showed no abnormalities. Abnormal laboratory findings are presented in Table 1.

Case 2: Laboratory analysis showed normal levels of serum electrolytes, cholesterol, myoglobin, creatine phosphokinase, troponin I, B-type natriuretic peptide, glycosylated hemoglobin, D-dimer, antistreptolysin O, rheumatoid factor, C-reactive protein, anti-cyclic citrullinated peptide, anti-nuclear, extractable nuclear antigen, anti-ds-DNA, and antineutrophil cytoplasmic and anticardiolipin antibodies. Red and white blood cell counts and the erythrocyte sedimentation rate were within normal limits. Serum liver, kidney, thyroid, and coagulation function indices showed no abnormalities.

Imaging examinations

Case 1: Carotid artery ultrasound showed bilateral carotid intima-media thickening, plaque formation, and right proximal internal carotid artery (ICA) stenosis (70%-99%). Brain magnetic resonance imaging (MRI) revealed a paraventricular white matter lesion in the right frontal lobe (Figure 1A) and a small acute cerebral infarction at the genu of the corpus callosum on diffusion-weighted imaging (Figure 1B). Head and neck CTA showed severe stenosis of the initial segment of the right ICA and right posterior cerebral artery, and CTP imaging reported decreased blood perfusion in the right anterior and middle cerebral artery territory. DSA revealed: (1) The persistent trigeminal artery compensated for the basilar artery supply; (2) Bilateral fetal-type posterior cerebral artery; (3) 70% stenosis of the initial segment of the right ICA (Figure 1C); (4) 80% stenosis of the local P2 segment of the right posterior cerebral artery; and (5) Mild stenosis of the CCA and initial segment of the external carotid arteries.

Case 2: Electrocardiogram, ambulatory blood pressure monitoring, echocardiogram, and ultrasound of the renal arteries and abdominal aorta results were unremarkable. Arterial ultrasounds of the lower extremities showed inhomogeneous thickening of the intima in artery segments on both sides and stenosis of the right common femoral artery and left superficial femoral artery (nearly occluded). Chest CT imaging reported scattered, patchy high-density lesions in both lungs (pneumonia was considered). Carotid ultrasound revealed a left CCA occlusion, right carotid artery stenosis, and local lumen dilation in the proximal CCA with an intima-like structure. Brain MRI showed no obvious abnormalities. Head and neck CTA showed left CCA occlusion (Figure 2A) and local bulging in the inferior segment of the right CCA with a strip-shaped low-density shadow (dissection or carotid web were considered, Figure 2B). Brain CTP images (Figure 2C) revealed that blood flow perfusion in the left frontal lobe, parietal lobe, right temporal lobe, and insula was lower than that on the contralateral side. Aortic arch angiography revealed an initial segment of the left CCA occlusion (Figure 2D). Angiography of the right CCA reported an initial segment of dissection (Figures 2E and F).

Table 1 Abnormal laboratory findings reported in cases 1 and 2

Parameter	Result	Reference range	Interpretation
Patient 1			
White blood cell count, × 10^9/L	10.53	3.5-9.5	Increased
Hemoglobin, g/L	125.0	130-170	Decreased
Urine glucose	2 +	Negative	Increased
Urine protein	1 +	Negative	Increased
C-reactive protein, mg/L	26.12	0-5	Increased
Total protein, g/L	63.7	65.0-85.0	Decreased
Serum glycocholic acid, mg/L	3.74	0.00-2.70	Increased
Serum creatinine, mmol/l	126.1	57-111	Decreased
Urea, mmol/L	9.8	3.6-9.5	Increased
Anticardiolipin antibody IgG, gplu/mL	20.60	< 12	Increased
Anticardiolipin antibody IgA, aplu/mL	26.40	< 12	Increased
Patient 2			
Urine protein	Weakly positive	Negative	Increased
Red blood cells in urine	48.40/μL	0-18/μL	Increased
Fecal occult blood test	Weakly positive	Negative	Increased
Interleukin-6 at 3-mo follow-up, pg/mL	13.56	< 6.6	Increased

IgG: Immunoglobulin G; IgA: Immunoglobulin A.

FINAL DIAGNOSIS

Case 1: Based on the patient's medical history and laboratory and imaging findings, he was given a final diagnosis of stenosis of the right ICA, right posterior cerebral artery, CCA, and external carotid arteries.

Case 2: Combined with the patient's medical history, the final diagnosis was CCA occlusion of the left and right initial segment.

TREATMENT

Case 1: IVUS-assisted CAS utilizing an Eagle Eye Platinum IVUS diagnostic instrument (Volcano Corporation, United States) with a phase array probe (external diameter: 3.5 F; 18.6 MHz) was performed under local anesthesia on day six of hospitalization. First, we performed arteriography of the diseased carotid artery. A 6 F long sheath head end was placed in the right distal CCA, and the road map was redesigned. The end of the catheter reached the C2 segment of the right ICA and a distal protection device was deployed. Next, an IVUS imaging catheter was placed and the road map guided the catheter through the site of the right ICA stenosis. Finally, IVUS imaging confirmed severe right ICA stenosis with plaque formation and noticeable calcification (Figure 1D).

We inserted a 5 mm × 30 mm balloon through the narrowest part of the right ICA and ensured correct positioning. Subsequent angiography demonstrated improved right ICA stenosis. A 7 mm × 40 nm Wallstent™ stent (Boston Scientific Corporation) was then positioned (Figure 1E). Subsequent IVUS confirmed unsatisfactory improvement of the narrowest part of the right ICA (Figure 1F). Therefore, post-stent balloon dilatation was performed.

Case 2: A long sheath was placed in the right distal CCA and a distal protection device was deployed. The IVUS probe was subsequently placed to check the dissection (Figure 2G), and a Wallstent™ stent (Boston Scientific Corporation) was deployed at the site of dissection. IVUS images obtained immediately after stent placement showed insufficient dilation of the true lumen with a large intermural hematoma (Figure 2H) and post-balloon dilatation was performed.

OUTCOME AND FOLLOW-UP

Case 1: Postoperative angiography revealed the right ICA stenosis had noticeably improved (residual stenosis, 20%;

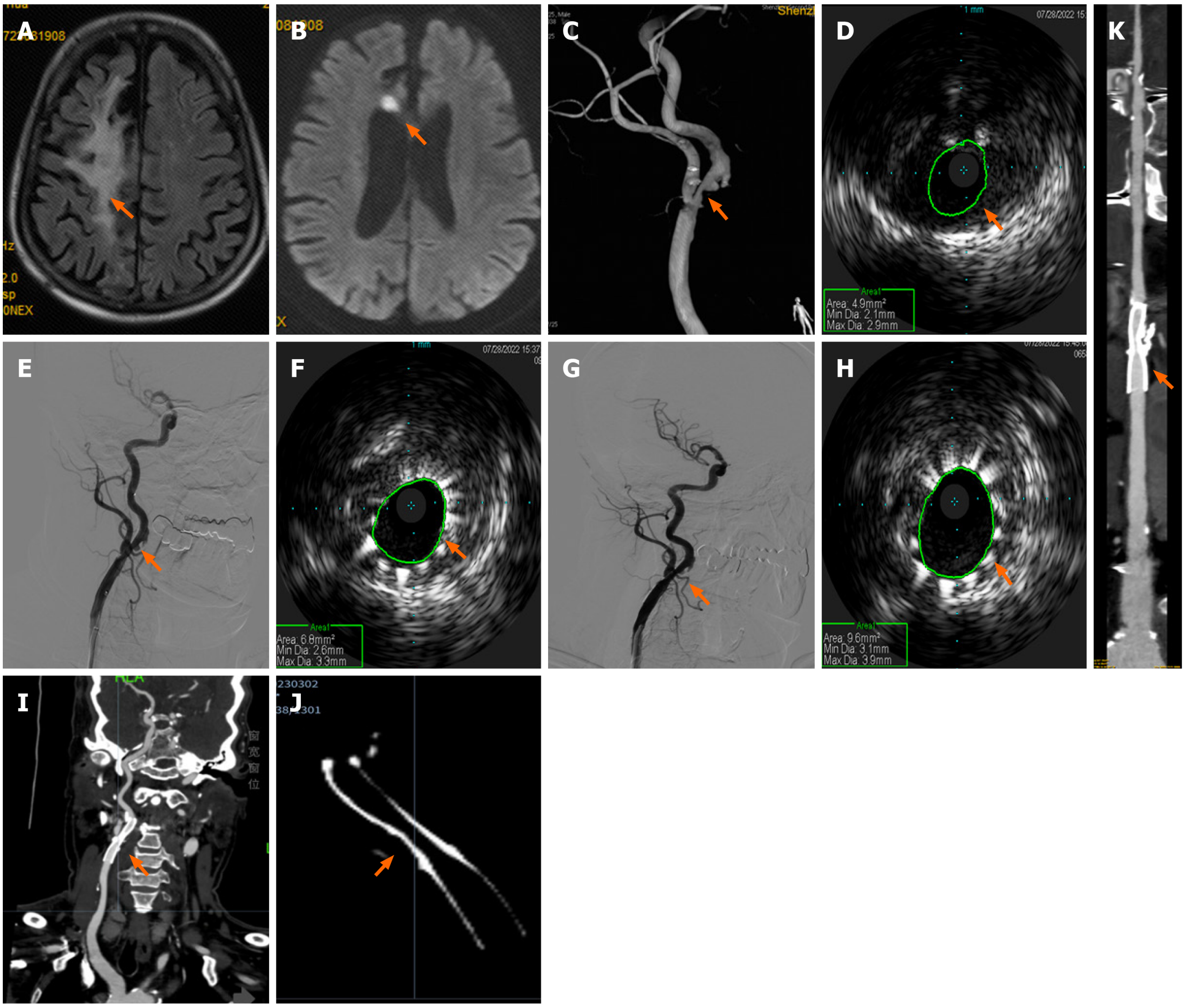

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Figure 1 Neuroimaging results of patient one during intravascular ultrasound-assisted carotid artery stenting. A and B: Brain magnetic resonance imaging demonstrates a paraventricular white-matter lesion in the right frontal lobe (A, arrow) on fluid-attenuated inversion recovery imaging, and a small acute infarction at the genu of the corpus callosum on diffusion weighted imaging (B, arrow); C: Angiography shows 70% stenosis of the initial segment of the right internal carotid artery (ICA) (arrow); D and E: Preoperative intravascular ultrasound (IVUS) displays severe stenosis with plaque formation and obvious calcification under plaque (D, arrow) and a well-positioned stent (E, arrow); F-H: Subsequent IVUS imaging confirmed improvement of the narrowest part (F, arrow), thus post-stent balloon dilatation was performed. Postoperative angiography shows a right ICA residual stenosis of 20% (G, arrow), and IVUS confirmed good stent expansion and adherence (H, arrow); I-K: Computed tomography angiography six months postoperatively revealed mild in-stent stenosis in the right initial segment of the ICA (I, multiplanar reconstruction; J, amplification imaging with adjusting parameters; K, curve planar reformation; arrows).

Figure 1G), and IVUS confirmed good stent expansion and adherence (Figure 1H) without signs of plaque protrusions. CTA at six months postoperatively revealed mild in-stent stenosis in the right initial segment of ICA, with no discomfort reported by the patient (Figures 1I-K). The patient was satisfied with the treatment he received and his recovery.

Case 2: Final angiography showed a smooth intra-arterial lumen (Figure 2I), and postoperative IVUS images showed the true lumen increased in size with good stent expansion and adherence (Figure 2J). The patient experienced no postoperative discomfort, and head CT imaging on postoperative day three showed no definite lesions. DSA three months postoperatively indicated good stent adhesion in the right CCA with mild stenosis (approximately 25%) in the proximal stent. The patient was satisfied with the treatment he received and his recovery.

DISCUSSION

These cases demonstrate that IVUS can accurately determine the cross-sectional area of the narrowest point in the carotid artery and assess the area of the false lumen in arterial dissections, as well as plaque properties. This allows the operator to use IVUS to evaluate the impact of stent placement during the procedure. Specifically, IVUS can effectively detect unsatisfactory stent expansion and improve arterial stenosis by using post-balloon dilatation. The operator can effectively

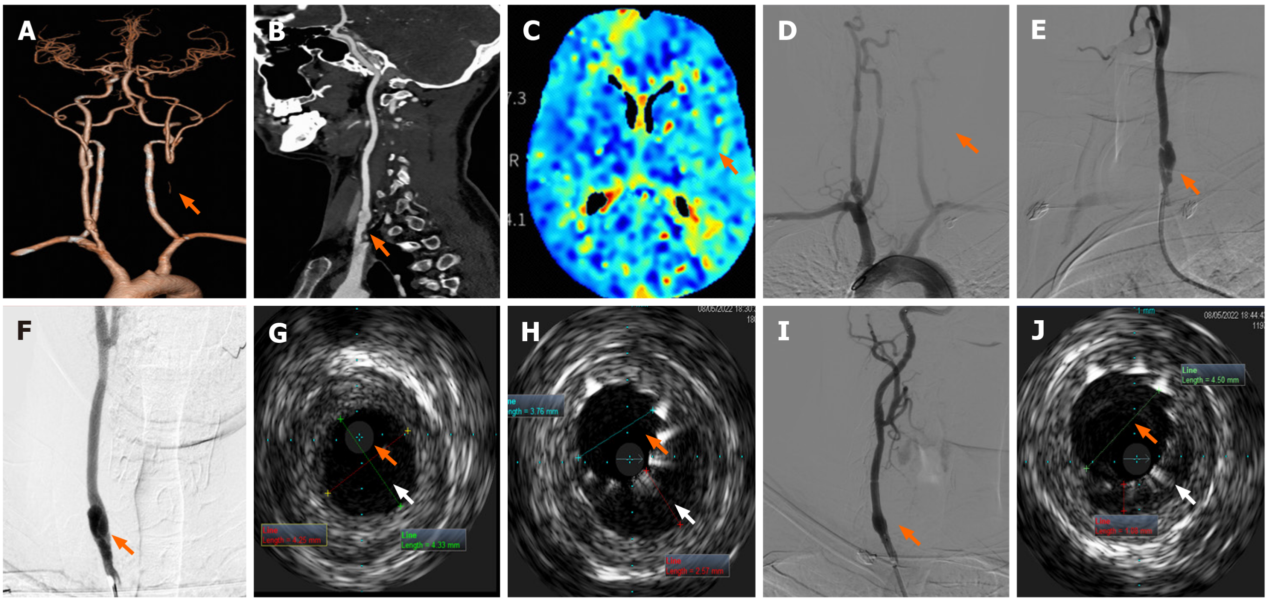

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Figure 2 Neuroimaging results of patient two during intravascular ultrasound-assisted carotid artery stenting. A and B: Head and neck computed tomography angiography showing left common carotid artery (CCA) occlusion (A, arrow) and local bulging in the inferior segment of the right CCA with strip-shaped, low-density shadow (B, arrow); C: Brain computed tomography perfusion images showed that blood flow perfusion in the left frontal lobe, parietal lobe, right temporal lobe, and insula was lower than that on the opposite side (arrow); D-F: Digital subtraction angiography shows the initial segment of the left CCA occlusion (D, arrow) and the initial segment of the right CCA dissection (posteroanterior film, E; left oblique film, F); G: Preoperative intravascular ultrasonography (IVUS) probe check dissection; H: IVUS images after stent placement show insufficient true lumen (orange arrow) with visible intimal flaps, and a relatively large pseudo-lumen (white arrow) with a large intermural hematoma; I: Angiography after post-balloon dilatation showed a smooth intra-arterial lumen; J: Postoperative IVUS images showed that the true lumen enlarged (orange arrow), the pseudo-lumen diminished (white arrow), and confirmed satisfactory stent expansion and adherence.

detect the postoperative residual false lumen using IVUS and accurately guide post-balloon dilatation. These advantageous characteristics of IVUS may help to improve patient prognosis.

IVUS enables a more accurate determination of stent size, expansion, and fit[13]. It also provides real-time intraluminal imaging, which is unavailable with DSA, making it a useful tool for endovascular treatment and pre- or postoperative assessments[14]. IVUS can also provide diagnostic information, specific intraluminal and transmural vessel data with high accuracy, aid the selection of appropriate angioplasty and intravascular devices, and assess intervention effects[12].

The role of IVUS in preoperative CAS

Using IVUS, we can precisely measure the cross-sectional area of the narrowest segment of the artery and false lumen and clarify the nature of the endovascular lesions. IVUS accurately reveals the cross-sectional morphology and changes after balloon dilatation[15]. IVUS plays an important role in preoperative balloon angioplasty and CAS, especially when managing challenging plaques, such as lipidic or fragile plaques[8], and in identifying the nature of stenotic lesions, such as dissection or carotid web. Furthermore, IVUS can be used to calculate the stenosis ratio (by measuring the minimum lumen area and distal reference lumen area), help select the stent diameter and landing zone, assess stent adhesion and expansion, and clarify whether the lesion can be completely covered by the stent. IVUS during CAS provides a more detailed assessment of events, such as atherosclerotic plaque protrusion through the stent cells[16]. Expert consensus provides standards for IVUS acquisition as well as for measuring and reporting boundary, lumen, atheromatous plaque, calcium deposit, reference segment, and lesion length measurements[17]. We measured the minimum and reference lumen area using IVUS and calculated the rate of stenosis to help select the appropriate stent. Identifying carotid artery dissections using IVUS for CAS, determining the size and length of lesions, and guiding the positioning and placement of stents, helps inform operators to make better decisions and improve patency rates[8,18]. In cases where other imaging methods indicate significant variations in the severity or nature of vasculopathy, using IVUS can support the treatment decision-making process[4].

The role of IVUS during CAS

In the second case presented (case 2), intermural hematoma within the dissection was detected by IVUS after stent implantation, followed by post-balloon dilatation. Finally, IVUS indicated the stent was well placed and attached to the wall, noticeably reducing the false lumen. IVUS has unique advantages for the treatment of aortic dissection. IVUS-assisted CAS may be an effective treatment option to prevent intraoperative complications and further stroke recurrence for isolated spontaneous CCA dissection[19]. IVUS compensates for the insufficiency in the assessment of atherosclerotic plaque composition and intravascular arterial morphology, which are difficult to evaluate using DSA[9]. IVUS can also provide information on stent placement to facilitate the successful completion of surgery.

The role of IVUS in postoperative CAS

Postoperatively, IVUS helps to visualize stent placement, adherence, expansion, and complications such as stent edge dissection and determines whether the stent fully covers the lesion to optimize immediate results[20]. In this study, it was demonstrated that IVUS can be utilized to assess stent placement and perform balloon post-dilation to improve vascular stenosis.

Security of IVUS

IVUS is safe to perform during CAS and may not require mechanical protection for small vascular foci, as high-risk lesions can be safely assessed using IVUS under flow blockade[21]. In-stent protrusions (ISP) may occur following CAS, which increases the risk of postoperative embolization. ISP may be related to vulnerable plaques and fragments, and IVUS contributes to the assessment of stent protrusion during CAS[8]. IVUS performs better than DSA in detecting ISP, which is imperative to ensure the proper treatment of ISP which can reduce stroke complications[22].

Development tendency of IVUS

A new type of virtual histology IVUS (VH-IVUS) was recently developed based on grayscale IVUS to detect atherosclerosis. VH-IVUS can identify various tissues with high accuracy, making it useful in identifying high-risk plaques[23]. As manual border detection is time-consuming, VH-IVUS integrates automatic border detection technology and can be used as a diagnostic tool for evaluating the suitability of carotid artery stenosis for CAS. As surgeons become more skilled in operating IVUS, utilizing it to assist stent placement and confirm post-stenting will help to ensure precise positioning and improve patency rates[18]. Continuous improvement has been made to the frequency, bandwidth, and resolution of IVUS probes[24]. The future development trend of IVUS is to innovate materials and improve manufacturing processes and equipment performance. IVUS transducers are miniaturized to meet the imaging requirements for smaller blood vessels [25]. Despite its high value in diagnosis and adjuvant treatment, IVUS is not recommended as a routine intraprocedural evaluation tool, as it is invasive and expensive. Some experts believe the use of IVUS in predicting microembolization remains limited[7].

CONCLUSION

IVUS was utilized preoperatively to evaluate the nature of plaques, measure lesions, reference vessels, and develop a preconditioning strategy. Intraoperative use of IVUS has incomparable advantages over other detection techniques in the identification of artery dissection and assessment of postoperative stent placement and expansion, which may improve patient prognosis. With the continued development of IVUS technology, and as doctors become more familiar with the application and operation of the technology, IVUS is expected to be widely used in interventional diagnosis and treatment.

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FOOTNOTES

Author contributions: Hu MH and Cao LM designed the study and provided resources; Fu PC and Wang JY acquired and analyzed data, and wrote the manuscript; Fu PC and Xu GL performed the interventional procedures; Su Y, Liao YQ, Li SL, and Huang YJ analyzed the imaging and provided constructive discussion; and all authors have read and approved the final manuscript. Fu PC and Wang JY have contributed equally to this work and share the first authorship. Hu MH and Cao LM contributed equally to this work.

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