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### Authors

Hiro, Takafumi  
Leung, Cyril Y  
Russo, Robert J  
[et al.](#)

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# Intravascular Ultrasound Identification of Stent Entrapment In Vivo With In Vitro Confirmation

Takafumi Hiro,<sup>1</sup> MD, Cyril Y. Leung,<sup>1</sup> MD, Robert J. Russo,<sup>2</sup> MD, Paul Teirstein,<sup>2</sup> MD, Lawrence A. Yeatman,<sup>3</sup> MD, and Jonathan M. Tobis,<sup>1\*</sup> MD

**Objectives:** One potential complication of stenting is “stent jail” due to placement of a stent across a side branch, which may impede additional interventions. Another form of stent entrapment may occur if the guidewire is accidentally withdrawn and then unknowingly passes through a stent loop during reentry with subsequent high pressure expansion. The purpose of this study was to evaluate this form of stent entrapment in vitro by intravascular ultrasound (IVUS).

**Methods:** A guidewire was passed through the end or middle diamonds of Palmaz-Schatz and Palmaz stents or the middle of Gianturco-Roubin stents. A 3.5 mm balloon was inflated over the guidewire through the various side holes of the stents.

**Results:** IVUS images presented three distinct patterns depending on the type of stent and position of balloon entry: 1) external compression and loss of wall continuity in the Palmaz-Schatz and Palmaz stents, 2) displacement of the side diamond across the lumen, and 3) external compression of the Gianturco-Roubin stent. The first and second patterns but not the third one were associated with impairment of lumen access.

**Conclusions:** Based upon this in vitro verification, IVUS imaging can be used to identify the presence of stent entrapment in vivo. *Cathet Cardiovasc Diagn* 40:40–45, 1997.

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**Key words:** stent jail; coronary artery; Palmaz-Schatz stent; Gianturco-Roubin stent

## INTRODUCTION

The use of stents in patients with coronary artery disease is increasing at a rapid pace compared to other interventional devices. One potential complication during deployment is the placement of a stent across a side branch, which may impede the insertion of interventional devices to the branch. This has been called “stent jail” [1,2]. Another form of stent entrapment may occur if the guidewire is accidentally withdrawn and then unknowingly passes through a stent loop during subsequent reentry. We recently experienced a form of stent entrapment which was not appreciated by angiography but was diagnosed by intravascular ultrasound (IVUS) due to its distinctive strut morphology. The purpose of this study was to reproduce the conditions of stent entrapment using an in vitro model, and to correlate the IVUS images with conformational changes in the stent so that this can be used during interventions to recognize stent entrapment.

## MATERIALS AND METHODS

### Case Examples

**Case 1.** A 52-year-old man with a history of anterior myocardial infarction and AICD placement developed ischemia on exercise associated with AICD discharges. Angiography revealed multiple stenoses of the right coronary artery (RCA). Three Palmaz-Schatz stents were

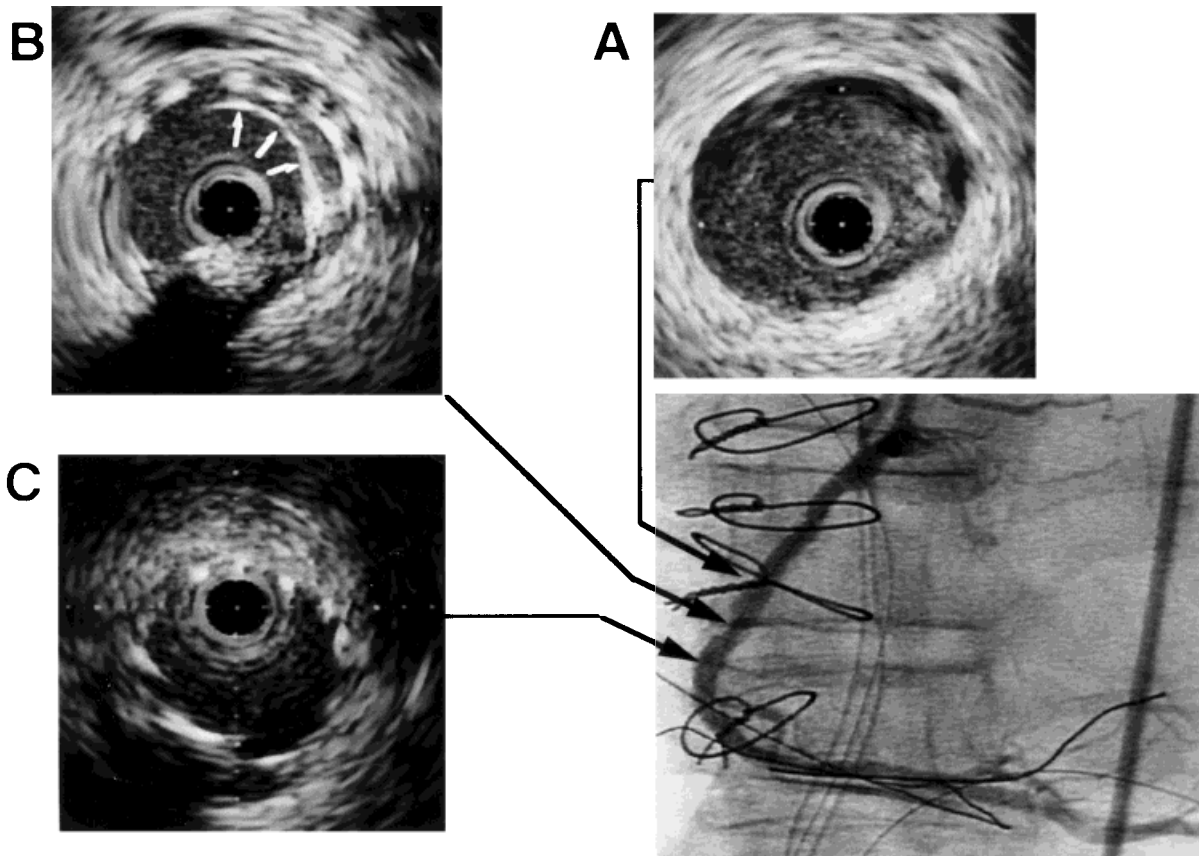
placed in the RCA. Before additional expansion was performed at high pressures, the coronary guidewire was mistakenly withdrawn. The guidewire was repositioned through the stents into the distal RCA. Angiography revealed a suboptimal residual stenosis that did not appear to be hemodynamically significant (Fig. 1), however balloons could not be passed without extreme difficulty through the proximal end of the second stent. The operator felt that there was a residual stenosis which was underestimated by angiography, so additional expansion was performed at 20 atm [3]. During expansion of noncompliant balloons, spontaneous rupture occurred three times. IVUS imaging was performed to help assess why there was still difficulty in inserting deflated balloons through the mid RCA.

From the <sup>1</sup>Division of Cardiology, University of California, Irvine, California, <sup>2</sup>Scripps Clinic and Research Foundation, La Jolla, California, <sup>3</sup>University of California, Los Angeles, California

\*Correspondence to: Jonathan M. Tobis, M.D., Department of Medicine/ Cardiology, University of California at Irvine, Bldg. 53, Route 81, Room 100, 101 The City Drive South, Orange, CA 92668–3298.

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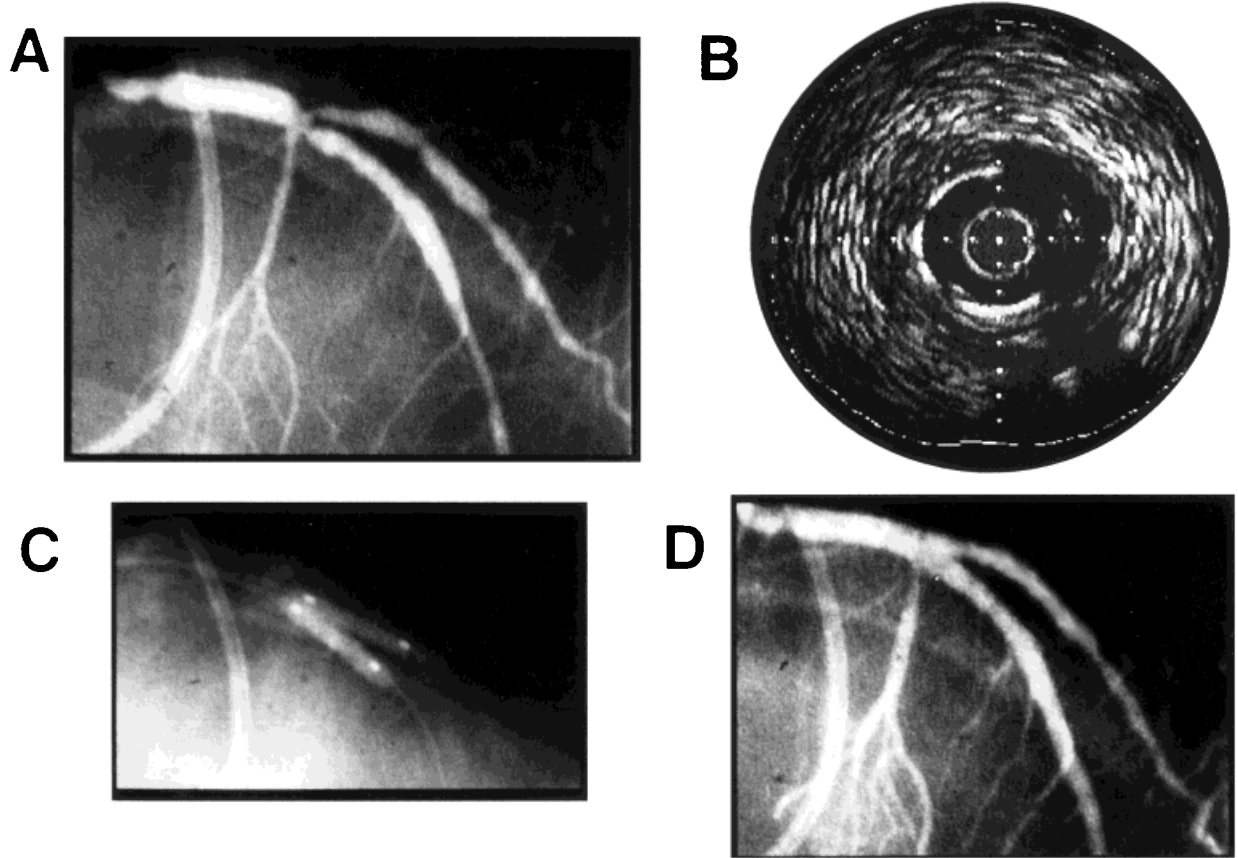
**Fig. 1.** Case 1. Right coronary angiogram in left anterior oblique view (right lower panel). A: IVUS image of the artery proximal to the stent reveals echo reflections of blood in the lumen with mild atherosclerosis. B: IVUS image of deformed stent (arrows) at the proximal end of the second stent. Injected

contrast was observed in the lumen and also between the continuous arc of metal and the stent struts apposed to the vessel wall. C: IVUS image of the distal half of the Palmaz-Schatz stent demonstrates complete apposition of the stent struts.

In the proximal part of the second stent, IVUS detected an unusual image (Fig. 1B) that we had never observed before. Although the stented lumen cross-sectional area was adequate, a metallic appearing, continuous, and curvilinear echo was detected. In addition, it was noted that there was no strut echo on the counterpart of the vessel wall, which is atypical of the IVUS pattern for a Palmaz-Schatz stent. In the distal part of the stent, ultrasound images demonstrated complete apposition and circumferential distribution of the struts (Fig. 1C). We hypothesized that this unusual echo pattern would be produced by distortion of the stent network during high pressure balloon expansion if the guidewire accidentally passed through a stent strut diamond during recrossing. Since the angiographic and IVUS lumen cross sectional area appeared adequate, the procedure was terminated. There has been no recurrence of ischemia on stress testing or spontaneous discharge of the AICD in the year following the procedure.

**Case 2.** A 54-year-old man, 3 years after an orthotopic heart transplant, underwent angiography which revealed

significant stenoses of the left anterior descending artery (LAD) at the bifurcation of the first diagonal branch (Fig. 2A). A Gianturco-Roubin stent was placed in each of the branches with a common proximal segment in the LAD (“Y” deployment). The stent to the LAD was deployed first after removing the wire to the diagonal branch. The wire in the LAD was then repositioned across the diagonal branch and a second Gianturco-Roubin stent was deployed with 10 mm of overlap into the proximal LAD stent and inflated to 18 atm. An attempt was made to perform simultaneous high pressure expansion in the diagonal and LAD by re-inserting a second wire down the LAD. However, after recrossing the stent in the LAD with prolapse of the wire tip, the second balloon could not be advanced. It was unclear whether this was due to guidewire entrapment under the stent or simple winding of the second wire around the first balloon catheter. To make this distinction, IVUS was performed. IVUS revealed that the stent was correctly apposed to the vessel wall and the pathway of the IVUS catheter was central and not entrapped (Fig. 2B). Therefore, the catheter in the



**Fig. 2.** Case 2. A: Left coronary angiogram in the cranio-caudal right anterior oblique view shows stenoses at the bifurcation of the LAD and diagonal branch. B: IVUS image of the Gianturco-Roubin stent in the left anterior descending artery. The stent is

well apposed to the wall and the pathway of the IVUS catheter is central in the lumen and not impeded by the stent. C: Simultaneous expansion of the two stents at the bifurcation of the LAD and diagonal arteries. D: Angiogram of final result

diagonal and the LAD guidewire were withdrawn. The LAD stent was recrossed with a wire, and the two balloons then passed without difficulty at the bifurcation (Fig. 2C).

**In Vitro Study**

To reproduce the conditions in case 1, Palmaz-Schatz, Palmaz, and Gianturco-Roubin stents were used in an in vitro study. After expansion of each stent by a 3.0 mm balloon to 6 atm, a guidewire was passed through one of the strut diamond holes of the Palmaz-Schatz and Palmaz stents or the middle of the Gianturco-Roubin stent in a direction from outside the stent to inside the lumen (Fig. 3A). A 3.5 mm balloon was inflated over the guidewire through the side of the stents at 20 atm (Fig. 3B). The metal struts compressed by the externally placed balloon were distorted and bent inward. This produced a form of stent entrapment which could impair the passage or removal of subsequent angioplasty balloons. These experimentally produced stent compressions were imaged with

a 30 MHz IVUS catheter (Boston Scientific) and a Hewlett-Packard ultrasound console at room temperature in a saline bath.

**RESULTS**

IVUS images of Palmaz-Schatz and Gianturco-Roubin stents after normal expansion are shown in Figures 4 and 5. Except for the number of struts and the presence of the articulation site, Palmaz stents provided ultrasound images similar to that of the Palmaz-Schatz stent. The Palmaz-Schatz stent has three typical echo patterns depending on the cross section that is imaged: 1) 12 struts in a circular distribution; 2) 6 thicker strut echoes which correspond to the junction of each diamond; 3) a single intense echo which corresponds to the articulation site (Fig. 4). The Gianturco-Roubin stent has a single discontinuous echo arc of various length which depends on the position of the cross section (Fig. 5). Each strut echo is often associated with radial tail echoes behind the strut

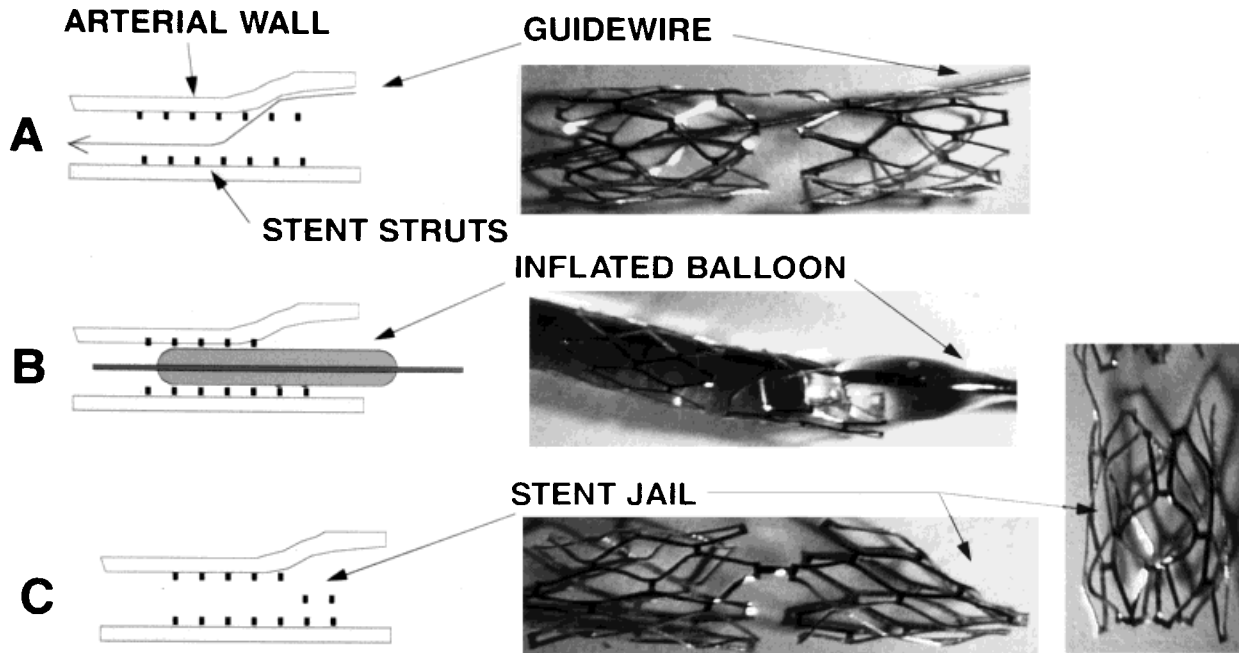


Fig. 3. A–C: Possible mechanisms of stent entrapment of the Palmaz-Schatz stent studied in our model.

due to reverberation of the ultrasound and vibration of the metal struts [4,5]. This echo tail is attenuated when the stent is apposed to the vessel wall due to decrease in the degree of vibration of the metal.

IVUS images following reentry of the balloon through the side of the stent reveal three distinct patterns depending on the type of stent and the position of balloon entry (Figs. 6 and 7). In the Palmaz-Schatz stent, there are three kinds of diamond holes, shown as A, B, and C in Figure 6. When the guidewire passes through the middle of the stent (diamond A), the subsequent stent compression provides two noncontinuous strut echo spots inside the lumen (Fig. 6I). When the guidewire passes through the most proximal hole (diamond B), the subsequent stent compression is detected as an intense, continuous and curvilinear echo due to displacement of the side strut across the lumen (Fig. 6II). This ultrasound image corresponds to that observed in case 1. Passage of the guidewire through diamond C provides a similar ultrasound image as that of diamond B. If the guidewire passes through the articulation, half of the stent is compressed and the echo pattern is similar to Figure 6I. When the guidewire passes from inside to outside of the diamond struts, similar but reversed patterns are seen.

With the Gianturco-Roubin stents, recrossing with a guidewire and balloon compression yielded a similar echo pattern regardless of the place of guidewire entry (Fig. 7). There was an irregular compact mesh of echoes

on one side of the vessel wall (Fig. 7). This form of stent compression did not inhibit advancement of the balloon catheter, compared to the Palmaz or Palmaz-Schatz stents.

During the in vitro experiments, several balloons ruptured (mean = 18 atm) similar to our experience in case 1 when they were placed through the stent diamond and inflated at high pressure. This occurred particularly with the Palmaz stent, presumably due to the thicker metal compared to the other types of stent (0.0025 in. vs. 0.0055 in.).

## DISCUSSION

The term “stent jail” has been used to describe the consequences when a stent is deployed across a side branch and interferes with the passage of interventional catheters [1]. A study of the immediate and long-term patency of lesion-associated side branches after Palmaz-Schatz stent deployment demonstrated that 1) acute side branch occlusion due to coronary stenting occurs infrequently (5%); 2) when side branch occlusion occurs, it is associated with intrinsic ostial disease; and 3) the patency of side branch ostia is well maintained at long-term follow-up. Another potential problem associated with stent jail is the interference to passage of additional interventional catheters into the side branch. Guarneri et al. tested several balloons in vitro and found that some

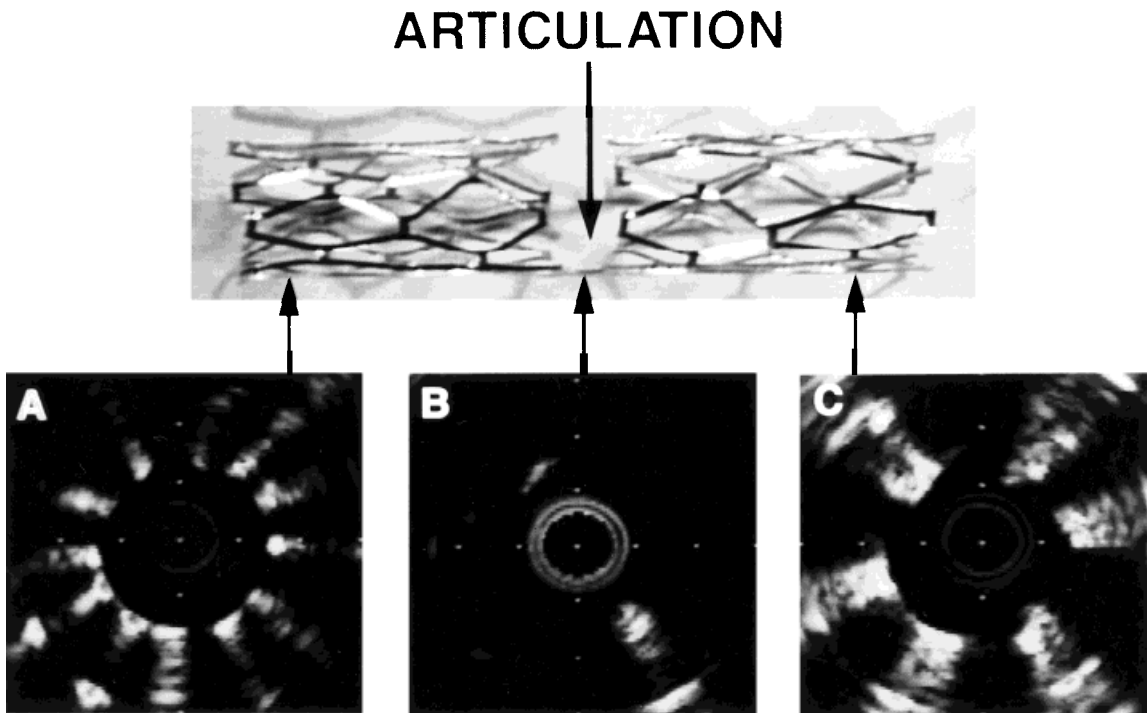


Fig. 4. A-C: IVUS images of a Palmaz-Schatz stent in vitro.

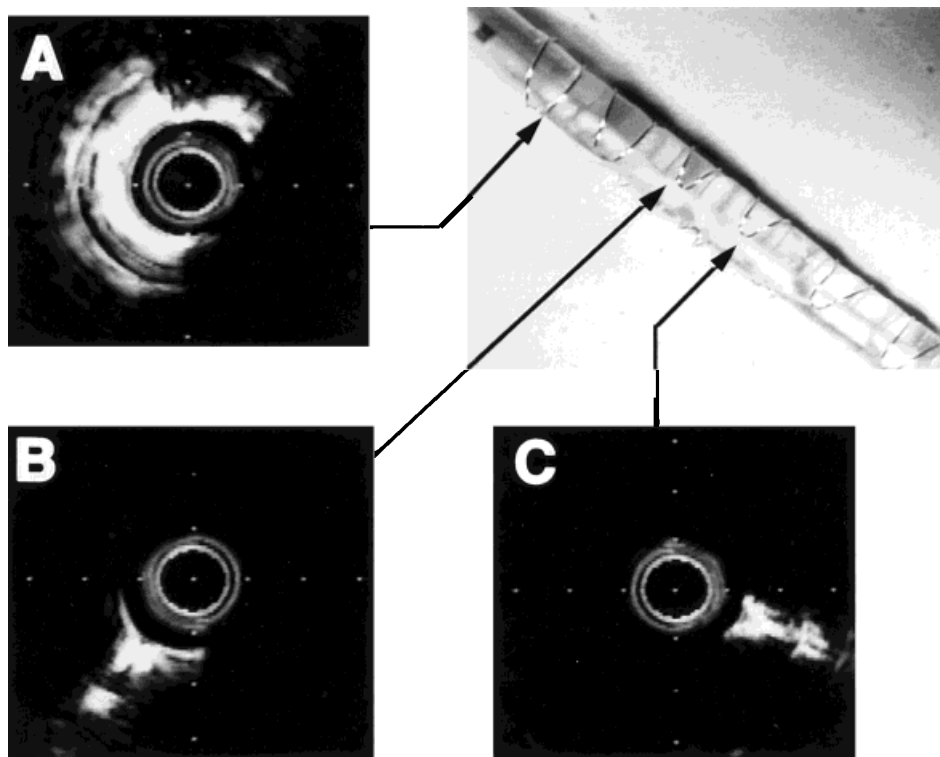


Fig. 5. A-C: IVUS images of a Gianturco-Roubin stent in vitro.

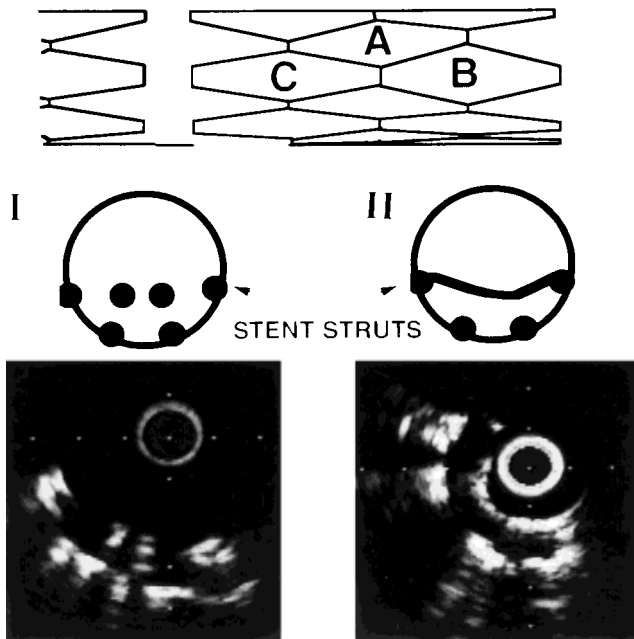


Fig. 6. IVUS patterns of entrapment with the Palmaz-Schatz stent.

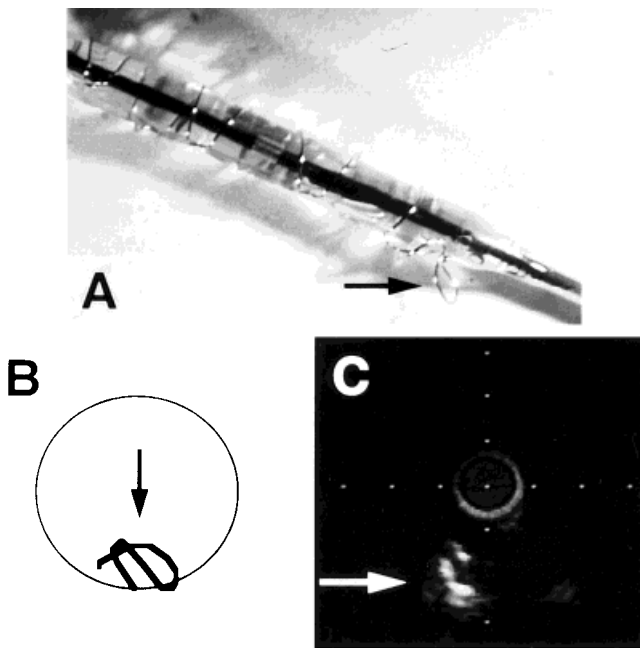


Fig. 7. A–C: IVUS image of stent distortion with the Gianturco-Roubin stent.

pass easier than others through a Palmaz-Schatz stent into a side branch [2].

In this study, another type of stent entrapment was demonstrated in vivo by IVUS and confirmed in vitro. In this situation, a repositioned guidewire was inadvertently

threaded through the diamond hole of a Palmaz-Schatz stent and subsequent high pressure inflations compressed the stent into the lumen. This form of stent entrapment can not be recognized by angiography. IVUS was able to recognize the presence of the stent entrapment and helped to understand the mechanism.

In the second case, IVUS distinguished the pathway of the guidewire and demonstrated that stent entrapment was not the cause of resistance to the balloon catheters. Recrossing Gianturco-Roubin stents incorrectly with a guidewire is not as critical a problem as with the Palmaz-Schatz stent. Although compression of the Gianturco-Roubin stent to one side decreases the structural support of the stent, it does not impede passage of other balloons. Another stent can be inserted if this condition is recognized clinically by IVUS imaging.

IVUS imaging has played a significant role in enhancing our knowledge about the mechanism of stenting [6] or how stent deployment can be optimized [7]. The recognition of stent entrapment is also facilitated by IVUS and is frequently not apparent by angiography. IVUS imaging is necessary as a complementary tool particularly in cases of stenting complicated lesions.

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