European Radiology (2019) 29:5007–5012
https://doi.org/10.1007/s00330-019-06015-z

VASCULAR-INTERVENTIONAL

# Percutaneous endovascular tissue sampling of endoluminal tumors using directional atherectomy

Alexander Massmann[1] · Roland Seidel[1] · Günther K. Schneider[1] · Arno Buecker[1] · Peter Fries[1]

Received: 26 August 2018 / Revised: 14 December 2018 / Accepted: 17 January 2019 / Published online: 22 February 2019


## Abstract

**Objectives** To evaluate technical feasibility and safety of endovascular tumor specimen sampling using an escalating endovascular biopsy strategy using a directional atherectomy device compared with forceps biopsy and catheter aspiration.

**Materials and methods** Between 2013 and 2017, a cohort of ten consecutive patients (6 male; median age 56, range 39–73 years) was referred for sampling of endovascular masses. Localizations included the abdominal aorta ($n = 4$), left brachiocephalic vein ($n = 2$), inferior vena cava ($n = 1$), and left pulmonary artery ($n = 3$). For each individual mass, all three endovascular tissue sampling approaches were applied including catheter-based aspiration, straight two-jaw biopsy forceps, and directional atherectomy during a single session.

**Results** Aspiration and forceps biopsy did not provide sufficient material for histological analyses. In contrast, technical success for endovascular tumor sampling using directional atherectomy was 100%. After two atherectomy passages, sufficient material was available for each vessel region allowing histologic diagnosis, which revealed sarcoma and chronic inflammation for masses in the aorta, angiosarcoma for brachiocephalic vein, hepatocellular carcinoma for inferior vena cava, and angiosarcoma for pulmonary artery. In case of a histologically benign diagnosis, no malignant tumor proliferation was obvious on follow-up imaging studies after 3 months and 1 year. Thus, the rate of false-negative results was considered 0%. No procedure-associated complications, e.g., vessel perforation, were recorded.

**Conclusion** Preliminary results in a limited number of patients proved directional atherectomy beneficial as a safe and feasible technique for endoluminal tissue sampling of vascular masses. Additional large-scale studies are necessary and worthy for further evaluation in clinical practice.

**Key Points**

- *Endovascular masses pose a challenge to appropriate clinical management.*
- *Off-label directional atherectomy proved to be a safe and feasible technique for endoluminal tissue sampling of vascular masses. Furthermore, directional atherectomy was superior to aspiration or forceps biopsy in our small study cohort.*
- *Directional atherectomy may represent the last or only option for tissue probing as a prerequisite for further treatment decisions.*

**Keywords** Endovascular procedure · Specimen collection · Biopsy · Atherectomy · Angiosarcoma

**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s00330-019-06015-z) contains supplementary material, which is available to authorized users.

✉ Alexander Massmann
Alexander.Massmann@uks.eu

[1] Clinic for Diagnostic and Interventional Radiology, Saarland University Medical Center, Kirrberger Straße, Gebäude 50.1, 66421 Homburg, Germany

## Abbreviations

| | |
|---|---|
| AO | Thoracoabdominal aorta |
| CT | Computed tomography |
| IVC | Inferior vena cava |
| LBCV | Left brachiocephalic vein |
| mm | Millimeter |
| MRI | Magnetic resonance imaging |
| PA | Pulmonary artery |
| PET-CT | Positron-emitting tomography |

## Introduction

Image-guided percutaneous core needle biopsy for tissue sampling of solid tumor masses represents a well-established procedure in clinical practice. Yet, life-threatening bleeding is the most dreaded complication for needle biopsy of intraluminal neoplasms or neoplasms in proximity to the large vessels [1–3]. Several endovascular techniques have been applied to address these issues including catheter aspiration, usage of liver biopsy kits, or endomyocardial biopsy forceps [1–7]. However, application of these rigid devices is limited due to the relatively large vessel access [5]. Furthermore, tissue sampling with straight forceps and biopsy needles may be unsuitable for targeted tissue sampling in case of curved and elongated vessel anatomy. Directional atherectomy is a standard treatment approach for endovascular revascularization in patients with occlusive artery disease. This technique intentionally removes atheroma from the inside of blood vessels, which entails sampling of atherosclerotic tissue. To overcome abovementioned shortcomings, we were inspired by two publications more than 25 years old dealing with case presentations on percutaneous directional atherectomy for biopsy of malignant superior vena cava stenosis by endovascular means [8, 9]. Here, the authors applied the Simpson atherectomy catheter, originally designed for treatment of subacute and chronic atherosclerotic occlusive lesions. Further evolution of this device resulted in the flexible plaque excision atherectomy device Silverhawk™ (Medtronic) [4]. Besides, the indication for treatment of peripheral artery disease safety and effectiveness of these devices was proven for tissue sampling of hollow organs such as bile ducts [10]. Directional atherectomy is a well-established treatment option at our institution for endovascular treatment of atherosclerotic lesions in daily clinical routine. Based on this experience, we sought to evaluate the technical feasibility and safety of endovascular soft tissue sampling using directional atherectomy and to compare procedural safety and success to established techniques based on catheter aspiration and forceps biopsy.

## Materials and methods

This study was conducted in accordance with the amended Declaration of Helsinki and was approved by the local institutional review board. All patients included in this study provided written informed consent and were informed regarding the off-label use of the directional atherectomy device for this purpose.

Between 2013 and 2017, ten consecutive patients (6 male; median age 56, range 39–73 years) were referred to a tertiary-level university hospital for diagnostic work-up of endovascular tumor masses. Imaging studies including contrast-enhanced computed tomography (CT), positron-emitting tomography (PET-CT), and magnetic resonance imaging (MRI) depicted ten soft tissue masses characterized by endoluminal growth. Locations included thoracoabdominal aorta (AO) ($n = 4$) (Fig. 1A), left brachiocephalic vein (LBCV) ($n = 2$) (Fig. 1B), inferior vena cava (IVC) extending to the right atrium ($n = 1$) (Fig. 1C), and left pulmonary artery (PA) ($n = 3$) (Fig. 1D). Associated thrombosis was apparent in LBCV and IVC. Tumor specimen sampling was considered mandatory in order to achieve histologic diagnosis. After the review of cross-sectional imaging studies, percutaneous transthoracic or endoscopic transbronchial access for core needle biopsy was considered unsuitable given the risks of pneumothorax or bleeding complications. Based on predominantly endoluminal tumor growth, tissue sampling by endovascular means was preferred. Pre-procedural laboratory tests including coagulation status were performed. Vascular access was established in all instances using an 8F sheath. The transfemoral arterial route was chosen for aortic access ($n = 4$), transjugular for IVC ($n = 1$), and transfemoral venous route for all other patients ($n = 5$). After target vessel catheterization, angiography by manual contrast material injection was performed to visualize the largest endoluminal tumor extent and the position of eccentric tumor masses relative to the vessel. For all following procedures, an angled 8F sheath was introduced for directing the following catheters to the mass. In all patients, a manually shaped angulated 8F aspiration catheter (Opti-Med Medizinische Instrumente GmbH) was used for initial tissue sampling. Secondly, endomyocardial straight 6.4F biopsy forceps (H. + H. Maslanka Chirurgische Instrumente GmbH) was advanced towards the endovascular masses. Finally, tissue sampling was performed by off-label directional atherectomy (Silverhawk™ LS-M 7F, Medtronic) for targeted specimen collection. More in detail, the SilverHawk™ consists of a mono-rail catheter running over a 0.36 mm/0.014-in. guidewire. A rotating cutting blade with a reservoir for plaque material is located at the catheter tip (Fig. 2). For tissue sampling, two slow-cutting passes were performed with the blade across the tumor-related stenosis (Video 1). After catheter removal, collected specimens were obtained out of the catheter housing. Angiography was repeated to exclude bleeding complications or embolization. Sampling probes were placed in formalin and sent for histologic evaluation. All procedures were performed in a single session under fluoroscopic guidance by two operators (A.M. and A.B.) experienced in interventional radiology for 10 and 25 years. A.M. had full access to the data in the study and takes full responsibility for its integrity and data analysis. Patients were prospectively followed up by clinical visits and imaging studies up to 1 year.

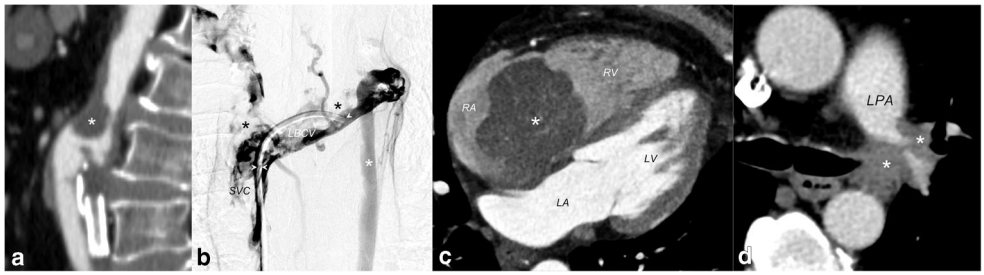


**Fig. 1** (**a**) Sagittal reconstruction of a contrast-enhanced computed tomography in arterial phase depicts an eccentric endoluminal tissue mass (asterisk) arising from the distal abdominal aorta. The suspected proliferation is located above the origin of an aorto-bi-iliac bypass, which was completed 2 years before following symptomatic occlusion of aorto-bi-iliac kissing stents. Histopathology of tissue specimen probed by directional atherectomy revealed chronic inflammation. (**b**) Phlebography by contrast media injection into the 6F guiding catheter (arrowheads) shows large filling defects (black asterisks) of the left brachiocephalic vein (LBCV) and superior vena cava (SVC) caused by a combination of endoluminal tumor growth and consecutive thrombosis extending from the LBCV into the SVC. Vessel occlusion results in collateralization to the hemiazygos vein (white asterisk). Histopathological analysis of tissue probes sampled by directional atherectomy showed angiosarcoma. (**c**) Four-chamber view reconstruction of an electrocardiogram-gated contrast-enhanced computed tomography of the heart illustrating a large hypodense mass in the right atrium extending into the right ventricle (asterisk). Histopathology of tissue probes obtained by directional atherectomy revealed hepatocellular carcinoma (HCC). (**d**) Contrast-enhanced computed tomography of the chest demonstrates a semicircular mass (asterisks) with endoluminal tumor growth resulting in lumen narrowing of left pulmonary artery (LPA)

## Results

Aspiration resulted in tissue sampling only in three instances with tumor-associated thrombus formation in the LBCV and IVC. However, aspirated material showed fresh and subacute clot but did not yield histologic tumor diagnosis. Tissue sampling by biopsy forceps failed in all cases. In seven instances, elongated vessel course impeded the advancement of stiff biopsy forceps to the target site. In one patient with straight access via the superior vena cava to a large tumor protruding into IVC/right atrium (Fig. 1C), forceps biopsy was technically impossible, as insufficient advancement of the straight biopsy forceps into the tumor caused the forceps to slip off the tumor surface without sampling of tissue material. In contrast, endovascular tumor sampling by directional atherectomy was achievable in 100%. The atherectomy device was successfully advanced to the designated location for tissue sampling in all patients. Flexibility of the catheter allowed bending along multiple vessel curves, e.g., pulmonary vasculature from transfemoral access. After two atherectomy passages, macroscopically sufficient material was available for each vessel region (Fig. 3) yielding histologic diagnosis in each case. Histopathologic results included sarcoma, chronic

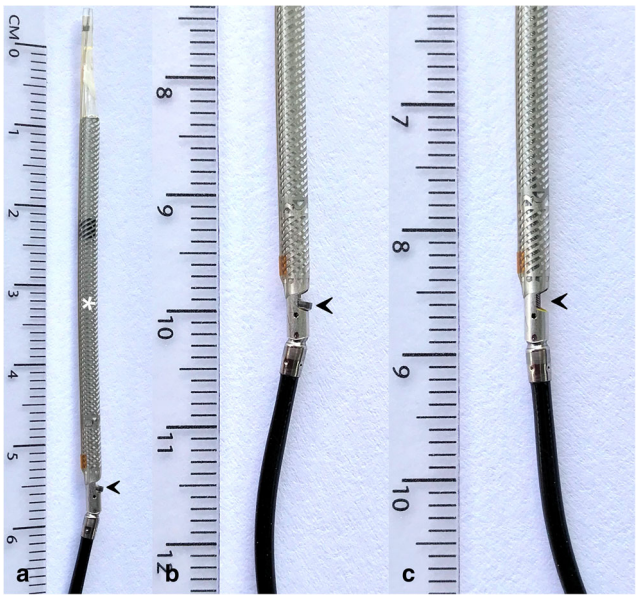


**Fig. 2** (**a**) The SilverHawk catheter (Medtronic) is used for percutaneous debulking of atheromatous plaque material in peripheral occlusive disease. A battery-powered drive unit is integrated in a handle and attached to the 0.014-in. mono-rail atherectomy catheter. After activation, a sharp carbide cutting blade (arrowhead) exits the nosecone housing (asterisk) of the catheter tip for engaging of endoluminal stenosis. (**b**) Magnification shows the concave design of the rotating blade to collect excised material into the nose cone compartment. (**c**) For the removal of captured specimen (Fig. 3), the catheter is deactivated, and the blade is securely pushed back into the nosecone housing (asterisk). The procedure is visualized in supplemental digital content Video 1

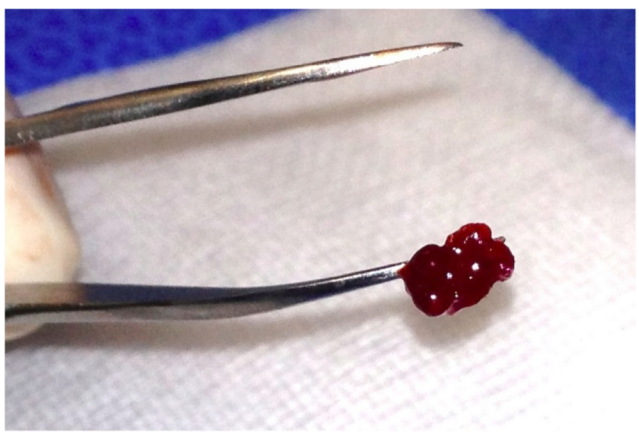

**Fig. 3** Photography of tissue specimen obtained by directional atherectomy (SilverHawk, Medtronic) for sampling of an aortic endoluminal mass shown in supplemental digital content Video 1

**Table 1** Procedural characteristics for tumor probing

| Patient no. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Sex | M | M | F | F | M |
| Age (years) | 38 | 51 | 55 | 57 | 40 |
| Localization | Brachiocephalic vein | Pulmonal artery | Pulmonal artery | Thoracic aorta | Brachiocephalic vein |
| Technical success catheter aspiration | No | No | No | No | No |
| Reason for failure | Insufficient material for histopathological evaluation | | | | |
| Technical success forceps biopsy | Yes | No | No | Yes | Yes |
| Reason for failure | | Catheter advancement impossible | Catheter advancement impossible | | |
| Result | False-negative non-target biopsy | – | – | False-negative non-target biopsy | False-negative non-target biopsy |
| Technical success Directional atherectomy | Yes | Yes | Yes | Yes | Yes |
| Diagnosis by endovascular approach | Angiosarcoma | Lymphoma | Angiosarcoma | Sarcoma | Angiosarcoma |
| Complications | None | None | None | None | None |
| Procedure-related hospital re-admission | No | No | No | No | No |

| Patient no. | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| Sex | F | M | F | M | M |
| Age (years) | 61 | 73 | 66 | 58 | 39 |
| Localization | Pulmonal artery | Abdominal aorta | Abdominal aorta | Right atrium/IVC | Abdominal aorta |
| Technical success catheter aspiration | No | No | No | No | no |
| Reason for failure | Insufficient material for histopathological evaluation | | | | |
| Technical success forceps biopsy | No | Yes | Yes | No | Yes |
| Reason for failure | Catheter advancement impossible | | | Slipping off tumor surface | |
| Result | – | False-negative non-target biopsy | False-negative non-target biopsy | – | False-negative non-target biopsy |
| Technical success Directional atherectomy | Yes | Yes | Yes | Yes | Yes |
| Diagnosis by endovascular approach | Angiosarcoma | Sarcoma | Atheroma | Hepatocellular carcinoma | Chronic inflammation |
| Complications | None | None | None | None | None |
| Procedure-related hospital re-admission | No | No | No | No | No |

**Table 2** Diagnostic accuracy of endovascular biopsy approaches

| | Catheter aspiration | Forceps biopsy | Directional atherectomy |
|---|---|---|---|
| Sensitivity | 0 | 0 | 1.0 |
| Specificity | 0.2 | 0.4 | 1.0 |
| Positive predictive value | – | – | 1.0 |
| Negative predictive value | 0.2 | 0.4 | 1.0 |

inflammation and atheroma for AO, angiosarcoma for LBCV, hepatocellular carcinoma for IVC, and angiosarcoma and lymphoma for PA (Table 1). No procedure-associated complications, e.g., vessel perforation, were recorded. Consecutive treatment was adapted to the histopathologic findings. Technical success for sampling of sufficient tumor tissue for aspiration was 0 out of 10 patients; false-negative tissue sampling by non-targeted forceps biopsy occurred in 6 out of 10; directional atherectomy yielded technical success in 10 out of 10 instances ($p < 0.0001$) (Table 1). For all histologically benign lesions, such as chronic inflammation, clinical follow-up including imaging studies after 3 and 12 months was available showing no occurrence of malignant disease. Thus, sensitivity and specificity were 100% for directional atherectomy. Diagnostic accuracy for all three different approaches is shown in Table 2.

## Discussion

Endovascular masses may present with heterogeneous and inconclusive imaging findings. For instance, soft tissue components within the pulmonary arteries may appear similar to clot in cases of acute or chronic pulmonary embolism. On the other hand, atherosclerotic plaques may mimic sarcoma of the vessel wall.

However, in comparison to atherosclerotic plaques or thromboembolic clots, intravascular neoplasms are very rare and mostly of a malignant character. In addition, large intravascular tumors may occlude the vessel and subsequently induce concomitant thrombosis masking the underlying process [1, 3, 6].

As a consequence, the combination of different diagnostic imaging methods is often required for accurate diagnosis and proper assessment of the pathology. While the combination of cross-sectional imaging modalities such as CT and MRI with molecular imaging such as PET helps to distinguish between benign and malignant entities, final diagnosis often remains unclear based on imaging findings alone.

Therefore, tumor specimen sampling is essential in order to establish a definitive diagnosis to start appropriate treatment.

Recent case studies described various approaches with different devices for endovascular tumor tissue sampling. One consists in a transjugular approach using a hepatic biopsy needle [2]. However, based on the lack of flexibility and the insufficient length of this device, we did not consider this approach in our series of patients. In addition, endomyocardial or endobronchial biopsy forceps are routinely used for endovascular tissue sampling of tumors of the inferior vena cava and aorta [1–3]. However, in our study application of these standard biopsy instruments, requiring a large-diameter vascular access failed to provide representative tissue samples in all our cases. It was not possible to steer the forceps along curved vessels, because of the device rigidity. More in detail, three of our patients demonstrated tumors of the pulmonary arteries where the use of forceps biopsy devices failed due to the tortuosity of the vessel anatomy and the distance to the target lesion.

Alternative approaches for endovascular tissue sampling consist in using more flexible aspiration catheters. While this technique may be of value for obtaining tumor-associated clots [6, 7], direct aspiration of tumor material remains very difficult and was only described by Hu et al [7]. This is in line with the results of our study where aspiration catheters failed to provide representative tumor samples in all patients. Thus, we consider this technique as insufficient for probing in this setting.

Application of directional atherectomy was technically successful in all of our patients and did not show false-negative histologic and clinical results. This is most likely related to the amount of material extracted from each lesion using the atherectomy device. Atherectomy was the only technique, which allowed for directed and controlled biopsy of relatively large tissue samples up to 3 cm in length by using the side-cutting instrument pressed towards the tumor tissue–related stenosis. The risk of potential vessel perforation by cutting tumor tissue was successfully minimized by visualizing the eccentric tumor relative to the vessel wall and proper image-guided steering of the device in relation to the mass. Additionally, previously acquired CT or MRI imaging studies were used for the localization of the tumor relative to the perfused vessel lumen and procedure planning. The cutting depth of the atherectomy blade of about 1 mm into the tumor or subintimal space is regularly well controllable by the user. In all our cases, tumor thickness measured 5 mm perpendicular to the vessel wall reducing the risk of potential vessel perforation.

This study has several limitations. First of all is the small number of cases included in this evaluation. However, the incidence of endovascular masses suspicious for neoplasm needing further histological work-up is very low. This also explains the long time period for patient recruitment. In addition, location and type of endovascular tumors were very heterogeneous, but still, including more individuals with the same entity or location of pathology would take even longer in a single-center study design. However, the discrepancy between heterogeneity of tumor location and entity and the success of the tumor tissue sampling supports the potential of directional atherectomy in this setting. Furthermore, the application of directional atherectomy for tissue sampling represents off-label use, which needs to be clearly communicated to the patient. Each patient underwent all of the three different biopsy techniques in the same sequence. The lack of randomization may result in a bias of the diagnostic yield of the biopsies.

## Conclusion

Preliminary results in a limited number of patients suggest that percutaneous endoluminal tissue sampling using directional atherectomy could be a safe and feasible technique even in challenging anatomical conditions for histopathologic analysis of endovascular masses. This approach may represent the last or only option for tissue probing as a prerequisite for further treatment decisions. Additional large-scale studies are necessary for further evaluation in clinical practice.

**Funding** The authors state that this work has not received any funding.

## Compliance with ethical standards

**Guarantor** The scientific guarantor of this publication is Univ. Prof. Dr. med. Arno Buecker.

**Conflict of interest** The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

**Statistics and biometry** One of the authors has significant statistical expertise.

No complex statistical methods were necessary for this paper.

**Informed consent** Written informed consent was obtained from all subjects (patients) in this study.

**Ethical approval** Institutional Review Board approval was obtained.

**Methodology**
- prospective
- case-control study
- performed at one institution



## References

1. Maingard J, Brooks M (2017) Transcaval core biopsy in malignant superior vena cava obstruction: potential for single stage diagnosis and treatment. J Med Imaging Radiat Oncol. https://doi.org/10.1111/1754-9485.12592
2. Robins JM, Bookstein JJ (1972) Percutaneous transcaval biopsy technique in the evaluation of inferior vena cava occlusion. Radiology. https://doi.org/10.1148/105.2.451
3. Winchester PA, Khilnani NM, Trost DW, Litvak B, Gold JP, Sos TA (1996) Endovascular catheter biopsy of a pulmonary artery sarcoma. AJR Am J Roentgenol. https://doi.org/10.2214/ajr.167.3.8751674
4. Massmann A, Katoh M, Shayesteh-Kheslat R, Buecker A (2012) Mechanical recanalization of subacute vessel occlusion in peripheral arterial disease with a directional atherectomy catheter. Cardiovasc Intervent Radiol. https://doi.org/10.1007/s00270-012-0364-6
5. Guirola JA, Laborda A, De Gregorio MA (2017) Percutaneous intravascular biopsy using a bronchoscopy forceps diagnosis of a pulmonary artery intimal sarcoma. Cardiovasc Intervent Radiol. https://doi.org/10.1007/s00270-016-1475-2
6. June AS, Harris DG, Yoo C et al (2017) Percutaneous treatment of multiple recurrent Thromboembolization from a descending thoracic aortic intimal sarcoma. Ann Vasc Surg. https://doi.org/10.1016/j.avsg.2016.06.036
7. Hu W, Xie Y, Zhang D (2013) Pulmonary artery intimal sarcoma diagnosed by percutaneous transcatheter aspiration. Chin Med J (Engl) 126:1590–1591
8. Dake MD, Zemel G, Dolmatch BL, Katzen BT (1990) The cause of superior vena cava syndrome: diagnosis with percutaneous atherectomy. Radiology. https://doi.org/10.1148/radiology.174.3.174-3-957
9. Castaneda F, Moradian G, Hunter D, Castaneda-Zuniga W, Amplatz K (1989) Percutaneous intravascular biopsy using a Simpson atherectomy catheter: technical note. Cardiovasc Intervent Radiol 12:342–343
10. Kaufman D, Widlus D, Lazinger M, Didolkar M, Kumar D, Dutta SK (2001) Diagnostic accuracy of Simpson atherectomy catheter biopsy in detecting pancreaticobiliary malignancy. Am J Gastroenterol. https://doi.org/10.1111/j.1572-0241.2001.03688.x