LASER USES IN NON-CORONARY ARTERIAL DISEASE

Jérémie JAYET^{1,4}, MD, Raphaël COSCAS^{1,2}, MD, PhD, Frédéric HEIM^{4,5}, PhD, Olivier GOEAU
BRISSENIERE, MD, PhD¹, Isabelle JAVERLIAT¹, MD, Nabil CHAKFE^{3,4}, MD, PhD, Marc COGGIA¹, MD

¹ Department of Vascular Surgery, Ambroise Paré University Hospital, Assistance Publique – Hôpitaux de Paris
(AP-HP), Boulogne-Billancourt, and Faculté de Médecine Paris-Ile de France-Ouest, UFR des sciences de la
santé Simone Veil, Université Versailles Saint-Quentin en Yvelines, Montigny-le-Bretonneux, France.

² UMR 1018, Inserm-Paris11 - CESP, Versailles Saint-Quentin-en-Yvelines University, Paris-Saclay University,
Paul Brousse Hospital, Villejuif, France.

³ Department of Vascular Surgery and Kidney Transplantation, Hôpitaux Universitaires de Strasbourg,
Université de Strasbourg, Strasbourg, France

⁴ Groupe Européen de Recherche sur les Prothèses Appliquées à la Chirurgie Vasculaire (GEPROVAS),
Strasbourg, France.

⁵ Laboratoire de Physique et Mécanique des Textiles, Mulhouse, France

Emails: jeremiejayet@gmail.com; rcoscas@gmail.com; frederic.heim@uha.fr; ijaverliat@yahoo.fr;
olivier.goeau-brissonniere2@orange.fr; Nabil.Chakfe@chru-strasbourg.fr; mpcoggia@aol.com.

Corresponding author: Dr Raphaël Coscas, MD, PhD, Department of Vascular Surgery, Ambroise Paré
University Hospital, 9 avenue Charles de Gaulle, 92104 Boulogne Cedex, France. Tel: +33 (0) 1.49.09.55.85;
Fax: +33 (0) 1.49.09.53.18; E-mail: rcoscas@gmail.com

ABSTRACT

Objectives: In the past decade, excimer laser angioplasty (ELA) has emerged in the field of peripheral atherosclerotic disease (PAD). Laser indications now extend to off-label uses, such as in situ fenestration of aortic endograft. The aim of this study was to review the different therapeutics applications of lasers in arterial disease treatment.

Review Methods: We reviewed the English-language literature using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. We selected 106 relevant papers. We excluded unrelated papers (n= 67), letters and commentaries (n = 6) and review articles (n=7), leaving 26 articles to form the basis of this review.

Results: A total of 18 articles were included in the analysis of ELA applications in PAD. Nine articles were related to atherosclerotic plaques. With a mean follow-up of 15 ± 7 months, primary patency was $65\%\pm 20\%$. Mean distal embolism rate during the procedure was 5%. Eight more articles focused on in-stent restenosis. The mean technical success was 98%, and the rate of distal embolism during the procedure was 9%. With a mean follow-up of 10 ± 4 months, primary patency was $68\%\pm 18\%$. Eight articles described “off- label” excimer laser indications in endovascular therapy, including five papers regarding in situ fenestrations for complex aortic aneurysms.

Conclusion: Laser atherectomy and laser assisted techniques are an important part of a vascular surgeon and interventionalist's armamentarium.

Keywords:

Excimer Laser, In stent restenosis, Atherosclerotic Plaques, In situ fenestration

MANUSCRIPT

INTRODUCTION

Since 1960, light amplification by stimulated emission of radiation (laser) has appeared as an applicable energy source for medical use thanks to its unidirectional, pulsatile and monochromatic characteristics. The different physical mechanisms account for the many ways to exploit the capacity of laser technology in medical utilization [1–6]. In this last decade, laser technology has emerged as a new tool in endovascular therapy [7,8]. Lasers in endovascular therapy were applied in the endovenous laser ablation for treating saphenous insufficiency [9]. On-label indications of excimer laser angioplasty (ELA) in peripheral artery disease (PAD), specifically in-stent restenosis [10] and non-crossable chronic occlusions [11], have appeared. More recently, other off-label indications have emerged for material ablation and fabric welding to perform in situ fenestration of aortic endografts [12].

The main laser used in arterial surgery is the excimer laser using the photoablative laser's characteristics. An excimer laser is produced by a high-energy voltage associated with a dimeric solution of xenon and hydrochloride. The high-voltage energy excites the dimer XeCl and creates a photon. The laser is conducted by optic fibers, at a wavelength of 308 nm located in the blue spectrum. Whereas many other lasers deliver their energy in the warm red spectrum, the excimer laser is a cold laser. This last characteristic allows vascular surgeons and interventionalists to use excimer laser with a theoretical low risk of thrombus formation or deterioration of the arterial wall. The light penetration depth is around 0.05 mm, and each photon carries enough energy to break a single carbon-carbon bond. Intracellular lipids and proteins absorb this high energy and are quickly destroyed. Finally, all the intracellular liquid is vaporized. Microscopic subcellular debris are created and washed distally with a theoretical benefit in terms of clinic emboli.

Whereas the first lasers were continuous-wave lasers, the excimer laser delivers its energy by pulse to avoid the heat diffusion from the catheter tip and the damage of surrounding tissues.

Each catheter conducts its energy from a generator to the catheter tip, composed of multiple optic fibers arranged around a guidewire lumen. Different diameters of the catheter exist according to the surgical applications, from 0.9 mm to 2.5 mm. Settings (Fluence (mJ/mm²) and rate (Hz)) can be modified per the power needed. In fact, for calcified lesions or occlusions, the average power should be increased to obtain a maximum debulking.

Two types of devices are commercially available. First, Turbo-Tandem (TT) (previous generation: Turbo-Booster (TB)/ CliRpath) (Spectranetics, Colorado Springs, CO, USA) is a laser-guided catheter combined with a laser atherectomy catheter, whereas Turbo-Elite (TE) (Spectranetics, Colorado Springs, CO, E-U) is just a laser atherectomy catheter. TT is preferred for diameters of target arteries over 5 mm or to obtain maximum debulking. Both devices progress on the wire after crossing the lesion or with a “step-by-step technique”. A speed progression of the catheter of 1 mm/s is advised to be more effective.

The aim of this study is to review the different therapeutics applications of excimer lasers in endovascular therapy.

METHODS

A literature's review was performed using of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [13] **Figure**.

Search Strategy

We reviewed the English-language literature regarding the use of excimer laser on several medical databases: Medline databases using a PubMed interface, the Cochrane Database, Web of Science, and Scopus. The search period was from June 2005 to May 2017. We used the key words "Excimer Laser", "in stent restenosis," "in situ fenestration."

Study Selection

Studies were included if they met the following criterion: laser uses in arterial disease including PAD and aortic or visceral procedures.

Clinical and experimental papers were studied. Only published data were included in this study. Two independent analysts (J.J. and R.C.) selected and further analyzed 106 relevant papers. We excluded unrelated papers (n= 67), letters and commentaries (n = 6) and review articles (n=7). Finally, 26 articles were included in the qualitative synthesis.

Data extraction

Data were extracted regarding the type of paper (clinical or experimental and case report or case series) and summarized using data extraction sheets. Relevant data were considered: on-label or off-label indications, number of subjects, device used (TE, TT or TB, or both), demographics, technical success, in situ fenestration type (retrograde or antegrade), in situ fenestration technique (catheter's diameter, graft type), technical success rate, and early and late results (primary patency, target lesion revascularization). Data were managed using three independent analyses: atherosclerotic plaques, in-stent restenosis, and off-label indications.

RESULTS

In selected articles, TE catheters were used in 1,107 cases (79%) [14–28], whereas TT or TB [10,15,17,19,21,22,24,26,29] devices were used in 230 cases (16%), and CliRpath (first laser-guided catheter generation) was used in 51 cases (5%) [11].

A total of 18 articles were included in the analysis of the applications of ELA in PAD. The main objectives and results of treatment of atherosclerotic plaques and in-stent restenosis are respectively shown in **Tables 1 and 2**. Eight other articles described off-label” excimer laser indications in endovascular therapy, including five papers regarding in situ fenestrations for complex aortic aneurysms.

Atherosclerotic plaques

Nine articles [11,14,15,17,21,25,27–29] related to atherosclerotic plaques were found. A total of 847 atherosclerotic plaques were treated, and 783 TE (88%) and 104 TT or TB (12%) devices were used. Rastan et al. and Wu et al. both included in stent restenosis and atherosclerotic plaques. CliRpath device was used for 51 revascularizations. Among the nine articles, four included femoropopliteal lesions [15,21,27,29]. Sultan et al. included infra popliteal lesions, and the four last authors included femoropopliteal, infra popliteal, and combined lesions [11,14,17,28], respectively. Five articles specified the lesion length [14,15,21,25,27]. Mean lesion length treated was 13.3 ± 4.6 cm. ELA was associated with percutaneous transluminal angioplasty (PTA) in $58\%\pm 37\%$ of cases. Stent implantation was performed in $29\%\pm 28\%$ of cases. Wu et al. compared spot stenting versus systematic stenting after ELA, and stenting was performed in 91% of cases. They concluded that primary stenting resulted in a longer primary patency rates at one year. Sultan et al. described the ELA technique for lower-limb arteries, and only 35% of the patients were treated by combined treatment ELA and stenting. No drug-eluting balloons were used for de novo arteries lesions.

Primary patency rates were available in five articles [14,15,17,21,27]. At 15 ± 7 months, mean primary patency rate was $65\%\pm 20\%$.

Mean distal embolism rate of four articles during the procedure was 5% [15,21,25,29].

In-stent restenosis

Regarding in-stent restenosis, inclusions criteria were met in eight articles [10,18–20,22–24,26]. A total of 427 femoropopliteal lesions were treated, and 316 TE (42%) devices and 123 TB or TT (58%) were used. Mean

lesion length treated was 17.5 ± 4.1 cm. The mean technical success was 98%, and mean rate of distal embolism during the procedure was 9%. ELA was systematically evaluated in combination with another treatment. Three studies combined ELA technique with drug-eluting balloons [18,20,23], four associated ELA with PTA [19,22,24,26], and the SALVAGE study [19] describe results of ELA followed by covered stenting. Primary patency rates were available in six articles [10,18,20,22-24]. At 10 ± 4 months, mean primary patency rate was $68\% \pm 18\%$. Finally, a clinical investigation focused on distal embolic events using ELA in 28 peripheral vascular lesions. A distal protection filter was deployed before laser therapy to recover debris produced by laser atherectomy. They highlighted 20% rate of clinically significant macrodebris [16].

Off-label indications

Among the eight selected articles regarding off-label indications, five were related to in situ fenestration of aortic endografts [12,30–33].

Seventy in situ laser fenestrations were performed, and results are described in **Table 3**. The main objective was to perform a retrograde fenestration from the left subclavian artery to a thoracic aortic endograft during emergency endovascular treatment of a thoracic aortic aneurysm. A total of 35 Talent endograft, 8 Gore TAG, 3 Cook TX2 and 2 LifeTech Scientific Corp. were fenestrated using the TE catheter or Lasemar catheter. Laser catheter diameter varied between 2.0 and 2.5 mm. Three authors specified that the contact between the endograft and the catheter tip was around 3 to 5s [30,31,33]. Two type II endoleak from the left subclavian artery, which was successfully treated by coil embolization were reported. Concerning the four clinical evaluations, the primary patency rate was 100% after 9 ± 1 -month follow-up. In the largest clinical study, technical success was achieved in 95.8% of cases [33]. An experimental study on pigs regarding embolism after antegrade fenestration of textile polyester stent grafts using a 2 mm TE catheter was performed. They concluded that the technique does not produce macroscopically visible emboli or clot.

Three articles described other off-label excimer laser indications in endovascular therapy. First, Chander et al. [34] reported a case series of 4 recanalizations of failed autogenous saphenous vein graft using laser revascularization. A 0.9 to 1.7 TE laser catheter was used with 100% technical success. Second, Topaz et al. [35] described a retrospective review of excimer laser debulking of 12 lesions unsuitable for standard renal angioplasty. The laser debulking using a 0.9 to 2 mm TE catheter was followed by renal artery stenting. No laser-induced complications and no controlled angiographic renal artery stenosis occurred. Finally, a case of

178 excimer laser use to treat a severe central venous lesion downstream to an arterio-venous access was reported
179 [36]. A 2 mm TE catheter was introduced in the right subclavian vein followed by an 8 mm high pressure
180 balloon angioplasty.
181

DISCUSSION

This work aimed to review the use of excimer laser in PAD and in other off-label indications such as in situ fenestration of aortic endografts.

The excimer Laser was first used for coronary revascularization specifically for treating in stent restenosis and atherectomy [37,38]. Other cardiologic applications such as transvenous extraction of implanted pacemakers and implantable cardioverter-defibrillator leads have emerged [39]. Neurosurgeons and neuroradiologists have also used this technology and developed a new technique called excimer laser-assisted non-occlusive anastomosis to perform anastomosis on intracerebral arteries and have reported encouraging results [40]. The large size of the devices and difficulty implementing them limited laser use for medical indications; miniaturization has allowed laser technology to develop and for the number of applications in medical and surgical use to increase.

The ELA procedure represents an alternative for treating in-stent restenosis and atherosclerotic plaques [16]. Neither significant arterial perforation nor saphenous nerve injury were reported. However, short and mid-term primary patency rates were available for only 11 articles among the 18 articles included in the analysis of ELA in PAD. Besides, bail out stenting was frequently needed in the treatment of atherosclerotic plaques because of local dissections following catheter crossing.

Embolization rates were substantial following an ELA procedure. Our analysis highlights a 5% and 9% embolization rate following ELA in atherosclerotic plaques and in stent restenosis treatment, respectively. Specifically, the DEEPEMBOLI registry assessed the presence of embolic debris following ELA using systematic distal filter [16]. A concerning rate of 20% of macrodebris was found. The authors suspected ELA treatment of complex atherosclerotic lesions and suboptimal debulking as risk factors for distal embolization [16]. This raises the question of systematic distal filter protection during ELA procedure.

In-stent restenosis rates due to myointimal hyperplasia reach up to 50% [41,42]. Several treatments, such as cutting balloons, directional atherectomy, and drug-eluting balloons, have been evaluated to cure myointimal hyperplasia. Some authors have prospectively studied, the treatment of in-stent restenosis using paclitaxel-eluting balloon angioplasty. After 1 year, the primary patency rate was 83.7% with a reintervention rate of 9.8% [43]. The excimer laser allows recalibrating the vessel lumen in the stent by destroying fibrous material. ELA was associated with adjunctive therapy, such as drug-eluting balloons, provides satisfactory results [20], but this treatment should be evaluated by large and randomized series [45]. In the last decade, several off-label

indications of ELA have emerged, mainly laser in situ fenestration of aortic endografts. Laser technology is an alternative to mechanical technique using transseptal needles or stiff guidewires [46]. Recently, it was stressed that needles compared to laser catheters were not flexible enough to enter a directional sheath, thereby limiting their use for antegrade in situ fenestrations [47]. Laser in situ fenestration consists of puncturing the endograft with the laser catheter angled by steerable sheath, enlarging the hole created if necessary and stabilizing the fenestration by covered or uncovered stent. The successful treatment of a proximal type 1 Endoleak using an Endurant aortic cuff with triple antegrade in situ fenestration was recently reported [48]. However, the choice of the best graft and the impact of laser fenestration on textile remain unknown. More experimental studies must be conducted to assess biomechanical textile modification and long-term effects following laser fenestration, for the latter to become an “on-label technique.”

ELA’s cost-effectiveness is yet to be demonstrated and remains a global concern. In our country, TE’s price reaches 1 900€ (approx. 2,200US\$) for the catheter and 175 000€ (approx. 204,000US\$) for the CVX 300 generator (taxes not included). Combined with adjunctive therapy such, as drug-eluting balloons, stenting, and perclose systems, the cost of ELA procedures can become extremely high. This may limit ELA diffusion [49].

Finally, reported results of the excimer laser open prospects for new applications such as arteriovenous accesses management. Venous stenosis caused by myointimal hyperplasia lead to high rates of reinterventions that could be simplified by laser use. Similarly, in situ fenestration was frequently performed using textile polyester endograft, but polytetrafluoroethylene (PTFE) endograft testing could be relevant to get away the fenestration from filament textile deterioration and extend the indication to the endovascular treatment of femoral bifurcation and popliteal occlusive disease.

CONCLUSION

The number of excimer laser applications is increasing. Laser technology represents a physical alternative to current mechanical means to treat various arterial diseases. Limitations include a concerning intra-operative embolism rate when treating PAD and a high cost. Long-term results and prospective comparative studies are lacking to validate the excimer laser as standard use in endovascular therapy.

Acknowledgments : We thank the “Société Française de chirurgie vasculaire et endovasculaire” (SCVE), the “Association chirurgicale pour le développement et l’Amélioration des techniques de Dépistage et de Traitement des maladies Cardiovasculaires” (ADETEC), and the « Association pour la Recherche et la Formation Chirurgicale en Ile de France » (ARFCIDF) for providing funding for this study.

REFERENCES:

- [1]. Mlacker S, Shah VV, Aldahan AS, McNamara CA, Kamath P, Nouri K. Laser and light-based treatments of venous lakes: a literature review. *Lasers Med Sci.* 2016 Sep;31:1511–9.
- [2]. Sjogren PP, Sidman JD. Use of the carbon dioxide laser for tracheobronchial lesions in children. *JAMA Otolaryngol-- Head Neck Surg.* 2013 Mar;139:231–5.
- [3]. Davoudi A, Sanei M, Badrian H. Application of Laser Irradiation for Restorative Treatments. *Open Dent J.* 2016;10:636–42.
- [4]. Gupta PK. Is the holmium:YAG laser the best intracorporeal lithotripter for the ureter? A 3-year retrospective study. *J Endourol.* 2007 Mar;21:305–9.
- [5]. Park Y-K, Park C-H. Clinical efficacy of photodynamic therapy. *Obstet Gynecol Sci.* 2016 Nov;59:479–88.
- [6]. Otsuji T, Sho K, Tsumura A, Koike N, Nishimura T, Takahashi K. Three-year results of a modified photodynamic therapy procedure (Ironing PDT) for age-related macular degeneration patients with large lesions. *Clin Ophthalmol Auckl NZ.* 2016;10:431–6.
- [7]. Cochenec F, Kobeiter H, Gohel M, Leopardi M, Raux M, Majewski M, et al. Early Results of Physician Modified Fenestrated Stent Grafts for the Treatment of Thoraco-abdominal Aortic Aneurysms. *Eur J Vasc Endovasc Surg.* 2015 Nov;50:583–92.
- [8]. Al Khoury G, Chaer R. Evolution of atherectomy devices. *J Cardiovasc Surg (Torino).* 2011 Aug;52:493–505.
- [9]. Jibiki M, Miyata T, Futatsugi S, Iso M, Sakanushi Y. Effect of the wide-spread use of endovenous laser ablation on the treatment of varicose veins in Japan: a large-scale, single institute study. *Laser Ther.* 2016 Oct 1;25:171–7.
- [10]. Laird JR, Yeo KK, Rocha-Singh K, Das T, Joye J, Dippel E, et al. Excimer laser with adjunctive balloon angioplasty and heparin-coated self-expanding stent grafts for the treatment of femoropopliteal artery in-stent restenosis: twelve-month results from the SALVAGE study. *Catheter Cardiovasc Interv.* 2012 Nov 1;80:852–9.
- [11]. Bosiers M, Peeters P, Elst FV, Vermassen F, Maleux G, Fourneau I, et al. Excimer laser assisted angioplasty for critical limb ischemia: results of the LACI Belgium Study. *Eur J Vasc Endovasc Surg.* 2005 Jun;29:613–9.

- 292 [12]. Murphy EH, Dimaio JM, Dean W, Jessen ME, Arko FR. Endovascular repair of acute traumatic
 293 thoracic aortic transection with laser-assisted in-situ fenestration of a stent-graft covering the left subclavian
 294 artery. *J Endovasc Ther*. 2009 Aug;16:457–63.
- 295 [13]. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA
 296 statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions:
 297 explanation and elaboration. *BMJ*. 2009 Jul 21;339:b2700.
- 298 [14]. Zhou W, Bush RL, Lin PH, Peden EK, Lumsden AB. Laser atherectomy for lower extremity
 299 revascularization: An adjunctive endovascular treatment option. *Vasc Endovascular Surg*. 2006 Sep;40(4):268–
 300 74.
- 301 [15]. Dave RM, Patlola R, Kollmeyer K, Bunch F, Weinstock BS, Dippel E, et al. Excimer laser
 302 recanalization of femoropopliteal lesions and 1-year patency: results of the CELLO registry. *J Endovasc Ther*.
 303 2009 Dec;16:665–75.
- 304 [16]. Shammas NW, Coiner D, Shammas GA, Christensen L, Dippel EJ, Jerin M. Distal embolic event
 305 protection using excimer laser ablation in peripheral vascular interventions: results of the DEEP EMBOLI
 306 registry. *J Endovasc Ther*. 2009 Apr;16:197–202.
- 307 [17]. Serino F, Cao Y, Renzi C, Mascellari L, Toscanella F, Raskovic D, et al. Excimer laser ablation in the
 308 treatment of total chronic obstructions in critical limb ischaemia in diabetic patients. Sustained efficacy of plaque
 309 recanalisation in mid-term results. *Eur J Vasc Endovasc Surg*. 2010 Feb;39:234–8.
- 310 [18]. Van Den Berg JC, Pedrotti M, Canevascini R, Chimchila Chevili S, Giovannacci L, Rosso R.
 311 Endovascular treatment of in-stent restenosis using excimer laser angioplasty and drug eluting balloons. *J*
 312 *Cardiovasc Surg (Torino)*. 2012 Apr;53:215–22.
- 313 [19]. Shammas NW, Shammas GA, Hafez A, Kelly R, Reynolds E, Shammas AN. Safety and One-Year
 314 revascularization outcome of excimer laser ablation therapy in treating in-stent restenosis of femoropopliteal
 315 arteries: A retrospective review from a single center. *Cardiovasc Revascularization Med Mol Interv*. 2012
 316 Dec;13:341–4.
- 317 [20]. Gandini R, Del Giudice C, Merolla S, Morosetti D, Pampana E, Simonetti G. Treatment of chronic SFA
 318 in-stent occlusion with combined laser atherectomy and drug-eluting balloon angioplasty in patients with critical
 319 limb ischemia: a single-center, prospective, randomized study. *J Endovasc Ther*. 2013 Dec;20:805–14.
- 320 [21]. Wu T-Y, Chou H-H, Chang S-H, Tsai Y-J, Hsieh C-A, Cheng S-T, et al. Comparison of immediate and
 321 2-year outcomes between excimer laser-assisted angioplasty with spot stent and primary stenting in intermediate

- 322 to long femoropopliteal disease. *ScientificWorldJournal*. 2013;2013:247102.
- 323 [22]. Schmidt A, Zeller T, Sievert H, Krankenberg H, Torsello G, Stark MA, et al. Photoablation using the
324 turbo-booster and excimer laser for in-stent restenosis treatment: twelve-month results from the PATENT study.
325 *J Endovasc Ther*. 2014 Feb;21:52–60.
- 326 [23]. Van Den Berg JC, Pedrotti M, Canevascini R, Chimchila Chevili S, Giovannacci L, Rosso R. In-stent
327 restenosis: mid-term results of debulking using excimer laser and drug-eluting balloons: sustained benefit? *J*
328 *Invasive Cardiol*. 2014 Jul;26:333–7.
- 329 [24]. Dippel EJ, Makam P, Kovach R, George JC, Patlola R, Metzger DC, et al. Randomized controlled study
330 of excimer laser atherectomy for treatment of femoropopliteal in-stent restenosis: initial results from the
331 EXCITE ISR trial (EXCImer Laser Randomized Controlled Study for Treatment of Femoropopliteal In-Stent
332 Restenosis). *JACC Cardiovasc Interv*. 2015 Jan;8:92–101.
- 333 [25]. Sultan S, Tawfick W, Hynes N. Cool excimer laser-assisted angioplasty (CELA) and tibial balloon
334 angioplasty (TBA) in management of infragenicular arterial occlusion in critical lower limb ischemia (CLI).
335 *Vasc Endovascular Surg*. 2013 Apr;47:179–91.
- 336 [26]. Armstrong EJ, Thiruvoipati T, Tanganyika K, Singh GD, Laird JR. Laser Atherectomy for Treatment of
337 Femoropopliteal In-Stent Restenosis. *J Endovasc Ther*. 2015 Aug;22:506–13.
- 338 [27]. Wissgott C, Kamusella P, Lüdtkke C, Andresen R. Excimer laser atherectomy after unsuccessful
339 angioplasty of TASC C and D lesions in femoropopliteal arteries. *J Cardiovasc Surg (Torino)*. 2013 Jun;54:359–
340 65.
- 341 [28]. Mallios A, Blebea J, Buster B, Messiner R, Taubman K, MA H. Laser atherectomy for the treatment of
342 peripheral arterial disease. *Ann Vasc Surg*. 2017;
- 343 [29]. Rastan A, Sixt S, Schwarzwälder U, Kerker W, Bürgelin K, Frank U, et al. Initial experience with
344 directed laser atherectomy using the CLiRpath photoablation atherectomy system and bias sheath in superficial
345 femoral artery lesions. *J Endovasc Ther*. 2007 Jun;14:365–73.
- 346 [30]. Ahanchi SS, Almaroof B, Stout CL, Panneton JM. In situ laser fenestration for revascularization of the
347 left subclavian artery during emergent thoracic endovascular aortic repair. *J Endovasc Ther*. 2012 Apr;19:226–
348 30.
- 349 [31]. Redlinger RE, Ahanchi SS, Panneton JM. In situ laser fenestration during emergent thoracic
350 endovascular aortic repair is an effective method for left subclavian artery revascularization. *J Vasc Surg*. 2013
351 Nov;58:1171–7.

- 352 [32]. Sonesson B, Dias N, Resch T, Kristmundsson T, Holst J. Laser Generated In situ Fenestrations in
353 Dacron Stent Grafts. *Eur J Vasc Endovasc Surg.* 2016 Apr;51:499–503.
- 354 [33]. Qin J, Zhao Z, Wang R, Ye K, Li W, Liu X, et al. In Situ Laser Fenestration Is a Feasible Method for
355 Revascularization of Aortic Arch During Thoracic Endovascular Aortic Repair. *J Am Heart Assoc.* 2017 Apr
356 21;6.
- 357 [34]. Chander RK, Oza P, Patel M, Balar N. Recanalization of failed autogenous conduit utilizing laser
358 revascularization. *Vasc Endovascular Surg.* 2011 Oct;45:636–40.
- 359 [35]. Topaz O, Polkampally PR, Topaz A, Polkampally CR, Jara J, Rizk M, et al. Utilization of excimer laser
360 debulking for critical lesions unsuitable for standard renal angioplasty. *Lasers Surg Med.* 2009 Nov;41:622–7.
- 361 [36]. Yevzlin AS, Urbanes A. Excimer laser assisted angioplasty in hemodialysis access intervention. *Semin*
362 *Dial.* 2009 Oct;22:580–3.
- 363 [37]. Hirose S, Ashikaga T, Hatano Y, Yoshikawa S, Sasaoka T, Maejima Y, et al. Treatment of in-stent
364 restenosis with excimer laser coronary angioplasty: benefits over scoring balloon angioplasty alone. *Lasers Med*
365 *Sci.* 2016 Nov;31:1691–6.
- 366 [38]. Ollivier JP, Avriillier S, Rougier J, Raynal E, Gandjbakhch I, Berthier JP, et al. [Contribution of excimer
367 laser to coronary angioplasty]. *Arch Mal Coeur Vaiss.* 1988 Mar;81:261–7.
- 368 [39]. Okamura H, Yasuda S, Sato S, Ogawa K, Nakajima I, Noda T, et al. Initial experience using Excimer
369 laser for the extraction of chronically implanted pacemaker and implantable cardioverter defibrillator leads in
370 Japanese patients. *J Cardiol.* 2013 Sep;62:195–200.
- 371 [40]. Bremmer J, van Doormaal TPC, Verweij BH, van der Zwan A, Tulleken CAF, Verdaasdonk R. Vessel
372 wall perforation mechanism of the excimer laser-assisted non-occlusive anastomosis technique. *Lasers Med Sci.*
373 2016 Aug;31:1169–75.
- 374 [41]. Del Giudice C, Gandini R, Simonetti G. Atherectomy for superficial femoral artery in-stent restenosis:
375 can lasers light the way to a better outcome? *J Endovasc Ther.* 2014 Apr;21:356–8.
- 376 [42]. Kornowski R, Hong MK, Tio FO, Bramwell O, Wu H, Leon MB. In-stent restenosis: contributions of
377 inflammatory responses and arterial injury to neointimal hyperplasia. *J Am Coll Cardiol.* 1998 Jan;31:224–30.
- 378 [43]. Bague N, Julia P, Sauguet A, Pernès JM, Chatelard P, Garbé JF, et al. Femoropopliteal In-stent
379 Restenosis Repair: Midterm Outcomes After Paclitaxel Eluting Balloon Use (PLAISIR Trial). *Eur J Vasc*
380 *Endovasc Surg.* 2017 Jan;53:106–13.
- 381 [44]. Shammass NW, Shammass GA, Jerin M. Differences in patient selection and outcomes between

SilverHawk atherectomy and laser ablation in the treatment of femoropopliteal in-stent restenosis: a retrospective analysis from a single center. *J Endovasc Ther*. 2013 Dec;20:844–52.

[45]. Ducasse E. Economic Evaluation Comparing Standard Balloon Angioplasty Versus Drug-eluted Balloon or Laser-Excimer in Association With Drug-eluted Balloon in the Treatment of Femoropopliteal Artery In-stent Restenosis. NCT02599389.

[46]. Coscas R, Glorion M, Javerliat I, Goëau-Brissonniere O, Coggia M. In Situ Fenestration Through the Contralateral Iliac Artery to Convert an Aortouni-iliac Into a Bifurcated Endograft. *J Endovasc Ther Off J Int Soc Endovasc Spec*. 2015 Jun;22:421–5.

[47]. Glorion M, Coscas R, McWilliams RG, Javerliat I, Goëau-Brissonniere O, Coggia M. A Comprehensive Review of In Situ Fenestration of Aortic Endografts. *Eur J Vasc Endovasc Surg*. 2016 Dec;52:787–800.

[48]. Touma J, Kobeiter H, Majewski M, Tacher V, Desgranges P. *Cardiovasc Intervent Radiol*. 2018 Mar;41(3):513-517.

[49]. Shishehbor MH, Jaff MR. Percutaneous Therapies for Peripheral Artery Disease. *Circulation*. 2016 Dec 13;134:2008–27.

LEGENDS :

Table 1: Tabular review of paper regarding de novo lesions treatment using ELA

PP: Primary patency, TLR: Target lesion revascularization, CLI: critical limb ischemia, FP: Femoropopliteal, ABI: Ankle brachial index, DEB: Drug eluted balloon, TBA: Tibial balloon angioplasty, NA: Not available, applicable

Table 2: Tabular review of paper regarding in stent restenosis treatment using ELA

PP: Primary patency, TLR: Target lesion revascularization, TVR: Target vessel revascularization, FPISR: Femoropopliteal in stent restenosis, ABI: Ankle brachial index, DEB: Drug eluted balloon, PTA: Percutaneous transluminal angioplasty, NA: Not available, applicable

Table 3: Tabular review of paper regarding laser in situ fenestration

LSCA: Left Subclavian artery, TEVAR: Thoracic endovascular aneurysm repair, ISF: in situ fenestration, PP: Primary Patency, NA: Not available, applicable

Figure : Flow chart depicting articles selection for the current review according to the PRISMA (Reporting Items for Systematic Reviews and Meta-Analysis) guidelines.

Identification

Records identified through
database searching
(n=106)

Screening

Records screening (n=106)

Records excluded
(n=67)

Eligibility

Full-text articles assessed
for eligibility (n=39)

Articles excluded
(n=13)

Included

Studies included in
qualitative synthesis
(n=26)

Reference	Main objective	Study Design	Results					
			N (Lesions)	Technical success (%)	Follow- up (months)	PP (%)	TLR (%)	Others relevant results
Bosiers 2005	Efficacy of Laser angioplasty in CLI	Prospective multicentric	51	NA	6	NA	NA	74% limb salvage
Zhou 2006	Evaluate effectiveness ELA+PTA for CLI	Retrospective monocentric	15	84	6	57	NA	NA
Rastan 2007	Safety and efficacy of ELA bias sheath catheter for SFA	Prospective monocentric	6	79	1	NA	NA	ABI 0.8 increase and Rutherford increase 3 points
Dave 2009	Evaluate EL recanalization for FP lesions	Prospective multicentric	65	100	6 and 12	59 and 54	23.1 (12 months)	NA
Serino 2010	ELA for treatment of CLI in diabetic patients	Prospective monocentric	51	88	12 and 24	97.6 and 82.7	13.4 and 17.3	Limb salvage 100% and 94%
Wisgott 2013	Application of ELA for refractory FP lesions	Retrospective monocentric	40	90	12	58.9	NA	Primary assisted Patency and Secondary assisted Patency 67.8% and 83.2%
Wu 2013	ELA+Spot stent vs ELA+systematic stenting FP disease	Retrospective monocentric	106	100	24	25 (ELA+spot stent) vs 45 (ELA+systematic stenting) (P=.03)	65 (ELA+spot stent) vs 45 (ELA+systematic stenting)	Earlier restenosis 67% (ELA+spot stent) vs 32% (ELA+systematic stenting) (P=.001)
Sultan 2013	Compare outcome of CoolELA vs TA	Retrospective monocentric	42	81	36	NA	14.8% (ELA) vs 36.2 (TBA) (P=.873)	Sustained clinical improvement ELA 81% vs 63.8% TBA (P=.013), Amputation free-survival 95.2% ELA vs 78.7%TBA (P=.016)
Mallios 2017	Clinical results of laser atherectomy in the treatment of PAD	Retrospective monocentric	471	99	28	NA	20	Freedom from major amputation 90% at 5years

Reference	Main objective	Study Design	Results					
			N (lesions)	Technical success (%)	Follow-up (months)	PP (%)	TLR (%)	Others relevant results
Laird 2012	Evaluate treatment FPISR with ELA+viabahn	Prospective multicentric	27	100	12	48	17.4	ABI increased 0.58 to 0.9
Shammas 2012	ELA+PTA FPISR	Retrospective monocentric	40	93	12	NA	48.7	TVR 48.7%
Van den Berg 2012	ELA+DEB for FPISR	Restrospective monocentric	10	100	7.6	70	0	Mean time of occurrence restenosis 7.2months
Gandini 2013	ELA+DEB vs DEB for SFA in stent occlusion for CLI	Prospective monocentric	24	100	6 and 12	91.7 and 66.7 (ELA+DEB) vs 58.3 and 37.5 (DEB)(P=.01)	16.7% (ELA+DEB) vs 50% (DEB) (P=.01)	NA
Schmidt 2014	Evaluate performance of TE and TB for FPISR	Prospective multicentric	90	96.7	6 and 12	64.1 (95CI 53-73.9) and 37.8 (95CI 27.7-49.2)	12.2 (95CI 7-21) and 35.5 (95CI 17.6-59.4)	NA
Van Den Berg 2014	Evaluate midterm follow-up ELA+DEB FPISR	Prospective cohort	14	100	19.4	91.7	7	Mean time of recurrence of restenosis 8.6 months
Dippel 2015	ELA+PTA vs PTA alone for FPISR	Multicentric prospective randomized	168	93.5	6	71.1 (ELA+PTA) vs 56.4 (PTA)	26.5(ELA+PTA) vs 49(ELA) (P<.005)	NA
Armstrong 2015	ELA+PTA vs PTA alone for FPISR	Retrospective multicentric	54	100	24	NA	14 (ELA) vs 44(PTA alone) (P=.05)	Class III ISR treated with ELA: 54% recurrent stenosis vs 91% PTA at 1year (P=.05)

Reference	Study Design	Main Objectives	N (fenestration)	Localization	Type	Follow-up (months)	Results
Murphy 2009	Case Report	Laser ISF after TEVAR covering LSCA	1	LSCA	Retrograde	8	No endoleaks/stent patent
Ahanchi 2012	Retrospective monocentric	Laser ISF during emergency TEVAR	5	LSCA	Retrograde	8	PP 100% /no endoleak related to fenestration
Redlinger 2013	Retrospective monocentric	Laser ISF during emergency TEVAR	22	LSCA	Retrograde	10	PP 100% / 2 type II endoleaks
Sonesson 2016	Experimental study on pigs	Evaluate if Laser ISF generate emboli	7	Iliac	Antegrade	NA	No produce macroscopically visible emboli or clot
Qin 2017	Experimental study on swine and clinical retrospective monocentric	Laser ISF of aortic arch during TEVAR	6 (swine) and 31(human)	Carotid and LSCA	Retrograde	10	No tearing of the fabric/ Technically feasible/ PP 100%/ No endoleaks