Update: Innovation in Cardiology (VIII)

New Treatment for Old Disease: Management of Resistant Hypertension by Percutaneous Renal Sympathetic Denervation

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ABSTRACT

Hypertension is a major contributor to cardiovascular events, such as stroke and myocardial infarction. It is a major predictor of metabolic disease. It is also an independent risk factor for non-cardiovascular events, such as renal failure.1 Many patients are not well-controlled with current medical therapies. A recent study demonstrated that 50% of patients with stage 2 hypertension, defined as greater than 140/90 mmHg, achieved less than 130/80 mmHg with optimal medical therapy.2 However, this study population had a mean SBP of 166 mmHg and a mean DBP of 95 mmHg, demonstrating that even optimally treated patients have significant residual blood pressure elevation.

The mainstay of blood pressure control is medical therapy with antihypertensive medications.3 However, for many patients, who do not respond adequately to optimal doses of a variety of antihypertensive agents, additional medication and/or medical therapy to optimize blood pressure control is necessary.4 For patients with uncontrolled hypertension, despite optimal doses of currently available medications, a device-based approach that utilizes sympathetic denervation has become an option for the management of resistant hypertension.

Denervation procedures involve the use of radiofrequency ablation, or other energy sources such as laser, over the sympathetic nerve chain in the thoracic or lumbar region. The FDA has approved the use of a device for the treatment of resistant hypertension. The Symplicity HTN-3 study demonstrated a significant reduction in antihypertensive medication use, with an overall mean reduction of 37% in antihypertensive medications.5 The study showed that renal sympathetic denervation led to an overall increase in renal blood flow and glomerular filtration rate, and a hemodynamic profile that is similar to that observed in the non-hypertensive population.6 This hemodynamic profile may be a result of sympathetic denervation, as the renin-angiotensin-aldosterone system is known to increase with sympathetic activity.7 The study also demonstrated a significant reduction in 24-hour mean arterial blood pressure (MAP) and 24-hour office SBP.8 However, the study was limited by the short follow-up duration (12 months) and the limited sample size (112 patients).9

Additional studies, such as the Symplicity HTN-2 study, have demonstrated that renal sympathetic denervation leads to significant reductions in BP, medication use, and cardiovascular events.10 These studies have also shown that renal sympathetic denervation is a safe and effective approach for the management of resistant hypertension.11

The Symplicity HTN-3 study was recently updated with 2-year follow-up results.12 In this study, the reduction in antihypertensive medication use was maintained over 2 years, with an overall mean reduction of 43% in antihypertensive medications.13 The study also demonstrated a significant reduction in 24-hour mean arterial blood pressure (MAP) and 24-hour office SBP.14 However, the study was limited by the short follow-up duration (2 years) and the limited sample size (112 patients).15

In conclusion, renal sympathetic denervation is a promising approach for the management of resistant hypertension. The reduction in antihypertensive medication use, and the reduction in BP, are significant and sustained over time. However, further studies are needed to determine the long-term efficacy and safety of renal sympathetic denervation.

REFERENCES


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populations. A percutaneous, catheter-based renal sympathetic denervation (RND) approach has been proposed to disrupt both afferent and efferent renal sympathetic nerves initially using radiofrequency (RF) ablation (later other modalities) as a therapy for resistant hypertensive patients (Fig. 1).

RENAL SYMPATHETIC DENERVATION PROCEDURE WITH THE SYMPLECTIC™ SYSTEM

The RND procedure is safe and simple, with an average procedure time of 38 min [interquartile range, 34–48 min] shown in the first pilot study. This procedure is performed via the femoral artery with administration of heparin (initially, 5000 units: target active clotting time >250 s) for anticoagulation. First, an aortogram is performed with a 5 Fr-pigtail catheter to confirm the anatomical figure of renal arteries. Once the anatomy is confirmed (appropriate diameter and length, essentially free of atherosclerotic disease), a 6 F LIMA or RDC guiding catheter is used. For the target renal artery for ablation, main renal arteries of ≥4 mm in diameter and ≥20 mm in length are applied. Accessory renal arteries and side branches of the main renal artery with adequate diameter and length might be considered when these are distributed >30% of kidney as a feeding artery. RF ablation at the catheter tip is then applied to the vascular wall to provide heat to the external layer and the sympathetic nerves that arborize around the artery and primarily lie within the adventitia (Figs. 2A and B). Treatment involves circumferential coverage involving 4 to 6 treatments of low-power RF energy (8 W or less) from the distal point in both renal arteries, lasting <120 s and administered in a spiral manner by manual rotation with approximately 5 mm pullback between ablation (Fig. 2A and C). To position the catheter, the tip is placed in the most distal point of each renal artery, and then gradually deflected into the vessel wall until the electrode is well-apposed to the vessel wall. Tip temperature and impedance is monitored in response to a predetermined algorithm during ablation. Higher (>300 Ω) and stable (<20 Ω in change) impedance over the respiratory cycle indicates better wall contact. A larger change in impedance indicates better delivery of energy, but abnormally high impedance and abnormally large change in impedance might suggest the electrode is in a side branch. The target reduction by impedance percentage is approximately −11% to −14%. RF ablation would be canceled when the tip temperature is ≥60 °C, and the change in impedance percentage is exceedingly large.

EFFECTIVENESS AND SAFETY

An initial first-in-man trial (Symplicity HTN-1) evaluated the efficacy and safety of this approach in patients with resistant hypertension (Table). The reduction of postprocedure office BPs was maintained even at 24 months’ follow-up without adverse events (reduction of 20/10, 24/11, 25/11, 23/11, 26/14, and 32/14 mmHg at 1, 3, 6, 12, 18, and 24 months, respectively) (Fig. 3). In addition to the reduction in BP, organ-specific sympathetic denervation was demonstrated. However, there was no control group with which to derive a comparison in the Symplicity HTN-1 trial. Therefore, the Symplicity HTN-2 trial, a multicenter, prospective, randomized trial, was performed to address this shortcoming. In this study, significant and sustained reduction in BP at 1 year follow-up was also demonstrated. Renal function was also evaluated by measuring the level of serum creatinine, based on estimated glomerular filtration rate.

Figure 1. Renal sympathetic denervation system Symplicity™. There are 2 components in the Symplicity™ system: the electrode-tipped catheter and the radiofrequency generator. The electrode tip has a low profile, is flexible and self-orienting. The electrode tip delivers radiofrequency energy to the treatment site. The radiofrequency generator is applied to deliver automated and low-power radiofrequency energy to the electrode tip and to monitor the tip temperature and impedance in response to a predetermined algorithm during ablation. RF, radiofrequency. Reproduced with permission from Medtronic Inc.
**Figure 2.** The renal sympathetic denervation procedure is safe and simple, involving femoral artery catheterization with the tip of the catheter placed in the distal renal artery (A). For the target renal artery for ablation, main renal arteries of ≥4 mm in diameter and ≥20 mm in length are applied. Radiofrequency ablation at the catheter tip is then applied to the vascular wall to provide heat to the external layer and the sympathetic nerves in the adventitia (B). Treatment involves circumferential coverage for 4 to 6 treatments of low-power radiofrequency energy (3 W or less) from the distal point in both renal arteries, lasting ≤120 s, and is administered in a spiral manner by manual rotation with approximately 5 mm pullback between ablations (A and C). The tip temperature and impedance is monitored in response to a predetermined algorithm during ablation. Reproduced with permission from Medtronic Inc.7

**Table**

Outcomes of Major Clinical Trials and Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Krum et al.6</th>
<th>Symplicity HTN-18</th>
<th>Symplicity HTN-29</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First-in-man Multicenter, open-label, no control, June 2007-May 2010 Multicenter, open-label, randomized, June 2009-January 2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patients, no.</td>
<td>50</td>
<td>153</td>
<td>106 (RND, 52; control, 54)</td>
</tr>
<tr>
<td>Age, years</td>
<td>58±9</td>
<td>57±11</td>
<td>58±12</td>
</tr>
<tr>
<td>Antihypertensive medications</td>
<td>4.7±1.4</td>
<td>5.1±1.4</td>
<td>5.2±1.5 (n=52); control 5.3±1.8 (n=51)</td>
</tr>
<tr>
<td>Class at baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACE inhibitors/ARB</td>
<td>96</td>
<td>91</td>
<td>95</td>
</tr>
<tr>
<td>β-blockers</td>
<td>76</td>
<td>82</td>
<td>75</td>
</tr>
<tr>
<td>CCB</td>
<td>69</td>
<td>75</td>
<td>81</td>
</tr>
<tr>
<td>Diuretic</td>
<td>96</td>
<td>95</td>
<td>89</td>
</tr>
<tr>
<td>Estimate GFR, mL/min/1.73 m²</td>
<td>81±23</td>
<td>83±20</td>
<td>RND 77±19 (n=52); control 86±20 (n=54)</td>
</tr>
<tr>
<td>BP at baseline, mmHg</td>
<td>177±10/101±15 (n=50)</td>
<td>176±17/98±14 (n=153)</td>
<td>RND 178±18/96±16 (n=52); control 178±17/97±16 (n=54)</td>
</tr>
<tr>
<td>BP at 6 months, mmHg</td>
<td>155±16/90±5 (n=26)</td>
<td>151/87 (n=86)</td>
<td>RND 146±23/84±11 (n=49); control 179±21/97±10 (n=51)</td>
</tr>
<tr>
<td>BP at 12 months, mmHg</td>
<td>155±16/90±11 (n=9)</td>
<td>153/87 (n=64)</td>
<td>RND 150±24.9/86±3.10 (n=49); control NA (crossed over in 6 months)</td>
</tr>
</tbody>
</table>

ACE, angiotensin-converting enzyme; ARB, angiotensin receptor blockers; BP, blood pressure; CCB, calcium channel blocker; GFR, glomerular filtration rate; NA, not available; RND, renal sympathetic denervation; SD, standard deviation.

Analysis is performed using the paired t-test. Data are expressed as mean ± standard deviation.

An initial first-in-man trial by Krum et al.6 evaluated the efficacy and safety of the renal sympathetic denervation approach in patients with resistant hypertension. With proven safety and efficacy of the renal sympathetic denervation procedure, an extended trial, was commenced. Later, the Symplicity HTN-2 trial, a multicenter, prospective, randomized trial, was initiated.

All trials demonstrated a significant and sustained reduction in blood pressure up to 24 months.6,9–10

* a P<.01 compared between baseline and follow-up.
* b P<.05 compared to control.
* c P<.01 compared between baseline and follow-up.
This measurement demonstrated that renal function remained unchanged over the follow-up period. However, albumin excretion was reduced, consistent with an overall beneficial effect on BP and possibly end-organ damage in these refractory hypertensive patients. It is also noteworthy that RND decreased renin secretion by approximately 50% and that cardiac baroreflex sensitivity improved after RND. In addition, cardiovascular magnetic resonance imaging revealed a substantial reduction in left ventricular mass at 12-month follow-up.

These results indicate that, in addition to aggressive pharmacological therapy, RND has the potential to safely lower BP in patients with resistant hypertension. Furthermore, the sustained BP-lowering effect of RND implies that there are neither overriding alterations in counterregulatory mechanisms nor re-innervation of renal afferent sympathetic nerve after the procedure, at least up to 36 months thus far.

**PROCEDURAL COMPLICATION**

Some complications were noted during the trials, none severe. These complications included 1 hypotension episode both in the Symplicity HTN-1 trial and the Symplicity HTN-2 trial, 1 renal artery dissection in the Symplicity HTN-1 trial, and some pseudoaneurysms/hematomas in the femoral access site, but these events were all subsequently managed without any additional complications or delays in hospital discharge.

**RENAL VASCULAR SAFETY**

Nitroglycerine is often administered through a renal guide catheter to reduce arterial spasm before and after the treatment in each artery. None was considered flow limiting upon termination of the procedure. One patient in the Symplicity HTN-1 trial who underwent computed tomography angiography at 6 months postprocedure was identified as having progression of prior existing renal artery stenosis in the proximal portion of the renal artery. Elective angioplasty and stenting was successfully performed for this lesion.

**PAIN**

During RND, ablation is accompanied by sustained visceral nonradiating abdominal pain; therefore, intravenous narcotic and sedative drugs (morphine or fentanyl and midazolam) are administered in the conscious state 2-5 min before the first ablation. The pain does not persist after RF ablation.

**FUTURE PROSPECTS FOR RENAL SYMPATHETIC DENERVATION**

Systemic BP is maintained by the autonomic nervous system, even during unconsciousness. The autonomic nervous system is made up of the sympathetic nervous system and parasympathetic nervous system. The autonomic nervous system connects the brain, heart, blood vessels, and kidneys, regulating the maintenance of stabilized systemic BP.

When BP suddenly decreases, afferent sympathetic nerve activity (SNA) is transmitted from the heart, kidney, and pressor organs to the central nervous system (CNS) (Fig. 4). Increased SNA in the CNS initiates efferent SNA to the heart, arterioles, and kidney, which in turn contributes to the heart, arterioles, and kidney, and thus increases BP to stabilize systemic BP. Efferent renal sympathetic nerves bring sympathetic signals from the CNS to the kidneys, causing increased renin release, sodium retention, and reduction in renal blood flow. In contrast, when BP suddenly rises, the activity of arterial baroreceptors is transmitted by suppression to the CNS, and efferent sympathetic nerve via the CNS, and then BP is decreased to stabilize systemic BP, influencing sympathetic outflow to the kidneys and other organs involved in cardiovascular control. Furthermore, the kidney is a strong initiator of afferent SNA in the CNS but does not initiate suppressive afferent parasympathetic nerve activity to the CNS. Therefore, renal SNA is a major activator of SNA; both the contribution of the kidney to central sympathetic drive and the consequences of sympathetic efferent drive to the kidney contribute to the development and sustenance of hypertension. Ye et al. showed that kidney injury induced by 10% phenol increased norepinephrine secretion from the CNS and raised systemic BP in rats, but that these increases were prevented by the prior denervation of afferent renal nerves. These data suggest that
information regarding the state of the kidney, such as hypertension, high glucose, ischemia, angiotensin II, and oxidative stress, is transferred via afferent renal sensory nerves to the CNS, thus stimulating efferent SNA to the heart, arterioles, and kidney, thereby elevating BP. Afferent SNA is regulated to increase BP due to low renal glomerular flow in chronic kidney disease (Fig. 5). Therefore, afferent renal SNA is activated, resulting in a decrease in renal glomerular flow via efferent renal sympathetic nerve activation, which in turn contributes to the development and maintenance of a vicious cycle of sympathetic overactivity in chronic kidney disease. Interestingly, this bidirectional relationship between sympathetic overactivity inducing insulin resistance and hyperinsulinemia producing sympathetic activation also initiates a vicious SNA cycle.\textsuperscript{15} As a consequence, RND in patients with insulin resistance or type II diabetes mellitus has the potential to improve insulin resistance and glycemic control.\textsuperscript{29} Moreover, the reduction in SNA by RND is presumed to improve cardiac dysfunction and might also prevent the development of the acute phase of heart failure in cardiorenal syndrome.

Currently, renal sympathetic nerve denervation is widespread in developed countries with expanded clinical trials. The Symplicity HTN-3 trial, designed as a prospective, randomized, masked procedure (sham operation), single blind trial, is in progress.\textsuperscript{21} New devices are also being developed\textsuperscript{22,23}, one is a balloon type with RF electrodes placed in a helical pattern, which allows for directed energy flow into the adventitia, promising lower RF energy delivery and reduction in procedure time. Another is a multiablation basket with an integrated 4-point contact surface to deliver RF energy. A cylindrical transducer–catheter (PARADISE\textsuperscript{TM} catheter, ReCor Medical; New York, United States),\textsuperscript{24} emits ultrasound energy circumferentially and might be of particular benefit for RND as it does not require direct tissue contact; with a water balloon around the transducer, it passes through the surrounding fluids and generates frictional heating in soft tissues, increasing temperature at depth but with less damage to nontarget tissues. These newly developed devices for RND are expected to simplify the procedure as well as to reduce the complication risk; however, further study is needed to verify these expectations.

**LIMITATIONS OF THE PROCEDURE**

Six patients (13%) had only small BP reductions\textsuperscript{8} after RND. In these patients, the procedure might have failed, or the patients’ sympathetic efferent or afferent activity might not have contributed to their hypertension. There is also concern that predicting adequate results by RND is not possible prior to or during the procedure.

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**Figure 4.** Blood pressure control in autonomic nervous system. Systemic arterial pressure is controlled and maintained by the autonomic nervous system under unconsciousness. The autonomic nervous system is made up of the sympathetic nervous system and parasympathetic nervous system. The autonomic nervous system connects the brain, heart, blood vessels, and kidneys. Hypertension is induced by accelerated sympathetic nerve activity.\textsuperscript{15} Increased sympathetic nervous activity in the central nervous system is transmitted by efferent sympathetic nerves to the heart, arterioles, and kidney, thus increasing blood pressure.\textsuperscript{15} Efferent sympathetic nerves in the kidney bring sympathetic signals from the central nervous system to the kidneys, causing increased renin release, sodium retention, and reduction in renal blood flow. From the other direction, afferent nerves carry the signals from the heart, kidney, and pressor organ to the central nervous system, thereby influencing sympathetic outflow to the kidneys and other organs involved in cardiovascular control. Thus, sympathetic drive creates a feedback loop that adversely affects the vasculature, heart, and kidneys, and plays a vital role in the autonomic nervous system. CNS, central nervous system; GFR, glomerular filtration rate.
CONCLUSIONS

Percutaneous, catheter-based RND represents a novel approach in the management of refractory hypertension. This procedure may also be a promising treatment for patients with less severe hypertension, congestive heart failure, chronic kidney disease, and metabolic syndrome implicated in the pathogenesis of potentiated SNA.

CONFLICTS OF INTEREST

Dr. Henry Krum has received research grants and consulting fees from Medtronic.

REFERENCES