

APPROACH TO THE PATIENT

Preoperative Management of the Pheochromocytoma Patient

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Pheochromocytomas are rare neuroendocrine tumors with a highly variable clinical presentation, but they most commonly present as spells of headaches, sweating, palpitations, and hypertension. Patients with pheochromocytoma may develop complicated and potentially lethal cardiovascular and other complications, especially in the setting of diagnostic or interventional procedures (e.g. upon induction of anesthesia or during surgery). The serious and potentially lethal nature of such complications is due to the potent effect of paroxysmal release of catecholamines. Because this warrants prompt di-

agnosis and treatment, the physician should be aware of the clinical manifestations and complications of catecholamine excess and be able to provide proper preoperative management to minimize catecholamine-related pre-, intra-, and post-operative adverse events. The following clinical scenario and discussion aim to enhance the knowledge of the physician regarding the behavior of pheochromocytoma and to outline current approaches to comprehensive preoperative management of patients suffering from this tumor. (*J Clin Endocrinol Metab* 92: 4069–4079, 2007)

A Patient's Presentation

A 57-yr-old white male presented to the community hospital emergency room with a 3-wk history of presyncopal and syncopal episodes, as well as abdominal pain with intermittent nausea. The patient had reported brief feelings of light-headedness and fainting upon standing on three separate occasions before his admission. The third episode resulted in an injury to his head. At the emergency room, he also complained of abdominal pain associated with nausea.

In the past, other symptoms and problems included episodes of sweating lasting 1–2 min, palpitations, and dizziness (all three usually occurring once every 1–2 wk for the past 6 months), and blurred vision for the last 2–3 months. Past medical history was also significant for labile and difficult-to-control hypertension [treated with amlodipine (Norvasc) 10 mg and metoprolol (Toprol XL) 50 mg once a day] for the past 5 yr. He also had a history of severe weight gain (over 110 pounds) during the last 2 yr, compounded by low energy level. A few months before hospitalization, the patient was put on a diet and a weight loss medication (phentermine, 30 mg once a day for 2 months) resulting in a 70-pound weight loss; however, he continued to be hypertensive. In addition, he was previously diagnosed to have uncomplicated umbilical hernia, benign prostate hypertrophy, and bilateral knee osteoarthritis.

At the emergency room, in view of the recurrent episodes of syncope and recent history of abdominal pain associated with nausea, a work-up for cardio- and cerebrovascular events and a possible small bowel obstruction was initiated.

Abbreviations: CT, Computed tomography; ECG, electrocardiogram; EPI, epinephrine; MIBG, metaiodobenzylguanidine; NE, norepinephrine.

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Computed tomography (CT) of the abdomen revealed a 6.4-cm left adrenal gland mass, in addition to a small umbilical hernia with partial small bowel obstruction. Magnetic resonance imaging confirmed the diagnosis of the left adrenal mass that appeared heterogeneous with a bright signal on T2-weighted images. It also showed moderately distended loops of the small bowel. Electrocardiogram (ECG) did not show any ischemia.

The patient was taken to the operating room for urgent umbilical hernia repair. Upon induction of anesthesia, the patient developed a hypertensive crisis with a blood pressure of 250/150 mm Hg and tachycardia with a heart rate of 95 bpm. Therefore, surgery was immediately aborted. The patient was subsequently transferred to the intensive care unit, and an endocrinology consult was requested for suspicion of a possible pheochromocytoma. Biochemical evaluation for pheochromocytoma revealed elevated urine norepinephrine (NE) of 738 $\mu\text{g}/24\text{ h}$ (with an upper reference limit of 100 $\mu\text{g}/24\text{ h}$) and epinephrine (EPI) of 779 $\mu\text{g}/24\text{ h}$ (upper reference limit, 24 $\mu\text{g}/24\text{ h}$). Two days later, the patient underwent hernia repair with blood pressure and heart rate controlled by iv α - and β -adrenoceptor blockade. The patient was discharged on phenoxybenzamine (Dibenzylamine), metoprolol, and amlodipine.

Subsequently, the patient was referred to the National Institutes of Health (NIH) for further evaluation of his left adrenal pheochromocytoma. The diagnosis of pheochromocytoma was confirmed, and the patient was put on preoperative α - and β -adrenoceptor blockade. Three weeks before surgery, the patient was started on phenoxybenzamine 10 mg per day by mouth, which was gradually titrated up to 30 mg three times a day. He was also put on atenolol 25 mg/d by mouth, which was gradually titrated up to 50 mg twice a day and metyrosine (Demser) 250 mg three times a day. ECG revealed a first-degree AV block with QT interval of 464

msec. A transthoracic echocardiogram showed a mildly dilated left atrium and ventricle. Therefore, a cardiology consult was obtained; but no further recommendations were given. After the patient's blood pressure normalized, a liberal salt diet was recommended.

The day before the planned surgery, the patient was admitted to NIH Clinical Center. His average blood pressure and heart rate were 134/76 mm Hg and 65 bpm, respectively. At midnight, the patient was given an extra dose of 40 mg of phenoxybenzamine, 12.5 mg of atenolol, and 500 mg of metyrosine. Additionally, he received 1 liter of 5% dextrose with 0.45% normal saline. During the surgery the following morning, there was no significant change in blood pressure during tumor manipulation and removal. Postoperatively, the patient developed a few hours of lasting hypotension (average blood pressure of 83/49 mm Hg and heart rate of 87 bpm), which was treated with a dopamine drip. Histopathological examination confirmed the diagnosis of pheochromocytoma.

Pheochromocytoma as Catecholamine Excess and Storm

The World Health Organization defines pheochromocytoma as a tumor arising from catecholamine-producing chromaffin cells in the adrenal medulla—an intraadrenal paraganglioma (1, 2). Closely related tumors of extraadrenal sympathetic (catecholamine producing) and parasympathetic (rarely catecholamine producing) paraganglia are classified as extraadrenal paragangliomas. For simplification, in this report, the term pheochromocytoma will be used to refer to both adrenal and sympathetic ganglia-derived extraadrenal tumors.

Practically all pheochromocytomas produce catecholamines with considerable variation in their content, depending on expression of biosynthetic enzymes as depicted in Fig. 1 (3–5). Most extraadrenal pheochromocytomas produce predominantly NE. Many adrenal tumors produce either NE and EPI, or few rarely produce predominantly EPI (e.g. in patients with multiple endocrine neoplasia type 2 and neurofibromatosis type 1). The concentrations of catecholamines in pheochromocytoma tissues are enormous (6), potentially creating a volcano that can erupt at any time. Significant eruptions result in a catecholamine storm called “attacks.” In addition, smaller and continuous eruptions usually result in various symptoms and signs that are characteristic of constant adrenoceptor overstimulation by catecholamines (Table 1). For example, in our series we found that in patients with sporadic NE-secreting pheochromocytomas, the average NE content was about 1,760,000 pg/g tissue with about 53% of its release each day. In sporadic EPI-secreting pheochromocytomas, the average EPI content was about 3,801,000 pg/g tissue, with about 5% of its release each day (Eisenhofer, G., unpublished observations). At such levels, any direct tumor stimulation may lead to abrupt and significant catecholamine release that exceeds normal plasma values 1000 times or more (7, 8). These differences in catecholamine content and release explain different clinical presentations and ultimately necessitate specific treatment for each patient.

However, in about 15–20% of patients with pheochromo-

cytoma, basal plasma or urine catecholamines are within normal limits (9, 10). Some of these cases may be explained by the presence of so-called “nonfunctional” or “silent” pheochromocytomas that do not secrete significant amounts of catecholamines. Nevertheless, most of these silent tumors synthesize and metabolize catecholamines to metanephrines (elevated either in plasma or urine) and show elevations in plasma catecholamines only during paroxysmal attacks possessing the same danger as other pheochromocytomas (11, 12). In addition to catecholamines, pheochromocytomas are known to produce other vasoactive substances (neuropeptide Y, adrenomedullin, and atrial natriuretic peptide) that may cause hypertension (9).

Catecholamines and Adrenoceptors

The adrenoceptors are the final targets for catecholamines that are found in excess in most patients with pheochromocytoma (Fig. 1). Both EPI and NE have overlapping but different effects on α - and β -adrenoceptors on various organs and systems (Table 2). In particular, EPI has a more potent effect on β_2 -adrenoceptors than NE, whereas NE is a more potent β_1 -adrenoceptor agonist than EPI. EPI is also a more potent α -adrenoceptor agonist than NE. However, the proximity of sites of NE and EPI release to adrenoceptors and the resulting concentrations at effector sites are also important determinants of adrenoceptor-mediated responses to these two catecholamines (13, 14).

In patients with pheochromocytoma, both NE and EPI behave as hormones as they are released into circulation. As a circulating hormone, EPI (more than 95% derived from the adrenal medulla) acts potently on β_2 -adrenergic receptors of the skeletal muscle vasculature causing vasodilation that results in hypotension (14–16). In contrast, NE released locally from sympathetic nerve endings within the vasculature causes α_1 -adrenoceptor-mediated vasoconstriction resulting in hypertension (14, 17). Both catecholamines, although NE to a higher degree, stimulate β_1 -adrenoceptors resulting in an increased heart rate. Furthermore, EPI is important as a metabolic hormone (18). In particular, EPI stimulates lipolysis, ketogenesis, thermogenesis, and glycolysis, and raises plasma glucose levels by stimulating glycogenolysis and gluconeogenesis. EPI also has potent effects on pulmonary function, causing β_2 -adrenoceptor-mediated dilation of airways. Thus, patients with EPI-secreting pheochromocytomas more frequently show episodic symptoms and signs with palpitations, light-headedness or syncope, anxiety, and hyperglycemia than patients with tumors that secrete mainly NE, who more often have continuous symptoms and signs including hypertension, sweating, and headache (3, 17, 19). These catecholamine-specific effects on adrenoceptors explain the wide range of clinical presentations of patients with pheochromocytomas and serve as the basis for appropriate preoperative adrenergic blockade. Although some patients need significant amounts of adrenoceptor blockers, some may not, despite high circulating catecholamine concentrations (often seen in patients with metastatic pheochromocytoma). This may be explained by so called “desensitization” that occurs by two mechanisms: internalization of receptors, reducing their number on the cell sur-

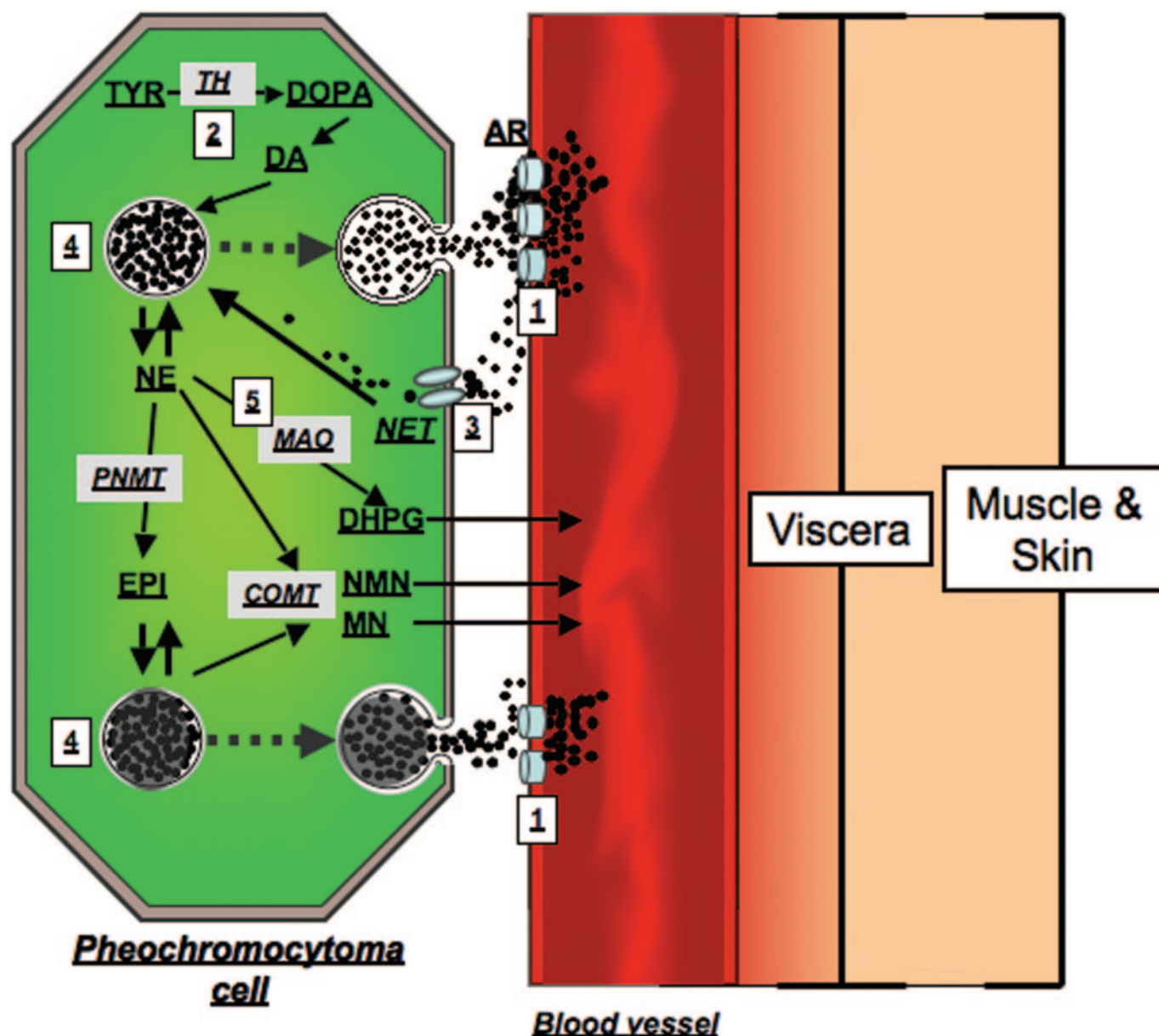


FIG. 1. Diagram illustrating the main pathways of catecholamine synthesis, release, and metabolism in pheochromocytoma. Numbers in squares indicate sites of: 1) action of α - and β -adrenoceptor blockers or weight loss medications [phentermine (Adipex, Fastin, Zantryl), phendimetrazine (Bontril, Adipost, Plegine), methamphetamine (Desoxyn), and phenylethylamine (Fenphedra)] as sympathomimetic amines with a direct action on adrenoceptors; 2) Metyrosine (Demser) inhibition of TH; 3) inhibition of NE reuptake via NET (mainly on sympathetic nerve terminals) by the effect of tricyclic antidepressants [amitriptyline (Elavil, Endep), nortriptyline (Aventyl, Pamelor)], combined serotonin and NE reuptake inhibitors [duloxetine (Cymbalta), venlafaxine (Effexor)], sibutramine (Meridia), and cocaine; 4) where sympathomimetics (*e.g.* ephedrine, pseudoephedrine), and food containing tyramine (*e.g.* wine, cheese) release NE and EPI from storage vesicles; 5) MAO inhibitors [deprenyl (*Selegiline*)] blocking the conversion of NE to DHPG that results in accumulation and higher release of NE (mainly at sympathetic nerve terminals). TYR, Tyrosine; DOPA, dihydroxyphenylalanine; DA, dopamine; DHPG, dihydroxyphenylglycol; NMN, normetanephrine; MN, metanephrine; TH, tyrosine hydroxylase; PNMT, phenylethanolamine-N-methyltransferase; MAO, monoamine oxidase; COMT, catechol-O-methyltransferase; NET, norepinephrine cell membrane transporter; AR, adrenoceptors.

face; or decreased binding affinity of the catecholamine to the receptor (20, 21). This mechanism prevents, at least partially, a patient from the harmful effects of catecholamines, which often favor the administration of lower doses of adrenoceptor blockers and catecholamine synthesis inhibitors to minimize drug-related side effects.

Current Views on Preoperative Blockade

The panel of experts at the First International Symposium on Pheochromocytoma recommended that all patients with a biochemically positive pheochromocytoma should receive appropriate preoperative medical management to block the

TABLE 1. Signs and symptoms in patients with pheochromocytoma

Signs		Symptoms	
Hypertension	++++	Headaches	++++
Sustained hypertension	++	Palpitations	++++
Paroxysmal hypertension	++	Anxiety/nervousness	+++
Postural hypotension	+	Tremulousness	++
Tachycardia or reflex bradycardia	+++	Weakness, fatigue	++
Excessive sweating	++++	Nausea/vomiting	+
Pallor	++	Pain in chest/abdomen	+
Flushing	+	Dizziness or faintness	+
Weight loss	+	Paresthesias	+
Fasting hyperglycemia	++	Constipation (rarely diarrhea)	+
Decreased gastrointestinal motility	+	Visual disturbances	+
Increased respiratory rate	+		

Frequency: highest (++++) to lowest (+). Adapted from Eisenhofer *et al.* (76).

effects of released catecholamines (2). Wide-ranging practices, international differences in available or approved therapies (22–29), and a scarcity of evidence-based studies comparing different therapies led to a lack of consensus regarding the recommended drugs for preoperative blockade. However, α -adrenoceptor antagonists, calcium channel blockers, or angiotensin receptor blockers were all recommended. For tachyarrhythmias, β -adrenoceptor or calcium channel blockers were recommended, but it was emphasized that if β -adrenoceptor blockers are used, they should be used only after adequate pretreatment with α -adrenoceptor antagonists to avoid hypertensive crisis from unopposed α -adrenoceptor overstimulation (usually 2 d after α -adrenoceptor blockers are given) (30). The mechanism for β -adrenoceptor blocker-associated adverse events is generally ascribed to inhibition of β_2 -adrenoceptor-mediated vasodilatation, leaving α -adrenoceptor-mediated vasoconstrictor responses to catecholamines unopposed (31).

The main goal of preoperative management of a pheochromocytoma patient is to normalize blood pressure, heart rate, and function of other organs; restore volume depletion; and prevent a patient from surgery-induced catecholamine storm and its consequences on the cardiovascular system. Therefore, when preoperative adrenergic blockade is started, drug doses are usually much higher, the combination of various drugs is often necessary, and targets for cardiovascular indices are much stricter than they would be if no operation was performed.

Currently, there is no consensus for when adrenergic blockade should be started when preparing a patient for surgery. In most medical centers, adrenergic blockade usually starts 7–14 d preoperatively to have adequate time to normalize blood pressure and heart rate and to expand the contracted blood volume (27, 32–36). In some patients who have organ damage from long-standing catecholamine excess (*e.g.* catecholamine-induced cardiomyopathy, vasculitis, recent myocardial infarction, and bowel movement dysfunction), adrenergic blockade can be initiated much earlier before the planned surgery. At our institution, our goal is to achieve preoperative blood pressure of 130/80 mm Hg or less while sitting and about 100 mm Hg systolic while standing (not less than 80/45 mm Hg) and target heart rate of about 60–70 bpm while sitting and 70–80 bpm while standing. At other institutions, the target blood pressure is either lower (37) or higher (9), depending on institutional experi-

ence. Nevertheless, recommendations regarding blood pressure and heart rate are supported by observational nonsystematic studies and personal experience rather than properly conducted prospective clinical studies.

α -Adrenoceptor antagonists

Phenoxybenzamine (Dibenzylamine; irreversible, noncompetitive, α -adrenoceptor blocker) is most commonly used for preoperative blockade (Table 3). Phenoxybenzamine has a long-lasting effect that diminishes only after *de novo* α -adrenoceptor synthesis. The initial dose of phenoxybenzamine is usually 10 mg twice a day and is increased until the clinical manifestations are controlled or side effects appear. Generally, a total daily dose of 1 mg/kg is sufficient. Some patients, however, may require much larger doses that, at our institution, are usually increased in increments of 10 to 20 mg every 2 to 3 d. If the initial dosage is too high, the patient will have significant postural hypotension with reflex tachycardia, dizziness, syncope, nasal congestion, and other side effects, and dose titration is warranted. As the correct dose is approached, paroxysmal hypertensive episodes are brought under control, and when the right dose is achieved the patient becomes normotensive or mildly hypotensive. Additionally, the prolonged action of phenoxybenzamine can contribute to hypotension in the first 24 h after tumor removal (38). Another option is to administer phenoxybenzamine by infusion (0.5 mg/kg·d) for 5 h a day, 3 d before the operation (39, 40). This approach, however, requires that the patient be admitted to the hospital and closely monitored; this period is usually too short to start catecholamine synthesis inhibitors to achieve maximum effect as discussed below. Two studies reported no correlation between duration of treatment (less than 1 wk *vs.* a longer time period) with phenoxybenzamine and cardiovascular intraoperative stability (41, 42). Furthermore, it should be mentioned that compared with α_1 -adrenoceptor blockers, phenoxybenzamine is an expensive drug; therefore, it is mainly limited to patients with appropriate health insurance.

Other α -adrenoceptor blocking agents of use are prazosin (Minipress), terazosin (Hytrin), and doxazosin (Cardura) (Table 3) (43, 44). All three are specific, competitive, and therefore short-acting α_1 -adrenergic antagonists. Prazosin is administered in doses of 2 to 5 mg two or three times a day, terazosin is given in doses of 2 to 5 mg per day, and dox-

TABLE 2. Adrenoceptor-mediated responses of effector organs

Effector organs	Receptor type	Responses	Most relevant clinical manifestations
Eye			
Radial muscle, iris	α_1	Contraction (mydriasis) ++	Blurry vision
Ciliary muscle	β_2	Relaxation for far vision +	
Heart			
SA node	β_1, β_2	Increase in heart rate ++	Palpitations, angina
Atria	β_1, β_2	Increase in contractility and conduction velocity ++	Palpitations, angina
AV node	β_1, β_2	Increase in automaticity and conduction velocity +++	Palpitations, angina
His-Purkinje system	β_1, β_2	Increase in automaticity and conduction velocity +++	Palpitations, angina
Ventricles	β_1, β_2	Increase in contractility, conduction velocity, automaticity, and rate of idioventricular pacemakers +++	Palpitations, angina
Arterioles			
Coronary	$\alpha_1, \alpha_2; \beta_2$	Constriction +; dilations ++	Angina
Skin and mucosa	α_1, α_2	Constriction +++	Pallor
Skeletal muscle	$\alpha; \beta_2$	Constriction ++; dilations ++	Hypertension
Cerebral	α_1	Constriction (slight)	Stroke
Pulmonary	$\alpha_1; \beta_2$	Constriction +; dilations ++	Edema
Abdominal viscera	$\alpha_1; \beta_2$	Constriction +++; dilations +	E.g. Bowel ischemia
Salivary glands	α_1, α_2	Constriction +++	
Renal	$\alpha_1, \alpha_2; \beta_1, \beta_2$	Constriction +++; dilations +	Renal failure
Veins (systemic)	$\alpha_1, \alpha_2; \beta_2$	Constriction ++; dilations ++	Orthostatic hypotension
Lung			
Tracheal and bronchial muscle	β_2	Relaxation +	
Bronchial glands	$\alpha_1; \beta_2$	Decreased secretion; increased secretion	
Stomach			
Motility and tone	$\alpha_1, \alpha_2; \beta_2$	Decrease (usually) +	Early satiety, discomfort
Sphincters	α_1	Contraction (usually) +	
Intestine			
Motility and tone	$\alpha_1, \alpha_2; \beta_1, \beta_2$	Decrease +	Constipation, ileus
Sphincters	α_1	Contraction (usually) +	
Secretion	α_2	Inhibition	Constipation
Gallbladder and ducts	β_2	Relaxation +	Gallstones
Kidney			
Renin secretion	$\alpha_1; \beta_2$	Decrease +; increase ++	
Urinary bladder			
Detrusor	β_2	Relaxation (usually) +	Urinary retention
Trigone and sphincter	α_1	Contraction ++	Urinary retention
Ureter			
Motility and tone	α_1	Increase	
Uterus	$\alpha_1; \beta_2$	Pregnant: contraction; relaxation Nonpregnant: relaxation	
Sex organs, male	α_1	Ejaculation ++	
Skin			
Pilomotor muscles	α_1	Contraction ++	Sweating
Sweat glands	α_1	Localized secretion +	
Spleen capsule	$\alpha_1; \beta_2$	Contraction +++; relaxation +	Hyperglycemia, glycosuria
Skeletal muscle	β_2	Increased contractility; glycogenolysis; K^+ uptake	
Pancreas			
Acini	α	Decreased secretion +	Hyperglycemia, glycosuria
Islets (β cells)	α_2	Decreased secretion +++	
	β_2	Increased secretion +	
Fat cells	$\alpha_2; \beta_1, \beta_2$	Lipolysis +++ (thermogenesis)	Hypoglycemia
Salivary glands	α_1	K^+ and water secretion +	Feeling warm
	β	Amylase secretion +	
Lacrimal glands	α	Secretion +	Lacrimation
Pineal gland	β	Melatonin synthesis	
Posterior pituitary	β_1	Antidiuretic hormone secretion	Decreased diuresis

Highest (+++) to lowest (+) intensity of adrenergic nerve activity in the control of various organs and functions listed. Where (+) is not given, intensity is not specified. SA, Sinoatrial; AV, atrioventricular. Adapted from Pacak *et al.* (86).

azosin in doses of 2 to 8 mg per day. However, all three have the potential for severe postural hypotension immediately after the first dose; thus, they should be given just as the patient is ready to go to bed. Thereafter, the dosage can be increased as needed; titration can be achieved more quickly with much less side effects (no reflex tachycardia, less postoperative hypotension) compared with phenoxybenzamine. In patients with EPI-secreting tumors, the absence of reflex

tachycardia (due to no effect on presynaptic α_2 -adrenoceptors, which if inhibited increase NE release) can be advantageous in patients who also have coronary artery disease. In volume-depleted patients, α_1 -adrenergic antagonists must be used cautiously because hypotensive effects may be more significant. Although some studies suggest that these drugs can control blood pressure pre-, intra-, and postoperatively as effectively as phenoxybenzamine, other studies do not

support such conclusions (25, 45, 46). Because of a short half-life of α_1 -adrenergic antagonists, these drugs should also be given in the morning before surgery. In some institutions, phenoxybenzamine is used first and then replaced by α_1 -adrenergic antagonists before surgery to reduce postoperative hypotension (37).

In summary, α -adrenoceptor blockade has a significant impact on surgical outcome as demonstrated in the study of Goldstein *et al.* (47) where 69% of patients without α -adrenoceptor blockade experienced perioperative complications compared with only 3% with blockade. Experience at our and other institutions along with current pheochromocytoma expert views confirm these conclusions and results (2, 48–50), whereas previously published data suggested that preoperative α -adrenoceptor blockade may not be necessary (51). Thus, currently it depends on institutional preference whether to use α - or specific α_1 -adrenergic antagonists because they both are well accepted in the preoperative management of a pheochromocytoma patient. Regardless of which α -adrenoceptor antagonist and its dose are used, no complete α -adrenoceptor can be achieved as presented by a number of patients with intraoperative hypertension and tachyarrhythmia (38, 41, 52).

β -Adrenoceptor antagonists

β -Adrenoceptor blocking agents are needed when catecholamine- or α -blocker-induced tachyarrhythmia occurs (Table 3). A β -adrenoceptor blocker should never be used in the absence of an α -adrenoceptor blocker because the former will exacerbate EPI-induced vasoconstriction by blocking its vasodilator component. This will make hypertensive episodes worse in subjects who are on a β -adrenoceptor blocker alone. Currently, cardioselective β_1 -adrenoceptor blockers are preferable (Table 3). Atenolol (Tenormin) is administered in doses of 12.5 to 25 mg two or three times a day, and metoprolol (Lopressor) in doses 25–50 mg three to four times a day (Toprol XL in doses 25–200 mg once a day). Propranolol (Inderal) as a nonselective β -adrenoceptor blocker is also used and is given in doses of 20 to 80 mg one to three times a day.

Combined α - and β -adrenoceptor antagonists

Although labetalol (Normodyne or Trandate), a drug with both α - and β -antagonistic activity, has been used for preoperative adrenoceptor blockade, it should not be used as the primary choice for blockade (53–55). With labetalol, one is forced to use a fixed ratio of α - to β -antagonistic activity that is about 1:7 (if given orally) (56), which may result in paradoxical episodes of hypertension or even hypertensive crisis (57). Note that the α - to β -antagonistic activity should be at least 4:1 to achieve adequate antihypertensive effect (58). Carvedilol (Coreg) is another new antihypertensive drug with similar effects as labetalol. Thus, these drugs are not recommended for preoperative adrenoceptor blockade, except in the situation when a patient is on α - and β -adrenoceptor blockers that need to be replaced (*e.g.* due to side effects). Moreover, labetalol significantly reduces the uptake of ^{131}I -metaiodobenzylguanidine (MIBG) and needs to be stopped about 2 wk before ^{131}I -MIBG scintigraphy (59).

Calcium channel blockers

Perhaps less effective than α -adrenoceptor blockers, calcium channel blockers provide another option for preparing the patient preoperatively (22, 26, 60, 61). These drugs block NE-mediated calcium influx into vascular smooth muscle, thereby controlling hypertension and tachyarrhythmias. It is the view of the author and others that currently, there are three main roles of these drugs in pheochromocytoma patients (9, 37): 1) to supplement adrenoceptor blockers in patients with inadequate blood pressure control, obviating the need to increase the dosage of α -adrenoceptor blockers; 2) to replace adrenoceptor blockers in patients with severe side effects; and 3) to prevent adrenoceptor blocker-induced sustained hypotension in patients with only intermittent hypertension. Calcium channel blockers do not cause hypotension or orthostatic hypotension during normotensive period (62). These agents may also prevent catecholamine-associated coronary spasm; therefore, they may be useful when pheochromocytoma is associated with catecholamine-induced coronary vasospasm. In some medical institutions, calcium channel blockers are the primary preoperative treatment of choice in normotensive patients with pheochromo-

TABLE 3. Main classes of drugs with contraindications in patients with pheochromocytoma

Drug class	Relevant clinical uses
β -Adrenergic blockers ^a	May be used to treat conditions that result from catecholamine excess (<i>e.g.</i> hypertension, cardiomyopathy, heart failure, panic attacks, migraine, tachycardia and cardiac dysrhythmias)
Dopamine D2 receptor antagonists	Control of nausea, vomiting, psychosis, hot flashes and for tranquilizing effect
Tricyclic antidepressants	Treatment of insomnia, neuropathic pain, nocturnal enuresis in children, headaches, depression (rarely)
Other antidepressants (serotonin and NE reuptake inhibitors)	Depression, anxiety, panic attacks, antiobesity agents
Monoamine oxidase inhibitors	Non-selective agents rarely used as antidepressants (due to "cheese effect").
Sympathomimetics ^a	Control of low blood pressure during surgical anesthesia; decongestants; antiobesity agents
Chemotherapeutic agents ^a	Antineoplastic actions; treatment of malignant pheochromocytoma
Opiate analgesics ^a	Induction of surgical anesthesia
Neuromuscular blocking agents ^a	Induction of surgical anesthesia
Peptide and steroid hormones ^a	Diagnostic testing

Adapted from Eisenhofer *et al.* (76).
^a These drugs have therapeutic or diagnostic use in pheochromocytoma, but usually only after pretreatment with appropriate antihypertensives (*e.g.* α -adrenoceptor blockers).

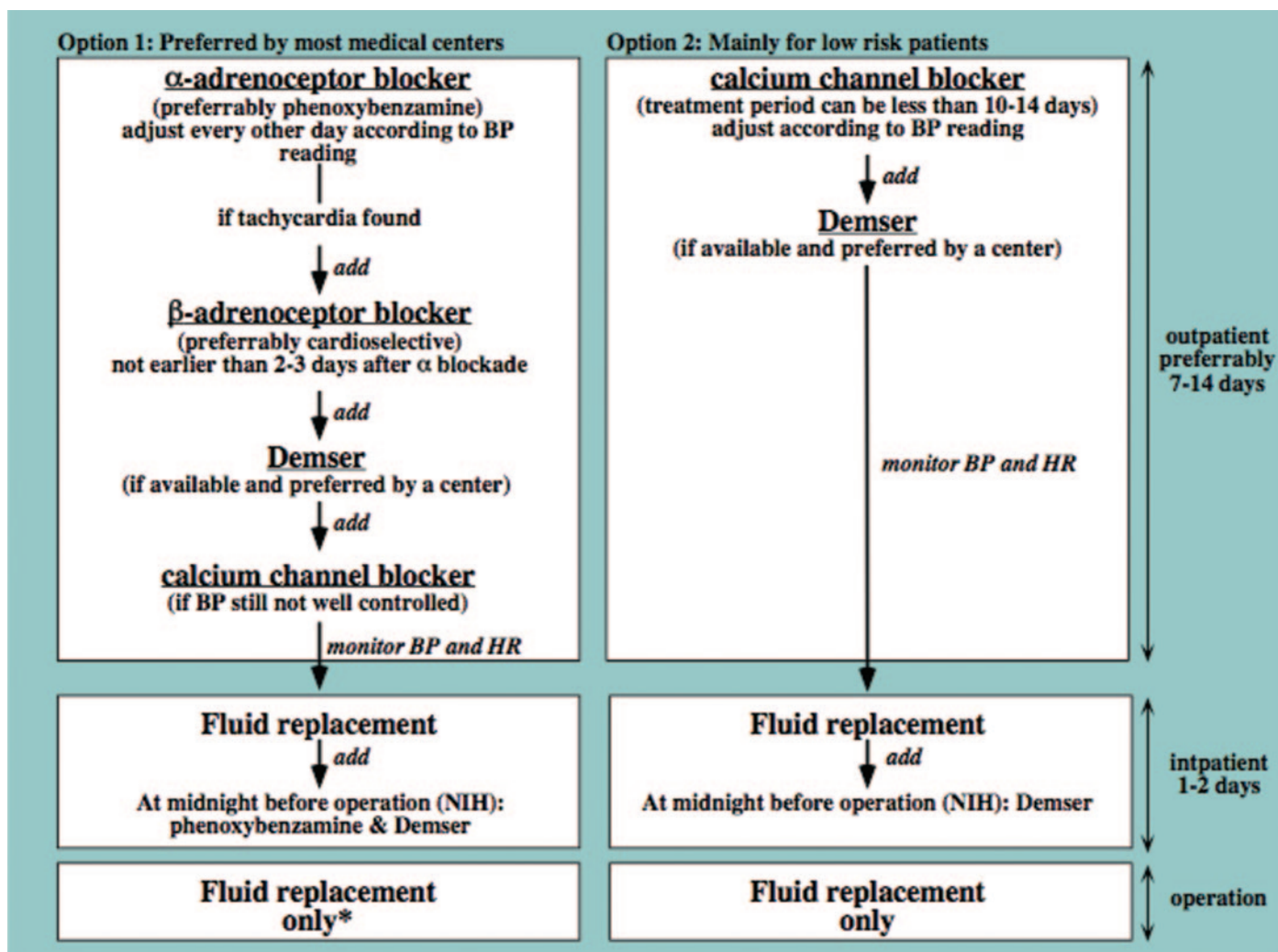


FIG. 2. Current recommended preoperative treatment algorithms in patients with pheochromocytoma. BP, Blood pressure; HR, heart rate. *, If α_1 -adrenoceptor blockers are used, then give one dose in the morning before surgery.

cytoma (51). Amlodipine (Norvasc) is given in a dose from 10–20 mg, and nifedipine (Cardene) in a dose from 60–90 mg per day. Nifedipine (Adalat) is given in a dose from 30–90 mg and verapamil (Covera-HS, Calan-SR) in a dose from 180–540 mg per day. Both nifedipine and verapamil have extended-release action.

Catecholamine Synthesis Inhibition

A good correlation exists between the perioperative cardiovascular instability and catecholamine release (41). Therefore, the administration of drugs that block catecholamine synthesis, thereby decreasing the stimulation of various adrenoceptors by lowering circulating catecholamine levels, is an important component of preoperative management. α -Methyl-L-tyrosine or metyrosine (Demser) is an analog of tyrosine that competitively inhibits tyrosine hydroxylase, the rate-limiting step in catecholamine biosynthesis (63). It significantly but not completely depletes catecholamine stores with maximum effect after about 3 d of treatment (Fig. 1) (64). The drug is usually used to control high blood pressure in

patients with pheochromocytoma, particularly those with extensive metastatic disease or preoperatively in patients with biochemically active tumors (65–68). It is preferably used together with other adrenergic blockers due to incomplete depletion of catecholamine stores regardless of the dose used (27, 37, 67, 69). Despite the well-documented effect of metyrosine on catecholamine synthesis, this treatment has been adopted by only a few institutions (37, 66, 69). This is partially due to the limited availability of this drug and its side effects evident at high doses.

Metyrosine facilitates blood pressure control both before and during surgery, especially during the induction of anesthesia and surgical manipulation of the tumor when extensive sympathetic activation or catecholamine release occurs (66, 67). At our institution, treatment is started in all surgical candidates at a dose of 250 mg orally every 8 to 12 h and, thereafter, the dose is increased by 250 to 500 mg every 2 to 3 d or as necessary up to a total dose of 1.5 to 2.0 g per day. We treat for 1–3 wk before surgery depending on blood pressure and heart rate normalization. The drug, a substi-

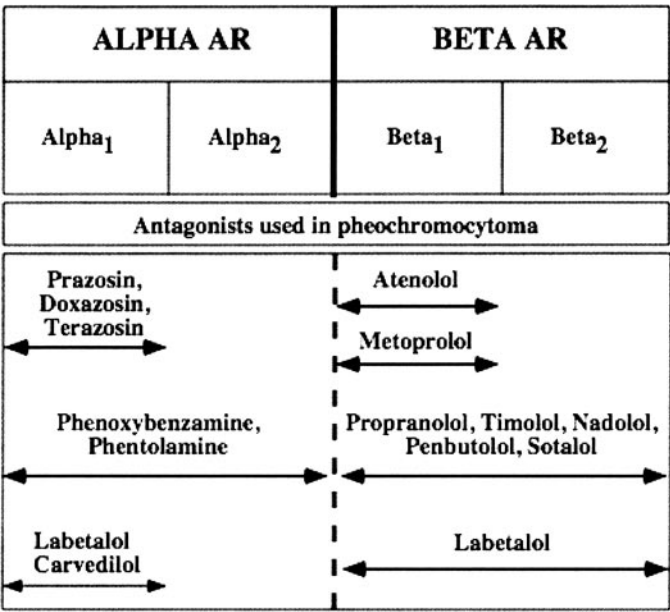


FIG. 3. PLEASE SUPPLY COPY

tuted amino acid, called α -methyl-L-tyrosine, readily crosses the blood–brain barrier. Thus, it inhibits catecholamine synthesis in the brain as well as in the periphery, frequently causing sedation (often sleepiness), depression, anxiety, and galactorrhea, and rarely causes extrapyramidal signs (e.g. parkinsonism in elderly patients) (27, 37). If these side effects do not resolve quickly when the dosage is lowered, the drug should be discontinued. Metyrosine also causes diarrhea and crystalluria, especially when doses are higher than 4 g per day, although such a dose is rarely used. Metyrosine and α -adrenoceptor blockers when used together result in less labile blood pressure during anesthesia and surgery (but elevated blood pressure still occurs in up to 30–80% of patients), reduced intraoperative blood loss, and reduced volume replacement during surgery compared with the use of α -adrenoceptor blockers alone (66, 67, and 70; and author’s personal observations).

In summary, although large randomized, prospective, and controlled studies are lacking, data from retrospective studies suggest that α -adrenoceptor blockade is currently the preferred choice in preoperative management of hypertensive pheochromocytoma patients to improve surgical outcome (Fig. 2) (28, 37, 47, 71). Calcium channel blockers and β -adrenoceptor blockers (72) are most often used as co-drugs when blood pressure cannot be well controlled while on α -adrenoceptor blockade or if tachyarrhythmia occurs. At some medical institutions metyrosine is given to all patients, and at others only to those patients who have highly active tumors associated with difficult-to-treat symptoms and signs of catecholamine excess.

Normotensive patients (in some series up to 30–40% so called low-risk patients) often become hypertensive during surgery, and demonstrate the unpredictable nature of blood pressure changes during an operation (34, 73–75). Thus, normotensive patients should also be given α -adrenoceptor or calcium channel blockers preoperatively. Exceptions where

treatment may not be required for blood pressure and heart rate control include patients with parasympathetic-derived head and neck paragangliomas that do not produce catecholamines or patients with very rare tumors producing only dopamine (5, 36).

Drugs with Interfering Effects on Catecholamine Turnover

The administration of drugs that provoke the release of catecholamines produced by the tumor or interfere with catecholamine turnover may have devastating, even lethal consequences (Fig. 1 and Table 3) (76). NE and EPI release can be provoked by glucagon, steroids, histamine, angiotensin II, and vasopressin. Displacement of catecholamines from storage vesicles by sympathomimetic amines (e.g. tyramine in cheese, bananas, wine, soy sauce, avocados, and any fermented, smoked, or aged meat and fish), followed by their release into circulation provides another example of how pheochromocytomas may be pharmacologically provoked (77). Of the drugs used for obesity management, phentermine (Adipex, Fastin, and Zantryl), phendimetrazine (Bontril, Adipost, and Plegine), methamphetamine (Desoxyn), and phenylethylamine (Fenphedra) are sympathomimetic amines with a direct action on adrenoceptors. Over-the-counter use of nasal decongestants, such as formulations containing ephedrine, pseudoephedrine, or phenylpropanolamine, and currently some weight loss medications provide the most common source of drug interference. Drugs that decrease NE reuptake [e.g. tricyclic and other antidepressants: amitriptyline (Elavil, Endep), nortriptyline (Aventyl, Pamelor), edronax (Reboxetine), duloxetine (Cymbalta), venlafaxine (Effexor); cocaine; weight loss medication sibutramine (Meredia); and those that influence NE metabolism, e.g. monoamine oxidase inhibitors: deprenyl (Selegiline)] contribute significantly to high circulating NE levels (mainly derived from sympathetic nerve terminals). NE reuptake inhibitors can interfere with the biochemical and imaging studies by two mechanisms: 1) blocking tumor cell uptake of ¹²³I- and ¹³¹I-MIBG and other imaging agents (¹⁸F-fluorodopamine) that use the NE transporter; and 2) blocking reuptake of NE by neuronal cell membrane NE transporter, thereby leading to false-positive elevations of plasma NE and downstream metabolites (metanephrines) (78). Regardless of tumor presence, they may increase catecholamine levels and increase the propensity for a hypertensive crisis. NE metabolism modulators such as monoamine oxidase inhibitors block the conversion of metanephrines to methoxyhydroxyphenylglycol, leading to false-positive elevations in plasma and urinary metanephrines (13). Furthermore, these inhibitors allow tyramine from the diet to escape into the systemic circulation where it promotes NE release from sympathetic nerves (cheese effect) in normal people and catecholamine release by tumors in patients with pheochromocytoma. Linezolid (Zyvox), a novel oxazolidinone antibiotic, has monoamine oxidase inhibitory properties; thus, caution is warranted in pheochromocytoma patients. Dopamine receptor antagonists, such as metoclopramide (Reglan), chlorpromazine (Thorazine), and prochlorperazine (Compazine), used

as antipsychotic and antiemetic drugs, can also provoke catecholamine release from pheochromocytoma.

Cardiovascular Evaluation, Blood Volume Restoration, and Other Recommendations

A detailed history, physical examination, and a complete laboratory and cardiac evaluation are essential in preparation of the patient with pheochromocytoma for surgery. An accurate preoperative cardiovascular examination should be carried out, especially to detect the presence of a cardiomyopathy or coronary artery disease. In younger, otherwise healthy patients, preoperative ECG is usually sufficient. In some cases, echocardiography can be helpful to delineate the degree of cardiac compromise, especially in patients with long-standing hypertension. The value of preoperative echocardiography in patients without cardiac symptoms or clinical evidence of cardiac involvement has been questioned (79). Assessment of reduced myocardial contractility using Doppler echocardiography appears to predict risk of perioperative collapse better than conventional echocardiography (80). Cardiovascular function is optimized by relaxation of the constricted vasculature, expansion of the reduced plasma volume, and normalization of blood pressure for 1 to 2 wk before surgery.

Normalization of blood volume minimizes the possibility of protracted hypotension or shock resulting from sudden diffuse vasodilation at the time of tumor removal. If the blood pressure is controlled and the patient is given a normal or high-salt diet (usually 3 d after α -adrenoceptor blocker is given), the patient's diminished blood volume is typically restored to normal, and the degree of postural hypotension decreases. However, the treatment with α -adrenoceptor blockers alone will result in blood volume restoration in only about 60% of patients (81). If catecholamine-induced hyperglycemia is found preoperatively, close monitoring should be initiated, and occasionally treatment may be necessary if hyperglycemia is severe.

In patients with a large left adrenal pheochromocytoma, splenectomy is likely; therefore, vaccination against pneumococcus, *Haemophilus influenzae*, and meningococcus should be given preoperatively.

Strenuous physical activity should be limited, and smoking and alcohol consumption should be avoided because they all significantly increase catecholamine release from a tumor.

Hospital Admission

In most medical centers, the patient is admitted the day before surgery. At our institution, we administer phenoxybenzamine and metyrosine (usually 0.25–1 mg/kg and 500 mg orally, respectively) at midnight before surgery. The patient is instructed to stay in bed, with the rails raised to prevent a fall from hypotension. To avoid further significant hypotension after the tumor is removed, no morning doses are given. The continuous administration of saline (usually 1–2 liters) starting the evening before surgery results in further expansion of intravascular volume and reduction of frequency and severity of postoperative hypotension (Fig. 2). Occasionally, sodium nitroprusside (Nipride) and labetalol

or phentolamine (Regitine) infusion can be used preoperatively in patients with drug-resistant hypertension or hypertensive crisis, respectively (37). Sodium nitroprusside and phentolamine have a rapid onset of action but also end of effect. All these drugs are given to patients upon admission to the intensive care unit.

Special Considerations

Often preoperative management includes CT imaging to either reassess tumor location and its growth or to rule out metastatic disease. Although, it is a common belief that contrast media used for CT scans can induce hypertensive crisis in patients with pheochromocytoma, previous studies and our observations (which included 17 pheochromocytoma patients and six control subjects) do not support such a conclusion (82, 83). Nonionic CT contrast does not have any appreciable effect on NE and EPI release in various types of pheochromocytoma patients; therefore, adrenoceptor blockade does not seem to be necessary as a specific precautionary measure before iv nonionic contrast.

For pediatric patients, there are no other special considerations except when metyrosine is administered. Parents must be given clear instructions to report to a physician immediately if their child develops symptoms of depression and anxiety after taking metyrosine (84).

In pregnant patients, none of the α - and β -adrenoceptor blockers have been associated with any problem except propranolol, which, anecdotally, was reported to be associated with intrauterine growth retardation, fetal bradycardia, and hypoglycemia as well as premature labor (85). Timing of surgery and delivery should be decided through a close discussion and work among obstetricians, endocrinologists, anesthesiologists, and surgeons (36).

Back to the Patient

This case clearly illustrates the need for the use of proper preoperative adrenoceptor blockade and other important preventive measures in pheochromocytoma patients. All such measurements are essential not only before a planned operation, but also before any procedures (e.g. biopsy, endoscopy, radiofrequency ablation) that are expected to be associated with excessive catecholamine release from the tumor. Regarding our patient, several teaching points are of value. Typical symptoms and signs suggestive of catecholamines excess (e.g. recurrent short episodes of sweating and palpitations), together with difficult-to-treat hypertension should arouse immediate suspicion of pheochromocytoma. The findings of a mass with bright signal on a magnetic resonance imaging T2-weighted image together with typical symptoms and signs of catecholamine excess almost invariably confirm the presence of pheochromocytoma. However, the possibility of drug-induced elevation of catecholamine levels with symptoms and signs similar to pheochromocytoma should be ruled out before the final diagnosis is established. The patient presented here was on phentermine, which most likely contributed to his cardiovascular problems. The biochemical confirmation of the presence of pheochromocytoma should be based on measurements of metanephrines in plasma or urine. α -Adrenergic blockers should

be used for preoperative preparation of a patient. β -Adrenergic blockers should be used if tachyarrhythmia is present and only after α -adrenergic blockers have been administered. Calcium channel blockers seem to be a useful alternative in low-risk patients.

Furthermore, to ensure ideal preoperative preparation of patients with pheochromocytoma, very close communication between the endocrine, surgical, medical, cardiology, pediatric, oncology, radiology, and anesthesia teams is essential. Such teamwork should be directed to meet the three most essential goals: treat hypertension and tachyarrhythmias, restore the vascular volume, and treat any tumor or catecholamine excess-associated medical problems. With all these current recommendations in place, the Hippocrates phrase “To do good or to do no harm” reflects a physician’s best effort toward a pheochromocytoma patient before surgery.

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