Bilateral adrenalectomy in the 21st century: when to use it for hypercortisolism?

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Abstract

Therapeutic options available for the treatment of Cushing's syndrome (CS) have expanded over the last 5 years. For instance, the efficient management of severe hypercortisolism using a combination of fast-acting steroidogenesis inhibitors has been reported. Recent publications on the long-term efficacy of drugs or radiation techniques have also demonstrated low toxicity. These data should encourage endocrinologists to reconsider the place of bilateral adrenalectomy in patients with ACTH-dependent aetiologies of CS; similarly, the indication of bilateral adrenalectomy is reassessed in primary bilateral macronodular adrenal hyperplasia. The objective of this review is to compare the efficacy and side effects of the various therapeutic options of hypercortisolism with those of bilateral adrenalectomy, in order to better define its indications in the 21st century.

Keywords

- Cushing's syndrome
- Cushing's disease
- primary bilateral macronodular adrenal hyperplasia
- surgery

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Introduction

Hypercortisolism or Cushing's syndrome (CS) is a rare condition; effective treatments are necessary because of an increased morbidity and mortality if left untreated. CS can be due to: i) an excess of adrenocorticotrophin (ACTH) production leading to an increased production of cortisol; it can originate from a pituitary adenoma (Cushing's disease (CD)) or an extrapituitary endocrine tumour (ectopic ACTH secretion (EAS)); ii) an increased production of cortisol originating from a unilateral adrenal lesion (adenoma or carcinoma) or bilateral hyperplasias:

primary bilateral macronodular adrenal hyperplasia (BMAH), a condition in which adrenal production of ACTH and *ARMC5* mutations have been recently evidenced (Assie *et al.* 2013, Louiset *et al.* 2013), or primary pigmented nodular adrenal disease (PPNAD) that is frequently due to mutations of *PRKARIA* (Bertherat 2006).

All of these conditions apart from the unilateral adrenal tumours can benefit from bilateral adrenalectomy (BA) to cure hypercortisolism (Lacroix *et al.* 2015, Nieman *et al.* 2015).

The recent Endocrine Society Guidelines have not recommended BA as a first-line treatment of CS (Nieman *et al.* 2015). Long-term efficacy and safety of steroidogenesis inhibitors or new modalities of radiation techniques as a second-line treatment have been recently shown. Reports also emphasized the efficacy of fast-acting steroidogenesis inhibitors in acute severe hypercortisolism as a first-line treatment. One should thus wonder whether BA still has a role in the management of hypercortisolism. Therefore, the aim of this review is to identify the potential indications of BA in the updated therapeutic algorithms of CS; we give our opinion on its current and likely future roles, in order to help clinicians choose the best options for their patients (Fig. 1). Current evidence on optimal therapeutic strategies is scarce, and head-to-head comparisons are inexistent. While the mean age at diagnosis of CD is 40–50 years, there are no follow-up data available for more than 10 years for medical therapies of hypercortisolism.

Search strategy and selection criteria

We searched the Cochrane Library and MEDLINE by using the terms ‘adrenalectomy’, ‘bilateral adrenalectomy’, ‘adrenals’, ‘hypercortisolism’, ‘Cushing’ or ‘bilateral hyperplasia’ from 1950 to 2015. We largely selected publications in English in the past 5 years but did not exclude commonly referenced and highly regarded older publications. We also searched the reference lists of articles identified by this search strategy and selected those that we judged to be relevant. Review articles and international guidelines are cited to provide readers with more details and more references than this review can allow. A pooled analysis was performed about outcome data and recurrence rate. For statistical pooling of the data, the DerSimonian and Laird method (random-effects model) was used. In this model, pooled data represent weighted averages related to the sample size of individual studies. Pooled data are presented as 95% CI. Statistical analyses were performed using the StatsDirect statistical

Figure 1
Suggested therapeutic algorithm in ACTH-dependent Cushing's syndrome.

software version 2.8 (StatsDirect Ltd; Altrincham, UK). Literature data and pooled results are summarized in Tables 1, 2, 3, 4 and discussed below.

The BA technique

BA was first performed by open anterior laparotomy. Young (1936) then described a posterior approach by removing the 12th rib. Russell *et al.* (1982) compared the anterior and posterior approaches in unilateral or BA and showed that the complications induced by lumbotomy were lower and led to less morbidity and a shorter hospital stay. Finally, Gagner *et al.* (1992) described the transperitoneal laparoscopic adrenalectomy, which has been improved since then and slightly modified by some teams with retroperitoneoscopy or robot-assisted surgery. The laparoscopic approach is now considered the gold standard for BA, as it results in less post-operative pain, decreased length of stay and faster recoveries. It is a safe procedure with 17–19% morbidity and 0–3% mortality rates (Ritzel *et al.* 2013, Reincke *et al.* 2015). The use of lateral transperitoneal (LTP) vs posterior retroperitoneal (PRP) routes remains to be debated; whereas no significant difference was reported in terms of the associated post-operative complications, the PRP approach is preferred in patients with smaller tumours (<6 cm) and lower BMI (<35 kg/m²) (Sharma *et al.* 2009, Miccoli *et al.* 2011, Lan *et al.* 2015). A significantly shorter operative time was reported for the PRP approach, but it was mainly due to the repositioning time in LTP, as two surgical teams could perform both adrenalectomies in the same time in PRP (Raffaelli *et al.* 2014, Lan *et al.* 2015).

Recently, robot-assisted BA was described without obvious advantages and a superior cost (Raffaelli *et al.* 2014).

BA in CD and EAS

The difficult management is illustrated by the broad range of clinical presentations, from rapidly severe signs in patients with very high cortisol levels (Nieman *et al.* 2015), to more insidious presentations with progressive onset of signs leading to a delayed diagnosis. Long-term exposure to hypercortisolism induces severe complications that are only partly reversible after remission (Ntali *et al.* 2013, Andela *et al.* 2015). The endocrinologist's goals are thus to make an earlier diagnosis, achieve a rapid control (within a few days) of cortisol levels in case of acute hypercortisolism and maintain long-term eucortisolism even when a definitive cure cannot be achieved. There are thus short-term and long-term therapeutic challenges, and BA has potential roles in both situations. Recent reviews have summarized the merits and pitfalls of BA. However, these reviews were usually not comparing BA with other therapeutic options, especially in the setting of acute severe hypercortisolism, or as a final option in patients treated long-term (Bertagna & Guignat 2013, Ritzel *et al.* 2013, Osswald *et al.* 2014, Katznelson 2015, Neychev *et al.* 2015, Reincke *et al.* 2015, Wong *et al.* 2015). We will focus our discussion on these specific points.

BA in acute severe hypercortisolism

Severe hypercortisolism is a life-threatening condition, particularly in patients with psychiatric symptoms.

Table 1 Main studies on the recurrence of adrenal remnants after bilateral adrenalectomy in the last 25 years

References	Patients	Persistent adrenal tissue	Significant clinical recurrence	Time to recurrence	Subsequent treatment
Chow <i>et al.</i> (2008)	68	NA	2 (2.9%)	Not cured immediately after surgery	Follow-up without treatment
Nagesser <i>et al.</i> (2000)	44	12 (27.3%)	2 (4.5%)	Early relapse	Additional surgery allowing cure (<i>n</i> =1), follow-up without treatment (<i>n</i> =1)
Kemink <i>et al.</i> (1992)	50	9 (18%)	1 (2%)	9 years	Transsphenoidal surgery
Chalmers <i>et al.</i> (1981)	5*	5	4	1, 2, 3 and 7 years after the surgery	Recurrence of Cushing's disease, pituitary radiotherapy, 5 months and 5 years later (<i>n</i> =2); pituitary radiotherapy (<i>n</i> =2); still in remission 4 years after glucocorticoid withdrawal (<i>n</i> =1)
Pooled data (95% CI)	162	23% (15–32%)	3.8% (1.4–7.3%)	–	

*Five isolated case reports from five different centres. NA, not available.

Table 2 Main studies reporting the outcomes of patients with severe Cushing's syndrome and their corresponding medical treatment

References	Patients	Treatment	Theoretical onset of action	Dose	Short-term antisecretory efficacy	Adrenal insufficiency	Short-term side effects
Corcuff <i>et al.</i> (2015)	14 EAS	Ke + Me	2–7 days	400–1200 mg/day (Ke) + 0.5–4 g/day (Me)	73% normal UFC	14%	Nausea and vomiting Hypokalaemia Increased liver enzymes
Kamenicky <i>et al.</i> (2011)	7 EAS 3 CD	Ke + Me + Mi	1–3 days	400–1200 mg/day (Ke) + 3–4.5 g/day (Me) + 3.5 g/day (Mi)	63% normal UFC	36%	Nausea and vomiting Hypokalaemia Increased liver enzymes
Castinetti <i>et al.</i> (2009)	8 ACTH dependent	Mifepristone	48 h	400–2000 mg/day	Improvement of clinical signs in all the patients, no biological follow-up available	14% (no biological evidence available)	Hypertension Hypokalaemia
*Preda <i>et al.</i> (2012)	12 case reports	Etomidate	12–24 h	0.03–0.3 mg/kg per h	83% normal UFC	Depending on the dose/sedation level	Haemolysis, thrombophlebitis, pain at the injection site, nephrotoxicity

*Review articles. EAS, ectopic ACTH secretion; CD, Cushing's disease; Ke, ketoconazole; Me, metyrapone; Mi, mitotane; UFC, urinary free cortisol.

Other risks include pulmonary embolism, acute respiratory distress due to opportunistic infections, severe hypokalaemia, and uncontrolled diabetes and hypertension. In this setting, rapidly decreasing cortisol levels can be life-saving. However, no study compared the efficacy of supportive therapies associated with slow progressive decline of cortisol levels vs strategies resulting in an acute reversal of hypercortisolism. Case reports of fatal outcomes during acute phases of hypercortisolism prompted physicians to combine both supportive and medical cortisol-lowering options. BA has long been considered the gold standard. However, performing BA in these highly fragile patients can be challenging. Very fast-acting medical therapies have thus been considered as alternatives (see Table 2), as they allow for a rapid radical option after the control of hypersecretion, or to maintain their use on a long-term basis (detailed below).

Two studies reported the efficacy of the combination of steroidogenesis inhibitors: ketoconazole and metyrapone, both rapidly acting cytochrome P450 enzyme inhibitors, are administered to control hypercortisolism rapidly, while the maximal efficacy of mitotane is achieved later. The strategy is to maintain mitotane on a long-term basis and to withdraw metyrapone and ketoconazole after 2–3 months of effective therapy. The addition of mitotane is not always mandatory, as ketoconazole was shown to be effective in long-term therapy. A total of 24 patients with EAS ($n = 21$) or CD ($n = 3$) and acute severe hypercortisolism were reported in two studies (Table 2): in the first study based on 14 patients with EAS, ketoconazole and metyrapone led to a decrease in urinary free cortisol (UFC) levels from 40- to 3.2-fold the upper limit of value (ULN) at the end of the first week; after 1 month, ten patients achieved normal UFC levels (Corcuff *et al.* 2015). In the second study of ten different patients, UFC levels dramatically decreased after 24–48 h in all patients, and seven patients achieved normal UFC levels; metyrapone and ketoconazole could be stopped after 3.5 months; control was maintained with mitotane alone (Kamenicky *et al.* 2011). In both studies, the overall tolerance was good: there were transient nausea and vomiting in the majority of patients and adrenal insufficiency in six patients; increased liver enzymes that were probably due to ketoconazole (greater than 3-fold the upper limit normal value) were also reported, but only two patients (including one who died rapidly due to liver metastases) had to withdraw from this drug. Most patients presented an initial worsening of hypokalaemia that could be controlled by oral potassium supplementation and/or a mineralocorticoid receptor antagonist. Interestingly, one-third of the patients were eventually treated by

Table 3 Main studies reporting the outcomes of patients treated by unilateral adrenalectomy for BMAH

References	Patients	Unilateral adrenalectomy	Corticotroph suppression	Immediate failure	Recurrence	Follow-up (months)	Need for second surgery
Debillon <i>et al.</i> (2015)	15	15 (100%)	2 (13.3%)	0	2 (13.3%)	39–105	1 (6.7%)
Albiger <i>et al.</i> (2015)	16	16 (100%)	NA	1 (6.2%)	8 (50%)	12–180	5 (31%)
Li & Yang (2015)	23	15 (65%)	0	0	3 (20%)	24–96	3 (13%)
Xu <i>et al.</i> (2013)	14	14 (100%)	1 (7%)	0	1 (7%)	47–69	1 (7%)
Pooled data (95% CI)	68	60	7.8% (1.4–18.5%)	3% (0.3–8.5%)	23.1% (8.7–41.8%)	–	17.5% (8.2–29.4%)

NA, not available.

tumour resection, whereas another third underwent BA once hypersecretion control was achieved (Kamenicky *et al.* 2011, Corcuff *et al.* 2015).

Mifepristone is currently the only available glucocorticoid receptor antagonist. Its very fast-acting efficacy in patients with cortisol-induced psychiatric disorders is very well known, as patients usually present dramatic improvement in 24–48 h. Mifepristone efficacy in controlling hyperglycaemia and hypertension was confirmed in a prospective study conducted in 50 patients with CS (mostly CD), but severe acute hypercortisolism was not specifically evaluated (Fleseriu *et al.* 2012). Mifepristone is usually well tolerated but is difficult to monitor: the glucocorticoid receptor blockade induces an increase in ACTH and subsequently in cortisol, making biological surveillance impossible to detect under- or over-therapy. Another frequently reported side effect was severe hypokalaemia and hypertension due to binding of high cortisol levels to mineralocorticoid receptors. In patients with severe hypercortisolism and hypokalaemia and hypertension, management with mifepristone could thus be highly challenging (Castinetti *et al.* 2009, 2012).

Etomidate is an imidazole derivative utilized as an intravenous hypnotic non-barbiturate induction anaesthetic agent; it was found to be an effective steroidogenesis inhibitor achieving a blockade in 12–24 h. Even if no report cited sedation when used as a treatment of severe hypercortisolism, etomidate is delivered in an intensive care unit to monitor vital signs and adrenal insufficiency. Etomidate use has been reported in 12 patients with severe hypercortisolism who were unable to take medications orally. The dose administered was 0.04–0.05 mg/kg per h, with a cortisol titration (short half-life 3–5 h) and a frequent need for glucocorticoid replacement (in a block and replace strategy). Of note, severe hypercortisolism in an immobilized patient increases the risk of thromboembolic events, which should lead to the use of prophylactic heparin or low-molecular weight heparin (Preda *et al.* 2012).

To summarize, in our view, several studies based on a relatively low number of patients have shown promising results that fast-acting medical therapy can correct acute hypercortisolism. Monitoring these drugs is, however, challenging, and their use should be reserved to expert

Table 4 Summary of the efficacy and short- and long-term side effects of various medical therapies

Medical therapy	Mechanism of action	Long-term antisecretory efficacy	Main side effects	Long-term specific side effects	Escape
Ketoconazole	Steroidogenesis inhibitor	50%	Liver enzyme increase Gastrointestinal discomfort	–	7%
Metyrapone	Steroidogenesis inhibitor	83%	Hypokalaemia Hypertension	–	?
LCI699	Steroidogenesis inhibitor	> 80%?	Hypokalaemia Hypertension	?	?
Mitotane	Steroidogenesis inhibitor	71%	Adrenal insufficiency Gastrointestinal discomfort Dizziness	Adrenal insufficiency?	Low if threshold obtained
Cabergoline	D2 receptor agonist	30–40%?	Nausea, hypotension	Cardiac valvulopathy?	25%?
Pasireotide	Somatostatin analogue	25%?	Diabetes Gastrointestinal discomfort	Gallstones?	?
Mifepristone	Glucocorticoid receptor antagonist	Unknown long-term blocking effect	Adrenal insufficiency? Hypokalaemia Hypertension	Endometrial hyperplasia	?

centres: in this setting, BA can be delayed if a very rapid decrease in cortisol levels (in the first few days) is achieved. Drug intolerance or incomplete efficacy should lead to BA.

BA in chronic hypercortisolism

The management of CD is initially based on transsphenoidal pituitary surgery, which leads to an immediate remission rate of 50–80%. Up to 25% of patients will, however, present recurrence during a long-term follow-up. Failed surgery can lead to different therapeutic options: radiotherapy and radiosurgery have shown antiseecretory efficacy in 50–80% cases, but the delayed maximal efficacy (up to 3 years or more after the procedure) requires an effective medical treatment during this period of time. Another option is the long-term use of medical therapy. BA can be aimed i) at curing imperfectly controlled patients, in case of partial efficacy of medical therapy (with or without radiotherapy), or poor compliance; ii) or more controversially, at curing controlled patients. Although medical therapy can maintain long-term eucortisolism without significant side effects in some patients, some physicians might eventually recommend BA, as withdrawal of these drugs would lead to a reappearance of the disease (Nieman *et al.* 2015, Pivonello *et al.* 2015).

The majority of the studies evaluating medical therapy of CS used UFC to evaluate the antiseecretory efficacy. Petersenn *et al.* recently reported that there was a major intra-patient variability of ~50% in 24-h UFC measurement in CD. Repeating four measurements of UFC in the same patient, on medical treatment, did not decrease this variability. This probably means that very fluctuating levels of cortisol secretion may expose patients on medical therapy to fluctuate between under- and over-treatment with periods of adrenal insufficiency. This issue will have to be examined in prospective studies as part of the decision process when choosing between medical therapy and BA (Petersenn *et al.* 2014).

Efficacy and recurrence after BA BA leads to biological control immediately after surgery but implies the need for gluco- and mineralocorticoid replacement therapy in almost 100% of cases. Obtaining normal cortisol levels should lead to a complete remission of the manifestations of hypercortisolism during the 1st year of follow-up (Sippel *et al.* 2008). However, dependent on the period of exposure to high cortisol levels, a large majority of patients will not be completely cured of morbidities such as hypertension, diabetes, osteopenia or even

psychiatric disturbances (Chow *et al.* 2008, Osswald *et al.* 2014). It is difficult to avoid the bias induced by the frequent glucocorticoid over-replacement, as this can, by itself, be responsible for the maintenance of such complications. Other studies have shown that the majority of patients were satisfied with a BA and had improved quality of life (Osswald *et al.* 2014).

While one should expect 100% long-term remission after BA, recurrence has been reported in some cases after moderate to long-term follow-up. There is a clear distinction between an adrenal remnant without clinical significance (20–30%) and the recurrence of hypercortisolism (1–3%) (Nagesser *et al.* 2000, Chow *et al.* 2008) (Table 1). Defining the presence of an adrenal remnant is also controversial: some authors use a cut-off of plasma cortisol >50 nmol/l after glucocorticoid withdrawal, others use the withdrawal or decreased glucocorticoid replacement therapy despite BA (Chalmers *et al.* 1981), and others recommend using NP53 scintigraphy to confirm the presence of an adrenal remnant (Kemink *et al.* 1992). Post-surgical remnants are usually due to difficult technical conditions such as intra-operative bleeding or poor visualization. While Chalmers *et al.* (1981) reported adrenal recurrence after BA in two patients with Nelson's syndrome, Kemink *et al.* (1992) did not find any difference in recurrence rates following BA in patients with Nelson's syndrome when compared with patients without progression of their corticotroph adenomas. The need for an additional treatment (e.g. repeating adrenal surgery to control clinically significant hypercortisolism) should be balanced by the benefits of obtaining eucortisolism in patients usually mildly oversecreting.

Our opinion is that endocrinologists should keep in mind that among patients with signs in favour of hydrocortisone overdose following BA, they should not hesitate to slowly decrease the dose of glucocorticoid replacement.

Specific complications of BA

The risk of Nelson's syndrome This topic has been recently reviewed, and we will thus not detail this specific point. The potential increase of a corticotroph adenoma remnant after BA justifies follow-up with appropriate ACTH measurement and pituitary magnetic resonance imaging (MRI); however, its rate is still debated, as well as the real risks for patients (Assie *et al.* 2007). The overall incidence is estimated to be 0–47% (median 21%), and this wide range of variability is probably explained by different definitions of Nelson's syndrome. The visual risk associated with Nelson's syndrome is probably not an issue in the 21st

century, as endocrinologists are aware of this condition and regularly follow patients after surgery. This also probably explains why systematic pituitary radiotherapy is no longer advised in the management of such patients (Azad *et al.* 2015).

The outcome of patients with adrenal insufficiency The main issue after BA is obviously the need for an optimal replacement treatment. This optimal dose and restoration of normal cortisol diurnal rhythm are difficult to achieve, but the impact of an over- or under-dose of hydrocortisone replacement is well described (Husebye *et al.* 2014). What was less obvious, and has been shown in a recent study, is that patients with adrenal insufficiency are at high risk for adrenal crises even if they receive education towards the management of their treatment: Hahner *et al.* (2015) reported a risk of 8.3 adrenal crises and a risk of 0.5 adrenal crisis-related deaths per 100 patients-year in 423 patients educated in an expert centre, while Ritzel's review showed a median number of 9.3 adrenal crises per 100 patients-years (Ritzel *et al.* 2013). The overall outcome, however, remains good, with a relatively low rate of mortality.

Comparison with long-term treatment with medical therapy The aim of this review is not to discuss medical therapy (pituitary targeted, steroidogenesis inhibitors or glucocorticoid receptor antagonist) in the classical management of hypercortisolism. These issues have been reviewed recently (Creemers *et al.* 2015, Nieman *et al.* 2015, Pivonello *et al.* 2015). We have focused on the data concerning the long-term efficacy and tolerance of medical therapy in patients with CD or EAS to make a comparison between BA and long-term medical therapy in seemingly controlled patients.

In CD The majority of the published studies on medical therapy focused on short-term efficacy, and it is thus difficult to evaluate the risk of escape and long-term side effects. This is particularly the case for the novel pituitary-targeted somatostatin receptor multi-ligand Pasireotide, which demonstrated a 25% antisecretory efficacy in a large phase 3 international multi-centre study after 12 months of follow-up (Colao *et al.* 2012, Pivonello *et al.* 2014). Long-term data are also missing for mifepristone and cabergoline (Petrossians *et al.* 2010, Pivonello *et al.* 2015).

Data on the long-term efficacy and side effects of medical therapy are thus mainly based on the use of steroidogenesis inhibitors. In the largest study reported to date, mitotane was administered to 76 patients either as a first-line ($n=49$) or as a second-line (after unsuccessful

surgery, $n=27$) treatment. Approximately three-quarters (76%) of the patients were controlled on treatment at their last follow-up visit, and some patients were treated for 60–120 months. Interestingly, five patients relapsed their hypercortisolism while on mitotane treatment when the dose was lowered because of side effects. The safety profile was unfortunately not provided based on the time after drug onset: the authors mentioned that serious adverse events leading to drug withdrawal were observed in 28% of the patients, including ten who were already in remission at the time of the side effects' occurrence. Mitotane is known to induce adrenal insufficiency, and one should wonder whether definite remission could be obtained after drug withdrawal: 71% of the patients presented with recurrent hypercortisolism, despite the fact that the majority of them had adrenal insufficiency at the time of drug withdrawal (Baudry *et al.* 2012). Of note, more than one-third of the patients finally had a BA during the follow-up.

Long-term ketoconazole use has also been reported recently. Of the 200 evaluated patients with CD, 51 were treated for at least 24 months (mean 108 months). At the last follow-up, 64% of the patients were controlled while 7% finally presented an escape to drug efficacy. The profile of side effects was favourable, provided that regular liver enzyme monitoring (which increased in 15.8% cases at the beginning of the treatment or dose change) is performed. No further increase in liver enzymes was reported on a long-term basis. No specific side effects were reported after 24 months of treatment. Of note, 4.4% of patients from the whole cohort underwent BA despite sustained antisecretory efficacy (Castinetti *et al.* 2014).

Finally, the largest UK multi-centre study on the use of metyrapone based on 115 patients with CD was reported recently. Using the average serum cortisol day curve $<12 \mu\text{g/dl}$ (331 nmol/l) as the main response criteria, 55% of the patients achieved the target goal and were improved clinically. In a subgroup of 38 patients treated long-term (mean 18 months), 77% were controlled. In the whole cohort, UFC levels were monitored only in 37 patients and decreased from 7.2- to 2.5-fold ULN; thus, despite clinical improvement, complete normalization of cortisol secretion may be incomplete. Metyrapone was generally well tolerated and the previously reported potential side effects of hypokalaemia, hypertension and hirsutism were not frequent; gastrointestinal upset (23%) and hypoadrenalism (7%) were the most frequent side effects (Daniel *et al.* 2015).

To summarize, data available on the long-term efficacy and safety of steroidogenesis inhibitors (at least for ketoconazole and metyrapone) do not provide

evidence for severe negative events during their maintenance. Such therapies could thus be maintained on a long-term basis. Their main advantage compared with BA is that they do not induce permanent adrenal insufficiency. Moreover, BA can still be considered in case of (rare) late escape. In contrast, specific conditions such as a young woman not cured by pituitary surgery and wishing a pregnancy would be a good indication for BA if residual resectable corticotroph adenoma is not an option. Poor drug compliance, financial restrictions to long-term use of steroidogenic inhibitors and very high cyclic ACTH and cortisol secretion requiring the block and replace therapy could also be conditions to recommend BA.

In EAS Data on the long-term efficacy of medical therapy in occult EAS are scarce, probably because clinicians prefer to perform BA rapidly. EAS includes aggressive poorly differentiated tumours (e.g. small-cell lung carcinoma) and well-differentiated neuroendocrine tumours (carcinoids). While the main issue is the difficulty in performing complete surgical excision in the former, the latter are usually small and difficult to visualize with classical imaging techniques and have a low progression rate. Conventional morphological imaging modalities such as computed tomography (CT) and MRI may be falsely negative. As much as 12–19% of EAS remains occult (Alexandraki & Grossman 2010). The utility of somatostatin receptor scintigraphy with [¹¹¹In]pentetreotide for the localization of EAS has been ambiguous (Tabarin *et al.* 1999, Torpy *et al.* 1999). Somatostatin receptor scintigraphy (Octreoscan) has been used, in addition to CT and MRI, for the localization of EAS (de Herder *et al.* 1994, Phlipponneau *et al.* 1994). In a systematic review, molecular imaging discovered 79.1% of tumours unidentified by conventional radiology. The tumours were localized by CT in 66.2% of cases, MRI in 51.5% of cases and Octreoscan in 48.9% of cases (Isidori *et al.* 2015). Hybrid PET/CT combining functional imaging (PET) with integrated anatomical imaging (CT) provides an advantage over conventional imaging alone and appears to be ideal for the localization of EAS (Rufini *et al.* 2006, Santhanam *et al.* 2015). [¹⁸F]FDG PET/CT sensitivity is high in small-cell lung neuroendocrine tumours, atypical thymic tumours and aggressive medullary thyroid carcinoma, but tumour uptake might be very low in well-differentiated/low-grade neuroendocrine tumours. [¹⁸F]DOPA PET seems to have a moderate detection rate (57.1%) for EAS despite some positive cases.

When the tumour is not visualized, medical therapy can be provided. Sharma & Nieman (2012) reported the

partial/total efficacy of steroidogenesis inhibitors in four patients treated by ketoconazole alone or with mitotane and/or metyrapone after 15–60 months. The first patient was considered to be in remission after 6 years of drugs but ultimately relapsed and was treated by a BA; the three others were considered to be in remission 24–60 months after drugs withdrawal. Isidori *et al.* (2006) in a large study based on 40 patients, mentioned that 28 patients were successfully controlled by metyrapone, associated with ketoconazole and/or mitotane, for 4 weeks to 96 months, without any serious adverse effect. Some case reports described a rapid antisecretory efficacy of octreotide and/or cabergoline before surgery, but long-term data were missing. These drugs cannot be considered as first-line treatments but could be delivered when other drugs are not effective, in aggressive tumours with metastases, or when parenteral administration is required (for octreotide) (de Bruin *et al.* 2009).

To summarize, progress in imaging techniques to identify the source of ACTH secretion might decrease the time before surgical resection of the tumour. The possibility of long-term efficacy of medical therapy (or even potential remission by still imperfectly understood mechanisms) should lead physicians to be more cautious with the indication of rapid BA, provided the patient responds favourably to an effective medical therapy.

Comparison with new radiotherapy modalities Recent studies on the use of new radiation techniques (Gamma Knife radiosurgery or fractionated stereotactic radiation therapy) have clarified their efficacy and side effects in comparison with conventional radiotherapy. The main advantage of stereotactic procedures is that the target is precisely defined, and this decreases the rate of side effects (mainly hypopituitarism).

The majority of the studies on long-term efficacy were based on Gamma Knife radiosurgery, but it is likely that similar results would be observed with the other techniques. Antisecretory efficacy has been reported in 40–60% of cases. Compared with conventional radiotherapy, the time to remission is shorter and is estimated to be 2–4 years. This remains a major issue, as it means that the patient will need effective medical therapy during this period of time. In addition, recurrence has been reported in up to 20% of cases, 3–5 years after remission. The safety profile has drastically improved, with only 20% of patients experiencing new pituitary deficiencies and the lack – at least after 10 years of follow-up – of extrapituitary side effects (Minniti *et al.* 2009, Castinetti *et al.* 2010).

To summarize, the low rate of side effects with new radiation techniques should lead to a more frequent use of such options, provided the fact that an obvious target is visualized and an effective medical therapy is available for 2–5 years. BA will remain an option for those in whom radiotherapy failed to control hypercortisolism after this delay.

Is there a need to achieve eucortisolism in patients scheduled for BA?

Preparing the patient before any surgical treatment of hypercortisolism is debated, and this also concerns BA. It is indeed still not known whether patients presenting with eucortisolism at the time of surgery will have a better outcome after BA. The only dedicated study was based on the use of ketoconazole and/or metyrapone before transsphenoidal surgery: 52 patients were evaluated retrospectively after a mean period of 4 months on steroidogenesis inhibitors. Approximately one-half (51%) were controlled clinically and biologically at the time of surgery. The overall rate of recurrence was similar in each group. The authors reported that hypertension was more persistent in patients without pretreatment up to 108 months after surgery. They also suggested that pretreatment could decrease the rate of thrombo-embolic events, but the number of events was very low (Valassi *et al.* 2012). Thrombo-embolic events are a well-identified potential complication of surgery for hypercortisolism: of the 1162 patients evaluated in the hypercortisolism literature, 7.2% had a thrombo-embolic event, 33% of which occurred in the year following surgery (Coelho *et al.* 2015); thus, adequate thromboprophylaxis is recommended (Nieman *et al.* 2015). The benefit of pretreatment was also questioned by the fact that the group of patients with partially controlled hypersecretion (UFC decrease without normal levels) with the pretreatment had a worse clinical outcome than untreated patients (Valassi *et al.* 2012). Finally, Ritzel *et al.* (2013) reviewed the morbidity and mortality rates in patients treated with BA to determine whether they were treated by medical therapy: in 22 studies based on 556 patients without pretreatment, the morbidity rate was 19% and the mortality rate was <1%, which was roughly comparable to the findings of the six studies that reported the pretreatment outcomes of 249 patients, with 21% of morbidity and 2% of mortality rates.

To summarize, even if achieving eucortisolism before BA appears to be a logical goal, there are no strong data in favour of a better post-surgical outcome: in acute severe hypercortisolism, BA should be performed, as mentioned previously, whatever the level of cortisol, if medical

treatment is not rapidly effective. Trying to obtain eucortisolism should not delay the surgery. However, medical therapy is indicated in patients in whom surgery has to be delayed for specific medical comorbidities such as recent pulmonary embolism.

BA in primary bilateral adrenal hyperplasias

Historically, BA has been considered the first-line treatment for patients with BMAH and overt CS. Cortisol excess is usually modest in BMAH, even in those with elevated UFC levels; this has led to the attempts to use unilateral adrenalectomy, particularly when UFC levels were <2–3 times ULN (Lacroix *et al.* 2015). Recently, the role of unilateral adrenalectomy in these patients was assessed in a small series of patients, summarized in Table 4 (Xu *et al.* 2013, Albiger *et al.* 2015, Li & Yang 2015). Very recently, Debillon *et al.* (2015) reported their experience in 15 patients with BMAH treated by unilateral adrenalectomy: resection of the larger gland led to a 3-month post-surgical remission of hypercortisolism in 100% of cases and a low risk of recurrence after 7–9 years of follow-up ($n=2$). The question of which gland to operate on is still a matter of debate. Debillon *et al.* chose to operate the largest gland on CT, which, in more than 50% of cases, was also the gland with the largest cholesterol uptake in adrenal scintigraphy. The potential benefit of adrenal scintigraphy is counterbalanced by the fact that the uptake is usually correlated with the volume of the gland, thus, stronger uptake does not necessarily correspond with superior secretory activity. One point to emphasize is the risk of adrenal insufficiency after unilateral adrenalectomy for BMAH: Debillon *et al.* (2015) indeed reported 40% of cases after surgery: even if half of them finally recovered, a peculiar surveillance should be performed post-operatively in all patients treated by unilateral adrenalectomy.

As recently underlined by the Endocrine Society Guidelines (Nieman *et al.* 2015), BA should be preferred in adult patients with PPAD: the risk of recurrence after unilateral adrenalectomy is indeed much higher and occurs much earlier, as there is usually an increased activity of the overall adrenal tissue (Vezzosi *et al.* 2015).

To summarize, the rarity of the published data makes it difficult to determine the outcomes of patients who undergo unilateral adrenalectomy for BMAH with modest hypercortisolism. It is likely that these patients will eventually present with recurrence, requiring a contralateral adrenalectomy. The time to recurrence is variable, from 3 to 10 years after surgery. These patients thus require a close biological follow-up. On the other hand, such

patients will gain 3–10 years without adrenal insufficiency, and this is strong evidence in favour of the use of unilateral adrenalectomy as a first-line treatment in BMAH. Unilateral adrenalectomy seems to be more efficient when there is asymmetric adrenal involvement. In rare patients with severe CS and BMAH and symmetrically enlarged adrenals, BA is still recommended. BA is indicated in patients with PPAD or other forms of bilateral micronodular hyperplasia.

Conclusions and perspectives

Bilateral laparoscopic adrenalectomy is the most effective definitive treatment of hypercortisolism when surgical removal of the source of excess ACTH is not possible. It is a rapidly acting technique, which, in experienced hands, should be considered safe. However, several other options are currently available, which, again in experienced hands, showed results that might modify the first/last options in the therapeutic algorithm of hypercortisolism. Defining the place of BA in the 21st century is thus challenging. It might be even more difficult in the future with long-term results on the efficacy of new drugs such as LCI699, a long-acting release form of Pasireotide, or potentially less toxic formulations of ketoconazole. All of these results might guide clinicians towards a prolonged ‘wait and see’ approach rather than radical treatments. From an imaging viewpoint, somatostatin agonists labelled with ^{68}Ga have shown very promising results in detecting endocrine tumours and need to be further evaluated in clinical settings: this might help earlier localization of an ACTH tumour source in EAS. In BMAH, preoperative assessment of the degree of functionality of each adrenal could guide surgeons towards the most appropriate management and could predict residual cortical function after unilateral adrenalectomy. To this end, high-affinity PET ligands for the LDL-C receptor and steroidogenic enzymes (^{11}C metomidate) or chemokine ligands may help clinicians choose unilateral adrenalectomy rather than BA. Moreover, the understanding of the genetic mechanisms involved in BMAH such as *ARMC5* mutations will help researchers understand the natural history of such lesions and will provide guidance towards early detection of affected individuals and personalized therapy to avoid morbidities of cortisol excess.

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Author contribution statement

C Guerin, D Taieb and F Castinetti designed the review, made the search, drafted and critically reviewed the report, and approved the final version. G Treglia performed the pooled analysis. G Treglia, T Brue, A Lacroix and F Sebag drafted and critically reviewed the report, and approved the final version.

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