Cortisol and Corticotrophin in Burned Patients

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In a study of 36 men burned in a fire, based on sequential early morning samples, plasma cortisol concentration was elevated in proportion to burn size. Plasma corticotrophin (ACTH) was not correlated with burn size, suggesting that factors other than ACTH contribute to the elevated cortisol. Cortisol levels did not fall on the days preceding death in nonsurvivors. During 24-hr sampling, burned patients exhibited a fitted cortisol curve mean that was elevated in proportion to burn size, a rhythm amplitude that was significantly less than that in uninjured controls, and a normal peak time. Metabolic rate, rectal temperature, and urinary catecholamine excretion were also elevated in proportion to burn size. Although plasma cortisol was positively correlated with metabolic rate and with temperature, this appeared to result from a common relationship of these variables with burn size. On the other hand, urinary-catecholamine values significantly reduced the residual variance of metabolic rate and temperature after accounting for variance related to burn size. Cortisol appears to be less prominent than catecholamines as a possible mediator of the elevated thermogenesis.

Burn injury results in hypermetabolism that has been thought to result from elevated catecholamine secretion (28). However, enhanced adrenocortical secretion after burns has also been shown by increased urinary corticoid excretion (13) and plasma cortisol concentration (17, 21, 23, 32). Such a response is expected as an immediate result of stress and is reflected in the rise of plasma cortisol within 8 hours of various types of injury (24). However, like the ensuing hypermetabolism, the adrenocortical response to burn injury extends well past the immediate post-traumatic period (31) and thus represents another feature of the altered internal milieu that characterizes the body's reaction to severe injury. Furthermore, it has recently been proposed that cortisol is the major hormonal determinant of the postburn metabolic response (1).

Plasma corticotrophin (ACTH) concentration varies widely but is often normal after major burns (12). Although simultaneous cortisol levels were not reported,

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PATIENTS AND METHODS

Thirty-six men, aged 17 to 23 years and burned in a single accidental gasoline fire, were air transported for treatment 123° longitude (7,000 miles) to the east from the site where they had been stationed and injured. They were admitted to this burn center on the second postburn day (PBD). Because of the suppression of thyroid hormone levels that occurs after burn injury, particularly in deteriorating patients (9), they were entered into a study to evaluate the effect of triiodothyronine (T3) administration. Eight of these patients had small burns over 2 to 7.5% of body surface and were designated as controls (CONT), since this degree of injury is not associated with measurable alteration in metabolic rate (28). The remaining 28 had a total burn size (TBS) of 18 to 93% of body surface and were randomly assigned in a double-blind fashion to treatment with either a placebo or T3, 200 μg per day orally or by nasogastric tube, until their wounds were healed. This dose had previously been
found to normalize T₄ levels in burned patients. Because four patients died while receiving placebo (NSURV) and four while receiving T₄ treatment (NSURV-TX), the data were analyzed within the five groups characterized in Table 1.

Beginning on PBD 3–5, and then approximately thrice weekly between 0500 hr and 0700 hr when the patients were under resting conditions in the supine position, blood was collected in plastic syringes, placed into heparinized plastic tubes on ice and centrifuged at 4°C. The plasma was then frozen at −70°C. Cortisol (supplies from Clinical Assays, Boston, MA) and corticotropin (ACTH) levels (2) were measured by radioimmunoassay. Results of plasma thyroid hormone and catecholamine studies will be presented elsewhere. On the days of sampling, 24-hr urine collections were obtained for measurement of creatinine and total catecholamines (26). The rectal temperature on the morning of sampling was recorded. Ward ambient temperature was 28–30°C. Wounds were treated with alternating topical applications of mafenide acetate and silver sulfadiazine. Clinical sepsis (obtundation or ileus) was recorded if present at the time of sampling. At weekly intervals, following at least 8 hr free of caloric intake, resting metabolic rate (MR) based on O₂ consumption (6) was measured in all surviving patients.

Data analysis was focused on the PBD 3–26 period, because a major decrement in catecholamines and MR occurred by PBD 26, the control patients were available for varying periods up to this time, and all survivors were sampled throughout this time (Table 1). All samples obtained within 24 hr of dopamine or glucocorticoid administration were discarded from analysis. In one assessment of the data, each variable was considered as the mean value of all measurements of that variable obtained during the PBD 3–26 period for each patient, but since major changes in most variables took place over this time, the time factor was accounted for in separate analyses using individual values of variables in a standard stepwise multiple linear regression program (BMDP, UCLA) performed on a PDP 11/40 computer. To assess curvilinear dependent variability, independent variables TBS and PBD were also entered as TBS² and PBD² into the multiple regression analyses. Hormonal variables were added to these to determine if they would significantly (p < 0.05) reduce the residual dependent variances. To assess the impact of T₄ treatment or clinical sepsis, one of these was included as an independent variable by assigning its presence a value of 1 and its absence a value of 0.

In a separate study (see below), nine normal subjects aged 24 to 36 years (seven men and two women) and eight burned patients aged 19 to 60 years (six men and two women) were sampled every 2 hours through an indwelling venous catheter over a 24-hr period for serum cortisol determinations. The results were evaluated by individual cosinor curve fitting, as well as by comparison of estimates of group cosinor parameters (8).

RESULTS

The more severely injured patients had higher cortisol concentrations than did CONT (Fig. 1). Multiple regression analysis showed no effect of T₄ treatment or the presence of clinical sepsis on cortisol beyond the variation accountable by TBS and PBD. Although cortisol was not related to ACTH in the T₄-untreated patients over PBD 3–26, consideration of all groups did allow inclusion of ACTH as a predictor of cortisol (Table II). The positive relationship between cortisol and TBS seen during this interval was beginning to develop by PBD 3 and PBD 5 (Fig. 2). The relationship of ACTH to cortisol was not discernible using mean values (Fig. 1), and ACTH was unrelated to TBS or PBD on multiple regression analyses. Cortisol was not correlated with days before death in nonsurviving patients. The final samples were taken within 48 hr of death in six of eight nonsurvivors and within 24 hr in three.

Multiple regression analyses did not demonstrate a significant effect of treatment with T₄ on MR, rectal temperature, or urinary catecholamine excretion. During the interval of PBD 3–26, MR was related to TBS and PBD (Fig. 3). Although cortisol was positively related to MR and to temperature, and both were related to TBS (Figs. 3 & 4), multiple regression analyses including all groups indicated that MR and temperature were not significantly correlated with cortisol nor with each other beyond their individual relationships to TBS and PBD.

Excretion of total urinary catecholamine per gram of creatinine (UCA) was elevated in proportion to TBS. and MR and temperature were correlated with UCA (Fig. 5). Multiple regression analyses showed that after correlation with TBS and PBD, the residual variance of both MR and temperature was significantly (p < 0.001) reduced by including values of UCA. TBS and PBD accounted for 70 to 75% of the variation in MR, and UCA accounted for an additional 5 to 9% (Table II). Cortisol was not correlated with UCA beyond their individual relationships to TBS and PBD.

In the study of nine normal subjects and eight burned patients the cortisol rhythm mesor (fitted curve mean) was significantly elevated above normal in burned pa-

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**TABLE I**

<table>
<thead>
<tr>
<th>Characteristics of patient groups</th>
<th>N</th>
<th>TBS (Mean)</th>
<th>TBS (Range)</th>
<th>Final Sample (PBD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONT</td>
<td>8</td>
<td>4.5</td>
<td>2-7.5</td>
<td>5-26</td>
</tr>
<tr>
<td>SURV</td>
<td>10</td>
<td>44.3</td>
<td>18-92</td>
<td>33-98</td>
</tr>
<tr>
<td>NSURV</td>
<td>4</td>
<td>68.4</td>
<td>55-93</td>
<td>5-54</td>
</tr>
<tr>
<td>SURV-TX</td>
<td>10</td>
<td>45.3</td>
<td>28-75</td>
<td>31-73</td>
</tr>
<tr>
<td>NSURV-TX</td>
<td>4</td>
<td>72.9</td>
<td>62-85</td>
<td>12-19</td>
</tr>
</tbody>
</table>

TBS: total burn size as % body surface; PBD, postburn day; CONT, controls with small burns; SURV, placebo-treated survivors; NSURV, placebo-treated nonsurvivors; SURV-TX, T₄-treated survivors; NSURV-TX, T₄-treated nonsurvivors.
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Fig. 1. Plasma cortisol concentration sampled serially on mornings following burn injury. The crosses nearest a final symbol for nonsurvivors indicate the day of death (top panel). Linear regression of mean cortisol and ACTH as the mean taken over postburn days 3-26 for each patient (bottom panel). For group designations in this and subsequent figures, see Table I.

Patients ($p < 0.01$), and within the burn group the cortisol mesor was positively correlated with TBS ($p < 0.05$). The burn group rhythm was statistically significant (Fig. 6), and group rhythmicity was still evident ($p < 0.05$) after excluding the two patients with the smallest burns (TBS 5.5 and 13.8%, remaining TBS 36-67%). That cortisol rhythmicity was reduced in burned patients is indicated by absence of a statistically detectable rhythm in
of traumatized patients are not known. We found the relative hepatic and renal extractions of these corticosteroids are influenced by body temperature.

Increased mortality. Such data are difficult to interpret, because it has been suggested that conversion of cortisol to cortisone is positively influenced by body temperature and negatively by elevated cortisol secretion.

We found cortisol concentration to be related to burn size as early as PBD 3 or 5. This elevation of plasma cortisol concentration reflected in elevated values for the entire 24-hr period in proportion to burn size. Molteni et al. (22) found no rhythmicity in cortisol during the first 4 postburn days, with a trend toward the normal rhythm apparent by the fifth day. Rhymicity was present at the time our nyctohemeral samples were taken (PBD 8-25 µg/dl), possibly because the morning samples taken in this study would have represented a time 8 hr earlier (evening) in their preinjury location. The new location and before possible rhythm re-entrainment, which was not identified by nyctohemeral sampling in this population, cortisol would be expected to be near the nadir of its daily cycle at the time of sampling.

The single time point morning samples did allow observation of elevated plasma cortisol in proportion to burn size in the first 4 weeks after injury in adults. This confirms a similar relationship reported in a study of both children and adults during the first 2 weeks postburn (32) and in children during the first 4 weeks (23). In addition, we found cortisol concentration to be related to burn size as early as PBD 3 or 5. This elevation of plasma cortisol concentration is reflected in elevated values for the entire 24-hr period in proportion to burn size. Molteni et al. (22) found no rhythmicity in cortisol during the first 4 postburn days, with a trend toward the normal rhythm apparent by the fifth day. Rhymicity was present at the time our nyctohemeral samples were taken (PBD 7-29). The suppression of rhythm amplitude that we observed may represent another expression of injury-induced alteration of hypothalamic function, which also includes elevated core temperature, an elevated ambient temperature of optimal comfort, suppressed growth hormone response to hypoglycemia (30), and excess sympathathic tone and hypermetabolism (28).

A recent report (20) suggests that reduced urinary excretion of cortisol plus cortisone is associated with increased mortality. Such data are difficult to interpret, because it has been suggested that conversion of cortisol to cortisone is positively influenced by body temperature and negatively by elevated cortisol secretion (10), and the relative hepatic and renal extractions of these compounds in traumatized patients are not known. We found no fall in plasma cortisol associated with death, in agreement with similar findings in other studies of urinary corticoid excretion and plasma cortisol levels (22).

Cortisol is reportedly elevated in bacterial sepsis (24). However, in our injured patients with already elevated cortisol, we did not see further elevation of cortisol levels during clinical sepsis.

The physiologic significance of elevated cortisol might be diminished if there were a sufficient elevation in plasma binding to prevent an elevation of free cortisol in burned patients. However, this appears not to be the case, since Mortensen et al. (21) found a decrease, roughly proportional to burn size, in cortisol binding by human postburn sera. More dramatically, Wise et al. (32) showed that the decreased serum-binding capacity in burned patients was associated with a two- to sevenfold rise in the free portion of total serum cortisol compared to that in normal volunteers. Thus the vigorous postburn response is even more robust for free than for total cortisol levels.

Although Dolecek et al. (12) found a rough correlation of ACTH with burn size, they state that quite normal or only slightly elevated ACTH levels were found in some patients after major burns and that ACTH levels were unpredictable and exhibited a wide range of values. Our results are similar, except that we also found no correlation of ACTH with burn size or time after injury. Using mean values over PBD 3-26, cortisol also was not significantly correlated with ACTH (Fig. 1), although mean cortisol was closely correlated with burn size (Fig. 2). Such observations suggest that factors other than plasma ACTH concentration are at least partially responsible for the large postburn cortisol response. Excessive adrenal responsiveness to ACTH is unlikely, in that Bane et al. (7) found no response of plasma cortisol after ACTH injection in either of two burned patients tested. The afferent portion of the adrenocortical response to injury appears to be neurally mediated (29). Possible efferent control of adrenocortical function that does not involve ACTH is also suggested by previous reports. Spinal cord section blocks circadian rhythmicity of corticosterone in rats (4), normal human subjects exhibit nocturnal pulses of cortisol that do not appear associated with pulses of ACTH (3), and hemorrhage in dogs provokes a rise in plasma cortisol without a preceding rise in ACTH (16).

However, ACTH may play some role, perhaps a permiss-
Fig. 2. Linear regressions of plasma cortisol and total burn size (TBS) based on mean values over postburn day (PBD) 3-26, or values for PBD 3 or PBD 5.

Fig. 3. Linear regressions of plasma cortisol and total burn size (TBS) based on mean values over postburn day (PBD) 3-26, or values for PBD 3 or PBD 5.

Fig. 4. Linear regressions of plasma cortisol and total burn size (TBS) based on mean values over postburn day (PBD) 3-26, or values for PBD 3 or PBD 5.

In analyses with larger numbers of samples, unrestricted according to group, ACTH concentration was found to be related to that of cortisol (Table II). Metabolic rate (Fig. 3) and body core temperature (Fig. 4) are both elevated as a function of burn size. This has already been reported for metabolic rate (28). These relationships support the thesis that the elevated thermogenesis in burned patients results not from attempts to restore heat content lost excessively to the environ-
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MR (Kcal/h M^2)

MR = 42.4 + 0.44 TBS - 0.68 PBD
\( r = 0.84 \)
\( p < 0.001 \)

Fig. 4: Relationship of metabolic rate (MR) to total burn size (TBS) and postburn day (PBD) for patients not treated with triiodothyronine (T\(_3\)). The equation for the plane of best fit is indicated.

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which body temperature increased (15). In addition, hypothermic patients had reduced responsiveness to injected ACTH (14), and elevated serum cortisol paralleled the degree of hyperthermia in several febrile illnesses (19). The interaction between temperature and cortisol seems likely for the direction of an influence of temperature on cortisol levels, and it is thus possible that hyperthermia may account in part for the elevated cortisol in burned patients.

The function of glucocorticoids in thermogenesis of experimental animals has been reviewed by Deavers and Musacchia (11). The results show that whereas glucocorticoid is necessary for animals to restore body temperature following induced hypothermia, there is no effect of glucocorticoid in thermogenesis in animals not exposed to cold. However, in burned patients, thermogenesis is reset around a higher core temperature, allowing the possibility that otherwise usual environmental temperatures may be sensed as cold (28). In this condition, cortisol might be envisioned as a potential mediator of hypermetabolism. Plasma cortisol has been linked to some of the metabolic substrates or intermediates in burned patients, the presence of which is thought to be related to hypermetabolism. Volenec et al. (27) found cortisol level correlated with plasma glucose level. Alberti et al. (1) noted correlations of cortisol with alanine, lactate, free fatty acid, ketone, and urea levels in burned patients. By raising cortisol in normal subjects using ACTH injections, they produced a rise in circulating glucose, lactate, and alanine. Those authors concluded that cortisol plays the major role in the catabolic response to injury.

However, there are several limits on interpretation of those data (1). Although in Alberti's study the known gluconeogenic and catabolic nature of cortisol was evident in the normal subjects, the relationship of this hormone to the metabolic response of burned patients was not assessed in a manner which would establish that cortisol bore a better relationship to metabolic response than did extent of injury, or determine whether variation of metabolic response was more closely related to variation in other gluconeogenic hormones after accounting for the extent of injury. These authors mentioned that plasma glucagon levels and excretion of metanephrine were elevated. Their results were essentially limited to the first 5 postburn days. Finally, the metabolic variables reported are elements of biochemical pathways in energy metabolism and are indirect and restricted reflections of the elevated resting metabolic rate that occurs after burn injury. Although we have found that cortisol level was closely correlated with both metabolic rate and temperature, this appears to reflect the general relationship of metabolic rate and temperature to burn size and postburn day, and no specific connection between cortisol and thermogenesis was identified. That cortisol may contribute to hypermetabolism is not excluded by these results. However, consideration of urinary catecholamine excretion reduced the residual variance of both metabolic rate...
Fig. 5. Linear regressions between excretion of total urinary catecholamines (UCA, µg/gm creatinine) and total burn size (TBS), metabolic rate (MR), or rectal temperature (TEMP), and between MR and TEMP, based on the mean values for each patient over postburn days 3-20.
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and temperature after accounting for variation associated with burn size and time since injury. These findings corroborate a role of catecholamines and suggest less importance of cortisol in postburn hypermetabolism.

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How then can clinical investigators dissociate these multiple stimuli? Three things are possible. One is to give epidural anesthetic to these severely ill patients and dissociate the relationship between afferent nervous stimuli and pain from other factors. Second, pharmacologic agents can be utilized to turn off the hypothalamic and pituitary gland. Third, the burn wound, which appears to initiate the response and correlate closely with ACTH output, can be excised. Such excisional treatment will eliminate the initiation of stress response and allow the neurohormonal response to return to normal.

Dr. Donald S. Gann (Rhode Island Hospital, Providence, RI 02902): I too enjoyed the study very much, and would like to compliment the authors on the conduct of a really arduous piece of clinical investigation.

There is at least one factor on the horizon which Doctor Wilmore didn't mention and which has been evolving in my own laboratory and that of Doctor Dallman in San Francisco over the past several years. Namely, there is at least one determinant of adrenal sensitivity to ACTH which is not ACTH itself. We have evidence that with respect to the time of day or the history of previous stimulation, such a factor can be turned on in the absence of any change in ACTH.

This factor is clearly stimulated by at least three physiologic stimuli—small hemorrhage, pain, and a decrease in circulating cortisol secretion—so that in most respects it behaves like the stimuli which we associate with ACTH release, but it isn't ACTH. I think Doctor Vaughan and his colleagues have at least given us a reason to want to examine the possibility that such a factor may obtain in the clinical situation as well.

Also, their data recalled to my mind a paper by Eigler and his colleagues, published in the Journal of Clinical Investigation about 2 years ago, in which they examined the effects of epinephrine, glucagon, and cortisol alone and in combination on glucose production and utilization. They found, somewhat to their surprise but consistent with the observations that we have just heard, that cortisol has no effect on glucose metabolism by itself. In contrast, it potentiated the effects of both epinephrine and glucagon on glucose production. Thus it is entirely possible that it is a synergism which the authors have found in their current studies. I would like to hear Doctor Vaughan's comment on this.

Dr. Charles Hartford (Crozer-Chester Medical Center, Upland, Chester, PA 19013): I would like to compliment the authors on helping to fit together another piece of the puzzle of steroid metabolism in burn patients.

We approached this problem by studying 24-hour urine cortisol and cortisol excretion using the high-speed liquid chromatography technique, and found that total steroid production related logarithmically to increasing burn size up to about 80%, where it then fell off, for what reasons we are not quite clear, and that total steroid production was elevated during the postburn period with increased production under the influence of stress of surgical procedures and during periods of sepsis. We also found that the highest levels occurred during the first 3 days. That piece of information is missing in this paper, and I wonder if it should be looked into.

The second point is that in the abstract they indicated that the peak levels were attained during the period of 7 to 14 days. Since this is the period of high likelihood of sepsis, I wonder whether the increased production doesn't reflect the stress of infection.

I would also like to ask the authors to comment on the clinical implications of their study.

Dr. Fred T. Caldwell (University of Arkansas Medical Center, Little Rock, AR 72205): I enjoyed Doctor Vaughan's presentation very much. I would like to make one comment and one question.

In studying the metabolic response to thermal trauma in children from 2 to 21 years old, we were unable to demonstrate...
any correlation between plasma adrenaline levels and the metabolic rate, whether the patients were with or without a dressing. Plasma adrenaline is the calorigenic amine. Noradrenaline has essentially no, or at most 10%, effect on the metabolic rate in man. In burned patients, the major portion of the increase in the catecholamines is noradrenaline, not adrenaline.

As far as I know, without cold adaptation noradrenaline has almost no effect on the metabolic rate. So, if indeed Doctor Vaughan made the statement that catecholamines drive this response, how does he explain this disparity?


Doctor Hartford's comment about lack of measurements in the first 3 days is correct. We didn't receive the patients until the second postburn day, and when we have examined other patients on days 1, 2, and 3 it was our impression that on day 1 some of the highest levels were obtained, although there is great variability in that regard. The apparent rise in plasma cortisol on postburn days 7 to 10 seemed to occur in both the Tc-treated and the placebo groups. When we added clinical sepsis (that is, obtundation or ileus) into the multiple regression analysis, we didn't find evidence that sepsis, whenever it occurred, increased the already high plasma cortisol levels. One clinical implication of this study is that adrenal insufficiency or exhaustion must not be an ordinary sequela of burn injury even in the absence of overt infection.

Doctor Gann mentions evidence that cortisol may have no effect as a sole stimulus for gluconeogenesis in dogs but may interact with other hormones in this regard (Eigler and Sherry: J. Clin. Invest., 63: 114-123, 1979). This idea, while in conformity with the known propensity of cortisol to generate amino acid substrate and of glucagon and catecholamines to stimulate conversion to glucose, seems at variance with the formulation of Alberti, but supports our findings of little correlation between cortisol and metabolic rate. Additionally, the effects of catechols on fat metabolism may have diluted any dependence of metabolic rate on glucose flow, in that burn injury was associated with lower IQ burn size vs. IQ, p < 0.05 for rectilinear regression. I think it is too early to tell if our ACTH results are interpretable in the same way as are Doctor Gann's. His group has shown that acute ACTH elevation is not necessary for the increased plasma cortisol secretory rate following hemorrhage in dogs and that a previous hemorrhage, but not a previous injection of ACTH, increases the adrenal sensitivity to ACTH (England, W. C., Byrnes, G. J., Presnell, K., et al.: Endocrinology, 108: 2149-2153, 1981).

I think at this stage we are not able to choose between a non-ACTH-dependent mechanism of elevated cortisol versus Doctor Wilmore's kind of explanation, namely, that the adrenergals would be more sensitive to ACTH because they have been stimulated by ACTH for some days or weeks. One and the latter and still attractive possibility are that we did not identify a fall of ACTH with time that might be expected if sensitivity to it were increasing and resulting in a feedback from the cortisol and if the stimulus to ACTH were also resolving as the injuries heal, and that we have not seen adrenocortical hyperplasia at autopsy. With reference to the question of the variety of treatments the patients underwent, they were treated in the standard fashion at our institution, including vigorous fluid and nutritional support, an ambient temperature of 30°C, alternating topical mafenide acetate and silver sulfadiazine (morning and evening, respectively), excision and grafting when indicated, antibiotics for sepsis, and opiates for pain. All the potential stress elements could not be controlled, cortisol was elevated before the time when surgical procedures were normal, and cortisol and ACTH were sampled simultaneously in the morning before procedures performed during the day were initiated. Nevertheless, in the setting of burn injury, cortisol bore little relationship to ACTH. In addition, cortisol was not correlated with catecholamine secretion beyond the interrelationships with burn size and postburn day.

Doctor Wilmore proposes several possible ways to separate the cortisol response or link it to ACTH. An epidural anesthetic might help if the already non-elevated ACTH would fall, or if cortisol would fall with no change in ACTH. But interpretation might be difficult if, as expected, there were a large element of pulsatile secretion or if a lengthy time course for the effect of such neuronal blockade would be necessary. One might first repeat some of Hume's early studies using a chronic, rather than acute, burn in a dog model with mechanical nerve interruption. Dexamethasone suppression of ACTH is a relatively safe and simple experiment and may reveal some ACTH dependence of cortisol. In considering possible alternate stimulation of cortisol, angiotensin II has been found to be markedly elevated after burns (Dolore, Adamkova, Sotomikova, et al.: Scand. J. Plast. Reconstr. Surg., 13: 9-16, 1979). Barter's group (Slater, Barbour, Hendon, et al.: J. Clin. Invest., 42: 1504-1520, 1963) showed that infusion of angiotensin II stimulates a big rise in catecholamines, the counter-regulatory hormones. Aldosterone in hypophysectomized, nephrectomized dogs. This may also point to a fruitful area of investigation in the future.