Visualisation of the 'Optimal Cerebral Perfusion' landscape in severe brain trauma patients

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Objectives: An 'optimal' cerebral perfusion pressure (CPPopt) can be defined as the point on the CPP scale corresponding to the greatest autoregulatory capacity. This can be established by examining the pressure reactivity index PRx – CPP relationship, which an approximately U-shape but suffers from noise and missing data. In this paper we present a method for plotting the whole PRx-CPP relationship curve against time in a form of a colour coded map depicting the 'landscape' of that relationship extending back for several hours and to display this robustly at the bedside.

Methods: Recordings from routine monitoring of traumatic brain injury patients were processed using ICM+. Time-averaged means for ABP, ICP, CPP, and PRx were calculated and stored with time resolution of 1 min. ICM+ functions have been extended to include not just an algorithm of automatic calculation of CPPopt but also the 'CPPopt landscape' chart.

Results: Examining the 'CPPopt landscape' allows the clinician to differentiate periods where the autoregulatory range is narrow and needs to be targeted, from periods when the patient is generally hemodynamically stable allowing for more relaxed CPP management. This information would not have been conveyed using the original visualisation approaches.

Conclusions: We describe here a natural extension to the concept of autoregulatory assessment, providing the retrospective 'landscape' of PRx-CPP relationship extending over the past several hours. We have incorporated such visualisation techniques online in ICM+. The proposed visualisation may facilitate clinical evaluation and use of autoregulation-guided therapy.

Introduction

'Optimal cerebral perfusion pressure' (CPPopt) has been defined as a pressure value corresponding to the point on the CPP-autoregulation characteristic where the autoregulation (as measured by the pressure reactivity index PRx) is the strongest [**Steiner at al 2002**]. The concept of using CPPopt as an individual target in treatment of severe brain injury patients has attracted a lot of attention over the recent years particularly after introduction of a continuous measure of CPPopt [**Aries et al 2010**]. However, a single value of CPPopt does not fully reflect the character of the PRx-CPP relationship, nor does it capture its dynamic nature, even when plotted as a time trend. What is more, the CPPopt trends tend to be fairly noisy, and may often contain many gaps where the PRx-CPP curves cannot be robustly determined. This represents a barrier to evaluating autoregulation guided CPP therapy in clinical practice. The objective of this project was to find a way of improving the CPPopt methodology by introducing a new visualization method that may provide insight into the complete characteristics of the CPP-PRx relationship, and its temporal evolution. We have demonstrated that this can be presented at the bedside in 'real time'.

Material and Methods

Monitoring data from severe TBI patients admitted to the neurocritical care unit at Addenbrooke's hospital, Cambridge, were collected using ICM+ software. Patients were managed according to published protocolised TBI guidelines [**Menon 1999**]. Patients were sedated, intubated and ventilated. Interventions were aimed at keeping ICP < 20 mm Hg and CPP > 55 mmHg. CPPopt guided therapy did not form part of the local management algorithm.

Arterial blood pressure (ABP) was monitored invasively using a pressure monitoring kit (Baxter Healthcare CA, USA; Sidcup, UK) at radial artery, zeroed at the level of the heart while an intraparenchymal probe (Codman & Shurtleff, MA, USA or Camino Laboratories, CA, USA) was used in order to monitor intracranial pressure (ICP). Waveforms of ABP and ICP were collected from GE Solar monitors digitally at their full available resolution of 120Hz

using ICM+® software (Cambridge Enterprise, Cambridge, UK, http://www.neurosurg.cam.ac.uk/icmplus/). All the analyses on the recorded raw waveforms were performed over 60-s long-sliding windows using the same software.

Time-averaged means for ABP, ICP, CPP (ABP minus ICP), and PRx (a running correlation coefficient between 10s averages of ABP and ICP signals) were calculated and stored with time resolution of 1 min. PRx-CPP curves and the corresponding CPPopt values were calculated every minute, with a calculation data buffer of 4 hours. The sequential PRx-CPP curves were then used to create a colour-coded map of PRx-CPP relationship evolution over time (Figure 1). The time (horizontal) axis represents the position of the moving window for CPPopt calculation, vertical axis represents the scale of CPP while PRx values are coded with Red representing completely impaired autoregulation (PRx = 1), green representing fully engaged autoregulation (PRx = -1), with the failing autoregulation zone of PRx 0.1 – 0.3 coded as yellow. The coding was adapted from the original color coding scheme of PRx that has been used in ICM+ for the past decade. The CPPopt landscape chart was fully implemented in ICM+ for bedside display alongside traditional plots of ICP, CPP and PRx.

Results

The new CPPopt visualization method seems to highlight features that would not have been apparent using the traditional approach. Figure 2 shows an example of recording taken from one patient with ICP, ABP, CPP, PRx trends plotted together with the CPPopt landscape chart, at the bottom. The light green homogeneous areas denote periods where CPPopt calculations were unavailable. The blue line represents the trend of CPP values. For clarity the CPPopt trend was not plotted as it is indicated in the chart anyway by the midpoint of the green/yellow zone. By observing the extent of the green zone one can assess the autoregulatory range at any given point of time, while the saturation level of the green colour in the centre of that range gives a feedback on the strength of autoregulation there. In the presented example the patient started off with a relatively wide autoregulatory range

centered at about 65 mmHg, and then went through a phase when that range has substantially narrowed and shifted towards higher CPP values.

Discussion

Individualising targets for management of traumatic brain injury patients is currently at the forefront of new management policy making efforts in neurocritical care. Whilst the CPPopt concept is still to be prospectively evaluated, it is physiologically attractive. A necessary future evaluation and implementation is impossible however unless the data can be presented in a format that is sufficiently robust that the clinician can reliably interpret it at the bedside. Continuous monitoring of cerebral autoregulation using real time analysis of waveforms of arterial blood pressure and intracranial pressure, via the pressure reactivity index PRx, has made it possible to relate its dynamically changing state to the corresponding value of cerebral perfusion pressure, thus revealing a relationship between the two. Furthermore, the character of that relationship, which can be described as generally U-shaped, is well suited for using it as the means of arriving at a value of CPP that maximises the autoregulatory capacity (that is minimizing PRx). However, due to limited CPP variability, the errors inherent in the assessment of autoregulation using PRx and other external factors that relationship are often unclear. This may make the trend of calculated CPPopt values appear noisy, with numerous gaps where the curve was undeterminable. Moreover, efforts to make the automatic calculations of CPPopt more stable and with higher yield of valid values that are currently under way may go a long way to inspire more confidence in this approach but they still fail to deliver a complete picture of the autoregulatory capacity. This is of particular importance in severe brain trauma management where the pathological processes develop often rapidly making the physiological defence mechanisms like cerebral autoregulation rather fragile. It is not uncommon for the cerebral autoregulation curve to be temporarily shifted towards higher cerebral perfusion pressures, to have its autoregulatory plateau severely shortened, or abolished all together in a state of total vasoplegia. To add to that management of brain

trauma patients is highly multifactorial, requiring constant adjustments of treatment to provide a delicate balance between different target priorities. Incorporating a rigid, even individualised, target for CPP management may not therefore be the best or safest approach of using this promising CPPopt methodology.

On the other hand giving the clinician an opportunity to examine the whole 'CPPopt landscape' allows one not only to assess the CPPopt trend but also the breath of the autoregulatory range, and its progression over time. Such an approach would allow differentiation of periods where the autoregulatory range is narrow and needs to be targeted, from periods when the patient is generally hemodynamically stable allowing for more relaxed CPP management and thus prioritising other needs. This information would not have been conveyed using the original visualisation approaches, which is trending of the automatically calculated CPPopt, or the single optimal CPP curve chart. One could argue that a set of charts showing the optimal CPP, the value of PRx at the optimal CPP point, and the CPP range corresponding to intact autoregulation would be sufficient, and perhaps easier to read. Whether or not this is true will have to be investigated further but intuitively the colour-coded, 3-dimensional representation of the CPP-PRx relationship contains a lot more information in a relatively simple, compact form and thus may perhaps appeal to clinicians more then a multitude of related charts.

Clearly, this new approach to CPPopt concept still needs to undergo a more thorough scrutiny but perhaps a combination of the landscape chart and the more traditional CPPopt trend, possibly with improved automatic calculation algorithms, may provide the ultimate robust, comprehensive and easily digestible information on the patient's dynamically changing state of cerebral autoregulation and offer clearer suggestions for targets of individualised management of cerebral perfusion pressure.

Conclusions

What we describe here is an extension of the concept of autoregulatory assessment, providing the full retrospective ‘landscape’ of PRx-CPP relationship extending over the past several hours in such a way that it can be presented at the bedside. Although further technical improvements and a test of functionality are needed, the proposed visualisation, while addressing some of the problems of the CPPopt methodology, may improve individual CPP management methods based on the status of cerebral autoregulation, current and past.

[1] Menon, D.K., 1999. Cerebral protection in severe brain injury: physiological determinants of outcome and their optimisation. British medical bulletin, 55(1), pp.226–58

[1] Steiner LA, Czosnyka M, Piechnik SK, Smielewski P, Chatfield D, Menon DK, Pickard JD. Crit Care Med 2002;30(4):733-8.

[2] Aries MJ, Czosnyka M, Budohoski KP, Steiner LA, Lavinio A, Kolias AG, Hutchinson PJ, Brady KM, Menon DK, Pickard JD, Smielewski P. Crit Care Med 2012;40(8):2456-63.

Figure 1. The concept of CPPopt landscape

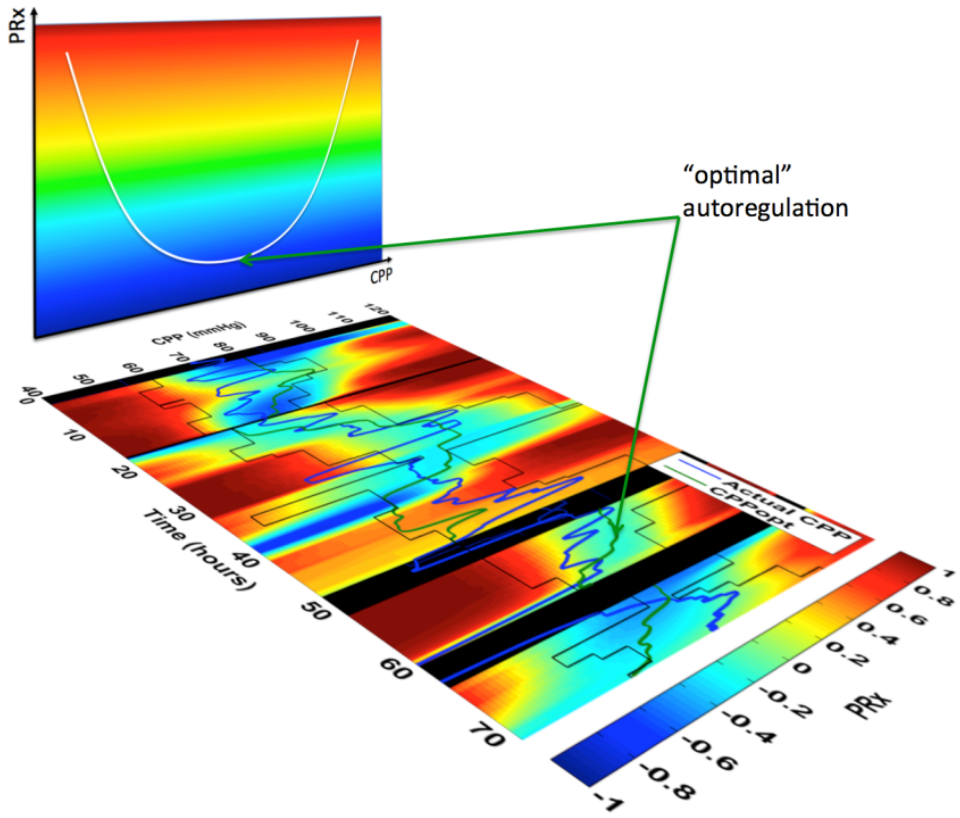

Figure 2. Example of a recording showing the CPPopt landscape alongside the trends of ABP, ICP, CPP and Prx.