Personal Protective Equipment impairs pulmonary gas exchange causing systemic hypercapnia-hypoxaemia and cerebral hyperperfusion-induced cephalalgia

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Research Letter

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Existential catastrophes inflict change so vast and dislocating that it's often hard to tell disaster from prospect. COVID-19 has forced radical shifts in working habits, in particular the recommendation that all clinical staff wear Personal Protective Equipment (PPE) in *at risk* environments[1]. Compounded by stressful tasks, staff have anecdotally reported respiratory distress, headaches, dehydration, and cognitive impairment, not reported previously without PPE[2]. To what extent PPE impacts integrated cardiopulmonary-cerebrovascular function has not been examined. The hypothesis tested was that PPE adversely influences pulmonary gas exchange, resulting in systemic hypercapnic-hypoxaemia and cerebral hyperperfusion-induced cephalalgia.

Eight male Higher Surgical Trainees (aged 33±2y) participated in a repeated-measures crossover study, completing two-hour laparoscopic simulation tasks, on two separate occasions: one conducted in standard surgical attire and the other in full PPE (FFP3 mask, visor, fluid-resistant apron and two pairs of latex gloves in addition to standard attire). Measurements were taken over 10-minutes, at zero and 120 minutes and included heart rate, mean arterial pressure (MAP), skin temperature, cephalalgia (visual analogue score) and body mass. Respiratory gases were sampled at the mouth through a sealed adaptation to each mask. Peak detection analysis was used to calculate respiratory rate and mean inspiratory concentrations of CO_2 (F_ICO_2) and O_2 (F_IO_2) from inside the mask, with peripheral oxygen saturation (SpO_2) measured via pulse oximetry. The proximal Middle Cerebral Artery (MCA) was insonated enabling measurement of MCA blood velocity (MCA_V), thereby cerebral blood flow, and calculation of the Cerebrovascular

Conductance Index (CVCi), Cerebrovascular Resistance Index (CVRi) and Pulsatility Index (PI).

Baseline measurements without standard attire or full PPE indicated the F_ICO_2 was 0.03% (±0.0%), F_IO_2 20.9% (±0.0%), and SpO_2 97% (±0%). With immediate effect, full PPE increased F_ICO_2 (p=0.025), and decreased both F_IO_2 (p=0.011) and SpO_2 (p=0.001), when compared with wearing standard attire, regardless of simulation duration. MCA PI was higher wearing full PPE compared with standard attire (p=0.004). Body mass decreased by 0.3kg after two hours in both conditions (p=0.049), with skin temperature increased in full PPE (p=0.046) and after two hours of simulation (p=0.001) and exacerbated further following two hours in full PPE compared to two hours in standard attire (33.7±0.9° vs. 32.9±0.6°; p=0.025). Further details of results can be found in Table 1. No headaches were reported during simulation in standard surgical attire, but three participants reported fronto-temporal headache after two-hours wearing full PPE (p=0.055), which corresponded with increased MCA_v (82±4 vs. 63±9 cm/s; p=0.008), CVCi (0.9±0.0 vs. 0.6±0.1 cm/s/mmHg; p=0.010) and CVRi (1.1±0.0 vs. 1.7±0.4 mmHg/cm/s; p=0.036) compared with cephalalgia-free participants.

The principal physiological findings were that full PPE adversely influenced pulmonary gas exchange, resulting in systemic hypercapnic-hypoxaemia and cerebral hyperperfusion-induced cephalalgia, supporting the hypothesis. Specifically, PPE was associated with an increase in F_ICO_2 to almost 8%; a 260-fold increase on atmospheric CO_2 (0.03%), with milder effects witnessed wearing standard operating attire (7%). These prevailing changes likely induced cerebral vasodilation (increased

MCA_V) and increased cerebral pulsatility, which can lead to symptoms including dyspnoea, fatigue, sweating, dizziness, nausea, cognitive impairment, and headaches[3-5]. Although the effects of mild hypoxia are largely mitigated by intrinsic homeostatic mechanisms, the effects of hypercapnia are clearly significant, and introduce substantial risk to performance, health, patient safety, and quality of care. Moreover, these findings were observed in young, fit trainees, posing the question of what findings might emerge in older surgeons with comorbidity, or anyone operating beyond the two-hour limit utilised in this study.

Urgent protective countermeasures should be designed to prevent risk to healthcare staff and patients alike. Future research must explore the relationship between the hypercapnia observed and specific metrics of manual dexterity, cognition, and cerebral perfusion in exposed surgeons.

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Tables

(Supplemental file as landscape format)

Table 1. Integrated cardiopulmonary-cerebrovascular responses following simulated surgery as a function of participant attire. Data are means (± SD). F_I = Fraction Inspired, MAP = Mean Arterial Pressure, MCA_V = Middle Cerebral Artery blood flow Velocity, PI = Pulsatility Index, CVCi = Cerebrovascular Conductance Index, CVRi = Cerebrovascular Resistance Index.