Letter to the Editor re: Beard Length and the Efficacy of an Aviator Oxygen Mask

DEAR EDITOR:

French and Wagner contend that beards do not compromise the respiratory protection afforded by airliner "quick don" emergency oxygen masks.[1] However, their normobaric study design is flawed and their method is insensitive to relevant mask leaks.

At sea level, peripheral oxygen saturation (S_pO_2) resists dilution of mask-supplied air with ambient hypoxic gas, unless leaks are severe and consistent, since initial desaturation must follow the shallow gradient of the hemoglobin oxygen dissociation curve as alveolar partial pressure of oxygen (P_AO_2) falls. However, P_AO_2 and S_pO_2 are already hypoxic at relevant high altitudes [over 33,500 ft (10,211 m)] despite breathing 100% oxygen; any entrainment of ambient air exacerbates hypoxia, severely if S_pO_2 tumbles down the steep portion of the curve. To be representative, normobaric testing should reproduce the most challenging equivalent P_AO_2 before leakage, e.g., mask-supplied 14.1% oxygen simulating steady exposure at 40,000 ft (12,192 m) breathing 100% oxygen [10,000 ft (3048 m) air equivalent: P_AO_2 55 mmHg; S_pO_2 ~91%]. S_pO_2 will then respond more sensitively to inboard leaks of hypoxic gas, albeit remaining a poor surrogate for accurate measurement of leak rates. In this normobaric study, S_pO_2 is insensitive to leaks and "absence of evidence" is not "evidence of absence" of meaningful leaks at high altitude.

Lack of detail concerning the normobaric hypoxia chamber, gas composition, and airflow hinders evaluation of study sensitivity. For normobaric S_pO_2 to drop below 95%, P_AO_2 must fall to ~85 mmHg and fractional inspired (tracheal) oxygen concentration to ~18.5%. To achieve this, assuming 5% ambient oxygen (conservative, as higher concentrations require greater leakage to dilute mask-supplied air), the inspirate must comprise ~15% ambient gas, i.e., consistent 15% inboard leakage. Slightly less conservative assumptions suggest insensitivity to 20% leakage. At 40,000 ft such leak rates would cause severe hypoxia. Further, unlike resting study subjects, pilots would be active while managing an in-flight emergency, with increased ventilatory demand and head movements exaggerating mask leaks and promoting further desaturation. Contrary to the authors' view, leak quantification under representative conditions is essential and readily achievable with respiratory mass spectrometry, a standard tool in contemporary altitude research.

The authors reference an unpublished hypobaric study of pilot oxygen mask efficacy in bearded use, stating erroneously that "beard length did not impact oxygen saturation levels."[2] One bearded subject's S_pO_2 fell to 93% at 25,000-ft (7620-m) pressure altitude despite breathing 100% oxygen supplied under positive pressure, implying gross (~50%) inboard leakage of ambient air. Comparable leaks above 35,000 ft (10,668 m) or following rapid decompression would cause severe hypoxia and likely incapacitation. Robust mask seals are also essential to exclude smoke/fumes during in-flight emergencies. Hence, for research purposes, challenge agent testing should quantify ambient and mask cavity concentrations to determine the protection factor achieved.

Higher quality studies provide compelling quantitative evidence, relevant to quick don systems, that beards degrade the respiratory protection of close-fitting masks.[3–5] Pertinent literature reviews are unambiguous: facial hair that interacts with the seal of a close-fitting mask may compromise its integrity (admittedly unpredictably).[6,7] This remains true for breathing gas supplied under positive pressure.[7–9]

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IN RESPONSE:

The author of the critique provides a learned, if somewhat condescending, tutorial of why he believes our study is "flawed" and "insensitive to relevant mask leaks." We were responding to the 1987 Federal Aviation Administration Advisory Circular[1] that states aviation mask leaks from beards "could result in reduced crew member capability and performance." We couldn't find any peer-reviewed articles that demonstrated aviation masks leak enough from beards to cause impaired performance of pilots.

We have three pieces of evidence supporting our absence of hypoxia finding. First, our study demonstrated that in conditions relevant to aviators exposed to air in a hypoxia chamber at 30,000-ft (9144-m) equivalent using tissue-level sensitive S_pO_2 measures, individuals with beards of any length remained normoxic with the masks on. Second, we showed that as soon as the masks were removed for about 3 min, our measures picked up hypoxic S_pO_2 within seconds. Third, smelling salts were not perceived by our masked individuals.

The author says that our measure of fingertip pulse oximetry (S_pO_2) "resists dilution of mask-supplied air." He seems to be saying that our bearded subjects were experiencing reduced blood-level gases (P_aO_2) and were in fact hypoxic by that measure, which we would not see with our oximeters, even though they wirelessly recorded S_pO_2 at 1 Hz the entire time in the chamber. The masks were worn for at least 20 min at 30,000-ft equivalent air and only normoxic levels were recorded. This is longer than commercial pilots are required wear masks to establish safe altitudes during a decompression. We would like to remind the author that in normoxic individuals, far more of the available oxygen is bound to hemoglobin (S_pO_2) not dissolved in the blood (P_aO_2). Henry's Law tells us this bound oxygen is more important for tissue than oxygen dissolved in blood.

The author suggests a (very confusing) study of what he considers the most challenging situation in a normobaric chamber, and we highly encourage him to try it. Stimulating more research was another purpose of the paper.

He cites three articles that he believes show that beards cause leaks. All used nonaviation conditions and nonaviation masks and had no measure of tissue-level S_pO_2. He seems to have missed the point of the Floyd et al. article.[2] They found that some industrial masks were still effective in meeting the strict Occupational Safety and Health administration fitness standards "even with substantial facial hair in the face seal area." The author also points out that the one person in the Ferguson study[3] had 2 oximeter readings out of 13 (i.e., every 15 s) at 25,000 ft (7620 m) that were 93% S_pO_2 (failing to mention that this is still considered normoxic). He also forgot to mention that this person was in a group of people whom most would not describe as having a beard (length < 0.5 cm). All but this one were in the +97% range. Therefore, we find his references and arguments to be flawed and insensitive to relevant measures of mask leakage.

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