Synergistic effects of deep breath volume and frequency on bronchoconstriction

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RATIONALE: Deep breaths (DBs) are known to cause bronchodilation or prevent more severe bronchoconstriction. It seems likely that the frequency of DBs and their volume affect bronchoconstriction but the overall effect on airway behavior during asthma attacks is unknown. We hypothesized that frequency and volume of DBs have a synergistic effect on bronchoconstriction, and on the emergence of ventilation defects (VDef), which are regions with very low ventilation or complete gas trapping.

METHODS: 50 different conditions with DBs of different frequencies and volumes were studied using our integrative model of bronchoconstriction to conduct computer simulations. More specifically, the model including a bronchial tree with 12 generations, and involves estimates of airflow, pressure, tidal expansion, parenchymal forces, airway smooth muscle behavior, and airway size for each individual airway over time. Breathing conditions included normal tidal breathing and intermittent DBs with different combinations of relative tidal volume of DBs ($V_{TD} / \text{mean } VT = 1.2, 1.4, \ldots, 3$) and time intervals with one DB and normal tidal breaths in between (5, 10, 20, 40, 80 breaths). Regional ventilation maps along with the fraction of closed terminal units for all combinations were calculated accordingly.

RESULTS: Both DB volume and frequency affected the time of emergence of VDefs and their size. For frequent DBs (every 5th breath) VDefs emerged when $V_{TD} / \text{mean } VT < 2$, while less frequent DBs (80 breaths interval) required $V_{TD} / \text{mean } VT > 2.8$ to prevent VDefs. The fraction of closed or hypoventilated terminal units ($F_c$) showed that VDefs were larger when DBs were less frequent, e.g., 43% vs. 30% at $V_{TD} / \text{mean } VT = 1.6$. Larger $V_{TD} / \text{mean } VT$ delayed under certain conditions the emergence of VDefs. Interestingly, less frequent DBs caused under certain conditions substantial fluctuations in $F_c$. The DB interval with the highest fluctuations had compared to its neighbors an extended range of $V_{TD} / \text{mean } VT$ with VDefs.

CONCLUSION: Our integrative model of bronchoconstriction predicts that DB volume and frequency have a synergistic effect on bronchoconstriction, and on the emergence of VDefs. The implications of our findings may be that combinations of smaller DB volumes and less frequent DBs can have a substantial effect on the magnitude of bronchoconstriction during an asthma attack while other conditions may prevent the emergence of VDefs.

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