there are dynamic swings in airway transmural pressures that are maximal at the thoracic outlet and decrease up the tree. Airways are dynamically expanded during inspiration and dynamically compressed during expiration. Accordingly there are swings in flow velocities and attendant fluctuations in gas shearing: greater mouthward during expiration than in the opposite direction during inspiration, and the net movement would be mouthward. This effect would be greatest near the thoracic outlet and diminish up the tracheobronchial tree. Overall mucus clearance would combine a diminuendo of ciliary action overlapping a gas shearing crescendo, the latter providing percussive sforzandos during coughing. And with coughing, I can put airway smooth muscle back to work. Nerve-activated generational bronchoconstriction could influence mucus clearance during a cough in two major ways, by determining: 1) the location and extent of airway collapse and 2) the lung volume at which collapse occurs. Without smooth muscle action, cough effectiveness would be limited to the central airways at low lung volumes. With bronchoconstriction, a few generations out of the tree, dynamic compression mouthward would be more extensive and easier to produce (flow limitation can be velocity enhancing!).

My overall conclusion is that airway smooth muscle’s utility is at least twofold; in both instances it assists mucus clearance.

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AIRWAY SMOOTH MUSCLE IS NOT USEFUL

Airway smooth muscle (ASM) is the appendix of the lung. That is the succinct description rendered by Wayne Mitzner (15). Chun Seow and I had argued similarly that airway smooth muscle serves no useful function (22). Certainly there is no known disease entity or appreciable physiological deficit that is associated with loss of airway smooth muscle contractility, and when it contracts excessively, or contracts even moderately within an altered microenvironment, ASM seems only to cause problems. So in those very instances when ASM manifests itself, the consequences seem to be almost uniformly undesirable, and for that reason medical science has focused itself mainly on the question of how to frustrate its actions, as has evolution itself (10). Things have come so far, in fact, that today ASM is literally being burned at the stake under the scholarly moniker “bronchial thermoplasty” (1, 5, 16). As is often the case, frustration coupled with lack of purpose can be a precursor of misbehavior. As such, Seow and I had suggested that among the various muscle cell types that populate the body we could think of airway smooth muscle not so much as an appendix of the lung as much as the Hell’s Angel of cells, sitting on a Harley-Davidson, unshaven, a cigarette in one hand, a can of beer in the other, and a tattoo on its arm reading “Born to Lose.”

Whether a simple loser in the game of evolution or an appendix of the lung, such points of view have clearly rankled my friend, mentor, and teacher, and seemingly to good effect. Unwilling to accept the loser’s fate for ASM, he has tried to rehabilitate its sinister image by searching for heretofore unappreciated redeeming values. And indeed, he may have found one. His idea reduces to this: if the beating airway cilium is the motor that drives the mucociliary escalator, then airway smooth muscle may act as its transmission—one that is automatic and continuously variable at that. As in shifting the gears of a bicycle transmission, the airway smooth muscle by contracting or relaxing tunes the thickness of the airway surface liquid layer and thereby modulates the mechanical advantage exerted by the beating cilium upon mouthward airway surface layer (ASL) transport.

Before addressing this idea, I will briefly reiterate the case against ASM. But to do so begs a question that is even more basic and that I will deal with first: why is there specialized muscle in general, and why is there smooth muscle at all? An elegant answer was suggested by Richard Murphy (17). The design of striated muscle seems to be optimized for the efficient conversion of chemical energy into external mechanical work. The design of smooth muscle, by contrast, seems to be optimized not at all for efficiency but instead for economy, that is, economical conversion of chemical energy into maintenance of the tone and shape of hollow organs. It is these hollow organs, after all, that are the only places in which smooth muscle is found. Since these latter functions in hollow organs involve only trivial amounts of external mechanical work, efficiency becomes virtually irrelevant, whereas economy becomes all important. Indeed, in support of this argument is the observation that in smooth muscle vs. striated muscle the rate of ATP hydrolysis required to maintain a given level of isometric active stress is smaller by ~300-fold.

It had been recognized quite early that lungs are irritable and that stimulation of its contractile machinery in an animal with an open chest can cause air to be expelled from the lungs, a rise in intratracheal pressure, and an increase in airways resistance (4, 7, 13, 20). However, until the second half of the last century, airway smooth muscle was not regarded as being a muscle of any particular significance in respiration mechanics (20). Airway smooth muscle was first described in 1804 by Reisseisen [as related by Otis (20)] and its functional properties first considered by Einthoven (9) and Dixon and Brodie (7). More recent studies have shown that the fraction of the tissue volume that is attributable to contractile machinery is comparable for airways, alveolated ducts, and blood vessels in the lung parenchyma (18); the lung parenchyma, like the airway, is a contractile tissue (3, 11).

Identification of a normal physiological role of airway smooth muscle has remained elusive (20) and in that regard airway smooth muscle stands in contrast with other smooth muscle systems whose primary functional roles are self-evident. In an earlier report, Mead questioned the extent to which changes of smooth muscle tone might play some homeostatic role to stabilize airways and air spaces (13). He speculated that a moderately constricted state of airway smooth muscle may make airways behave more like the lung parenchyma in which they are embedded, thus improving the homogeneity of lung expansion; he reasoned that homogeneous lung expansion might depend on mechanical interdependence among lung...
structures, all operating on a background of smooth muscle activity. It has been argued by others that contraction of airway smooth muscle might serve to modulate the tradeoff between dead space vs. airway resistance in a way that minimizes the work of breathing (23), serve to adjust airway caliber among parallel pathways and parenchymal compliance among peripheral lung regions in a way that optimizes the distribution of ventilation (6, 8, 18), serve to narrow the airway in a way that improves the ability of cough to expel worms or other foreign objects from the airway, serve to stiffen the airway sufficiently to prevent extreme airway collapse during forced expiration (2, 19), or serve to match the mechanical hysteresis of small airways and alveolated ducts to the rather appreciable mechanical hysteresis of the alveolar surface film in a way that allows for synchronous and uniform alveolar expansion (12–14). Schittny et al. (21) have demonstrated that gestation of the fetal mouse lung there exist peristaltic waves of airway smooth muscle contraction propagating proximal to distal in the airways; they showed that fluid displaced by this milking action maintains an appreciable positive intraluminal pressure in peripheral airways and air spaces and suggested that this fluctuating distending pressure might provide a crucial stimulus for lung growth in utero.

Each of these arguments is plausible, but evidence in each case remains less than compelling. Still another explanation for the utility of airway smooth muscle, and perhaps a better one, is that there is no explanation; that is to say, both the phylogeny and the ontogeny of the lung shows that airways derive from the foregut, so it cannot be ruled out that the presence of smooth muscle within this adapted piece of gut is merely vestigial and represents nothing more than a frozen accident of nature that finds no useful function.

This brings us back to the airway smooth muscle as a variable transmission of the mucociliary escalator, as is now proposed. I see no logical flaw in the argument, so the issues reduce to two. First, how big is the effect? Second, if it can be shown to have an appreciable physiological effect, can a specific mechanism then be found to effect the local regulation that is proposed? Jere’s hypothesis fits the bill of being simple, plausible, and mechanistic, but we cannot expect him to come out of retirement to test it. That being the case, someone else will have to take up the cause of gathering evidence that might reestablish the virtue of the oft-maligned airway smooth muscle cell.

So, is airway smooth muscle an appendix, a transmission, or a loser yet again? The answer to this question places more at stake than mere philosophy, especially if bronchial thermoplasty is to enter the armamentarium of routine tools to treat asthma.

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REBUTTAL FROM DR. FREDBERG

My antagonist in this debate had the impossible task of proving a negative, but with a pleasant side effect, a put-down for Intelligent Design. As agonist, my impossible task was to prove a positive with a less pleasant side effect: no data. With only five months of my pension left, I can only make a suggestion. Take advantage of the speed differences of striated muscle, and perhaps a better one, to adjust airway caliber among parallel pathways and parenchymal compliance among peripheral lung regions in a way that optimizes the distribution of ventilation (6, 8, 18), serve to narrow the airway in a way that improves the ability of cough to expel worms or other foreign objects from the airway, serve to stiffen the airway sufficiently to prevent extreme airway collapse during forced expiration (2, 19), or serve to match the mechanical hysteresis of small airways and alveolated ducts to the rather appreciable mechanical hysteresis of the alveolar surface film in a way that allows for synchronous and uniform alveolar expansion (12–14). Schittny et al. (21) have demonstrated that gestation of the fetal mouse lung there exist peristaltic waves of airway smooth muscle contraction propagating proximal to distal in the airways; they showed that fluid displaced by this milking action maintains an appreciable positive intraluminal pressure in peripheral airways and air spaces and suggested that this fluctuating distending pressure might provide a crucial stimulus for lung growth in utero.

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