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Measuring intra-subject changes in respiratory mechanics by oscillometry: impedance *versus* admittance

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To the Editor:

Recent state-of-the-art reviews [1, 2] and research [3] have pointed out the potential interest of oscillometry for noninvasively characterising lung mechanics from the relationship between oscillatory pressure (P) and flow (V') at different frequencies. Two magnitudes have usually represented this relationship: resistance (R) and reactance (X), which are the real and imaginary parts of respiratory impedance ($Z=R+j{\cdot}X$). Clinical [1, 2] and modelling data [4] show that both R and X depend on the interaction between resistances and compliances of central and peripheral airways and lung tissues. Even at the low oscillometry frequency of 5 Hz (which is a critical reference frequency for clinical studies [1, 2]), a simple interpretation of R and X is not possible [4]. Interestingly, the same pathophysiological information is contained in Z and in its reciprocal: admittance (Y; $Y=1/Z$). The real and imaginary parts of Y ($Y=G+j{\cdot}B$; where G is conductance and B susceptance) are univocally equivalent to R and X: $G=R/(R^2+X^2)$, $B=-X/(R^2+X^2)$, and, therefore, changes in R and X are paralleled by changes in G and B. Although Y is currently not so familiar as Z, it should be mentioned that both are conceptually similar (*i.e.*, V'/P instead of P/V'). In particular, G has an interpretation as simple as that of R: G is the component of flow in phase with pressure. Given that almost all the oscillometry literature is referred to Z, why focus here on Y?

The reason is that Y is conceptually superior to Z in many clinical applications of oscillometry, specifically in those where changes in lung mechanics within the same patient are explored. For instance, in bronchoprovocation/bronchodilation tests [1, 2], when detecting changes within inspiration and expiration to detect expiratory flow limitation [5], or when monitoring time variance for anticipating exacerbations [3]. In fact, from the early years of oscillometry, it is well-known that the impedance measured by the conventional technique (Z_m) is not the patient's respiratory impedance (Z_{rs}) but its parallel association with the impedance of his/her extrathoracic upper airways (Z_{eua}) [6, 7]. Therefore, according to the rule for computing the equivalent of impedances and admittances in parallel, respectively: $1/Z_m=1/Z_{rs}+1/Z_{eua}$ and $Y_m=Y_{rs}+Y_{eua}$. This artefact could be virtually eliminated by applying oscillations around the patient's head (a setting known as "head generator") instead of directly at the mouth as with the standard oscillometry device [7], but such a setting is not practical for clinical applications. Interestingly, when comparing oscillometry data within the same patient, and reasonably assuming that Z_{eua} is not modified between repeated measurements, changes in measured admittance (Y_m) are, contrary to those in impedance, freed from the extrathoracic upper airway artefact since $\Delta Y_m=Y_{m2}-Y_{m1}=(Y_{rs1}+Y_{eua1})-(Y_{rs2}+Y_{eua2})=Y_{rs2}-Y_{rs1}=\Delta Y_{rs}$, because $Y_{eua1}=Y_{eua2}$. This fact, which was recently acknowledged [1], was proven when comparing clinical oscillometry data in bronchoprovocation in children [8]. Indeed, figure 1a shows the challenge-induced changes in resistance (ΔR) and in the modulus of admittance ($|\Delta Y|$) when the "head generator" (almost freed from the extrathoracic upper airway artefact) and the conventional oscillometry device were used in the very same bronchoprovocation test. As expected, ΔR measured with the standard device was considerably decreased whereas the admittance changes were very close regardless of the device used.

However, recommendations regarding thresholds to indicate positive bronchodilation/bronchoprovocation tests are still focused on changes in R and X. For instance, 40% and 50% reductions in R(5 Hz) and X(5 Hz), respectively, for positive bronchodilation [1, 2]. While it is reasonable to set a threshold for lung impedance changes (*e.g.* on Z_{rs}), it is questionable to set a threshold for a variable such as Z_m, which not only depends on Z_{rs} but also on Z_{eua}. For illustration, figure 1b shows how Z_{eua} interferes in the

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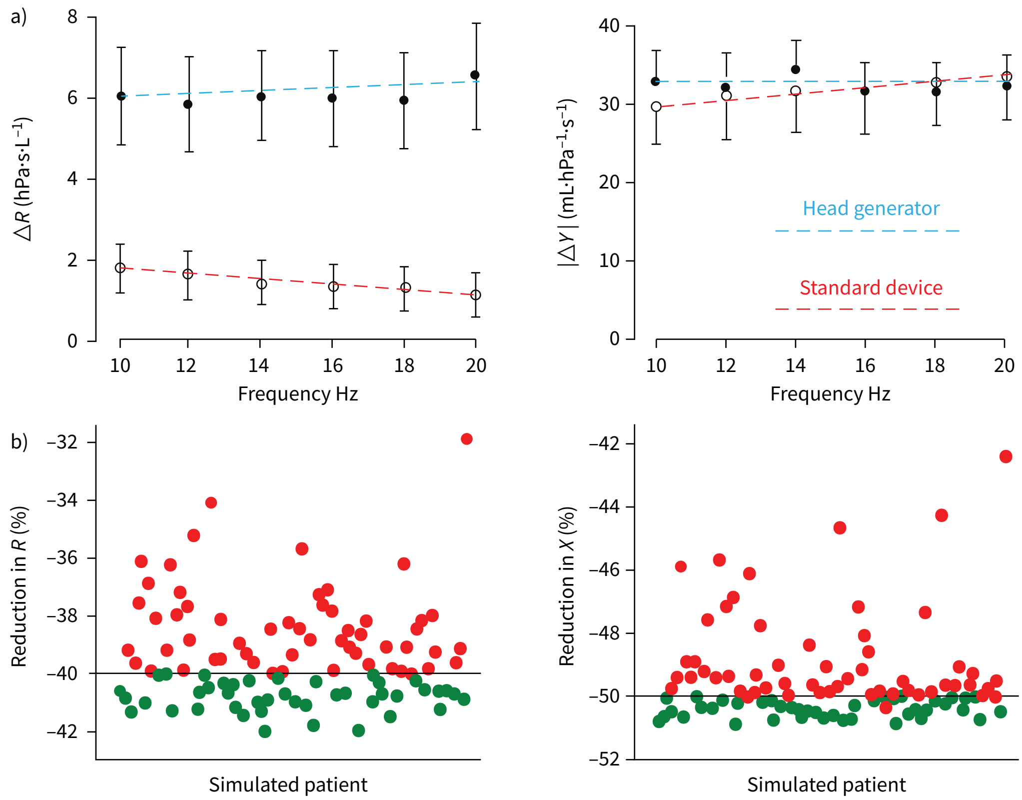

FIGURE 1 a) Changes in resistance (ΔR, left) and in the modulus of admittance (|ΔY|, right) induced by a bronchoconstriction test when measured using the "head generator" (almost freed from the extrathoracic upper airway artefact) and the conventional oscillometry device. Reproduced and modified from [8] with permission. b) Effect of the extrathoracic upper airways shunt on the changes in measured resistance (*R*) and reactance (*X*). A simulated patient experiences a positive bronchodilation test: his/her measured impedance (at 5 Hz) changes from 5−j·4 to 3−j·2 $cmH_2O·s·L^{-1}$. These changes correspond to 40% and 50% reductions in *R* and *X*, respectively. Assuming that the impedance of the patient's extrathoracic upper airways (Z_{eua}) is 12−j·45 $cmH_2O·s·L^{-1}$, which is an average figure [6], his/her respiratory impedance (Z_{rs}) changes from 5.98−j·3.95 to 3.29−j·1.94 $cmH_2O·s·L^{-1}$. The figure shows the changes in measured *R* and *X* for 100 simulated patients experiencing the same change in Z_{rs} and each one having a value of Z_{eua} sampled from a normal distribution with a mean of 12−j·45 $cmH_2O·s·L^{-1}$ and standard deviation of ±4±j·15 $cmH_2O·s·L^{-1}$. Green/red colour indicates patients with a change higher/lower than the threshold (40% for *R* and 50% for *X*). See text for explanation.

application of bronchodilation thresholds for reductions in measured *R* and *X* in 100 simulated patients. Each patient experiences the same change in Z_{rs}, having each one his/her individual value of Z_{eua}. The percent reductions of measured resistance and reactance of these simulated patients are distributed around the thresholds of 40% and 50%, respectively. But, whereas all of them experience the same positive bronchodilation, a significant part of them (∼50%; red points in figure 1b) do not pass the threshold if applied to ΔZ_m. By contrast, if assessed by means of admittance (*G* and/or *B*) change, all these simulated patients exhibit the same measured ΔY_m (which equals ΔY_{rs}) regardless of the individual values of Z_{eua}. Of note, ΔY_m is an absolute value change and any attempt to compute a relative change (*i.e.* percentage) should avoid normalisation by baseline Y_m since this value is affected by the upper airway shunt. Alternatively, normalisation for setting relative thresholds could be carried out, for instance using the expected values of impedance (admittance) from anthropometric data in published reference equations [2]. Setting absolute or relative thresholds that are not affected by Z_{eua} is particularly interesting taking into account that the effect of the extrathoracic upper airway shunt depends on practical issues, such as how the patient's cheeks are supported [9] or whether oscillometry is applied through a mask instead of a mouthpiece [10].

In conclusion, it seems reasonable to assess oscillometric changes within a patient in terms of variations in admittance. This of course does not preclude maintaining the traditional and well-documented indices on impedance, but also requires processing of the admittance data. Such a procedure would not require additional work since *Y* data are always available from *R* and *X*. In fact, testing how changes in admittance work could be retrospectively carried out by simply reprocessing the *R* and *X* data already available in past studies. Finding a potential improvement, even if minor, in sensitivity and specificity would be very useful for the clinical application of oscillometry.

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