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Maximal inspiratory pressure: does reproducibility indicate full effort?

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Abstract

***Background* – Maximal inspiratory pressure (MIP) is often relied upon as an index of inspiratory muscle strength, and reproducibility of MIP taken to indicate maximal effort. This study was designed to determine whether reproducibility is a valid indicator of maximal effort.**

***Methods* – Ten normal subjects were studied, all of whom were familiar with the MIP test but none was an experienced subject. They were told that the purpose was to measure how accurately they could generate 50% of their MIP. Each performed nine MIP efforts and nine submaximal efforts. Means and coefficients of variation of peak negative inspiratory pressure (Pmax) and the ranges of the best three efforts were calculated for each type.**

***Results* – Mean (SE) Pmax averaged −93·8 (6·0) cm H_2O for the maximal efforts and −60·6 (7·7) cm H_2O for the submaximal trials, with coefficients of variation averaging 8·71 (1·75)% and 14·58 (2·63)%, respectively and the ranges averaging 6·5 (1·1)% and 13·4 (3·5)%, respectively. There was no clear separation between the coefficients of variation or ranges of maximal and submaximal efforts. In four cases the ranges of the best three submaximal efforts were less than 5 cm H_2O and less than 5% – criteria that have been used to validate MIP results. These four subjects had lower ranges for submaximal than maximal efforts, even when expressed as percentages of the means.**

***Conclusion* – Reproducibility should not be relied upon to indicate a valid MIP test, especially for research purposes when relatively small changes in inspiratory muscle strength must be discriminated.**

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Keywords: respiratory muscles, pulmonary function testing, muscle strength.

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Maximal static inspiratory pressure (MIP) is the only widely available index of inspiratory muscle strength. It is often relied upon during clinical pulmonary function testing[1 2] and in research[3–10] to be an accurate reflection of the contractile strength of the inspiratory muscles. MIP is effort dependent, however, and it is clear that it can only be a reliable index of inspiratory muscle strength if the subject's effort is truly maximal. In practice it is often assumed that reproducibility of multiple MIP efforts indicates that the efforts are maximal,[1–9] an assumption that may not be justified. In a study of patients on mechanical ventilation we recently showed that MIP could not be relied upon as an index of strength, despite relatively good reproducibility of triplicate efforts.[11]

For clinical purposes, if MIP is better than some arbitrary threshold value of perhaps −40 cm H_2O, a patient can be judged to have adequate inspiratory muscle strength. Thus, it is not always essential to be sure that a subject has made a truly maximal effort. For research, however, especially in the investigation of factors that could improve[6–10] or worsen[3–5] inspiratory muscle strength, precise and accurate measurements are crucial. We report the results of a study designed to determine whether reproducibility of MIP can be used to document maximal effort.

Methods

Ten normal subjects (nine men) were recruited from the medical house staff at Montefiore Medical Center and gave informed consent for the study procedures which were reviewed and approved by the Institutional Review Board for the protection of Human Subjects. All subjects were in good health, adequately nourished, and well rested at the time of the study. None was taking any sedative or hypnotic drug, but no effort was made to control previous intake of caffeine. All were familiar with the MIP test as it is used clinically, but none had been a subject for any previous pulmonary or respiratory muscle function studies. They were told that the purpose of the study was to determine how accurately they could generate 50% of their maximal inspiratory effort.

The MIP efforts were performed using the instrument described by Black and Hyatt[12] connected to one side of a differential pressure transducer (Model MP-45, Validyne Corp, Northridge, California, USA). The subjects were instructed to breathe out to residual volume (RV) prior to their inspiratory efforts, but we did not insist on prolonged expiratory efforts nor did we verify that they achieved RV.

To familiarise the subjects with the technique, each of them made at least three MIP efforts with visual feedback from the aneroid pressure gauge mounted on the instrument until they were confident that they had achieved their maximal inspiratory effort. Subsequently, with the pressure gauge masked, they attempted nine MIP efforts and nine 50% efforts, in groups of three, in random order. For MIP efforts they were asked to produce the strongest possible vacuum; for the 50% efforts they were asked to achieve as close as possible to a vacuum level that they perceived as 50% of their max-

Table 1 Mean (SE) maximal and submaximal inspiratory efforts of 10 study subjects

	Maximal efforts	*Submaximal efforts*	*p*
Best Pmax (cm H_2O)	−108·1 (6·5)		
Best Pmax (% predicted)*	100·1 (9·6)		
Average Pmax (cm H_2O)	−93·78 (6·02)	−60·64 (7·71)	<0·01
Average Pmax (% predicted)	89·67 (9·01)	58·01 (8·30)	<0·01

Pmax = peak negative inspiratory pressure.
* % predicted data are based on the normal values reported by Black and Hyatt.[12]

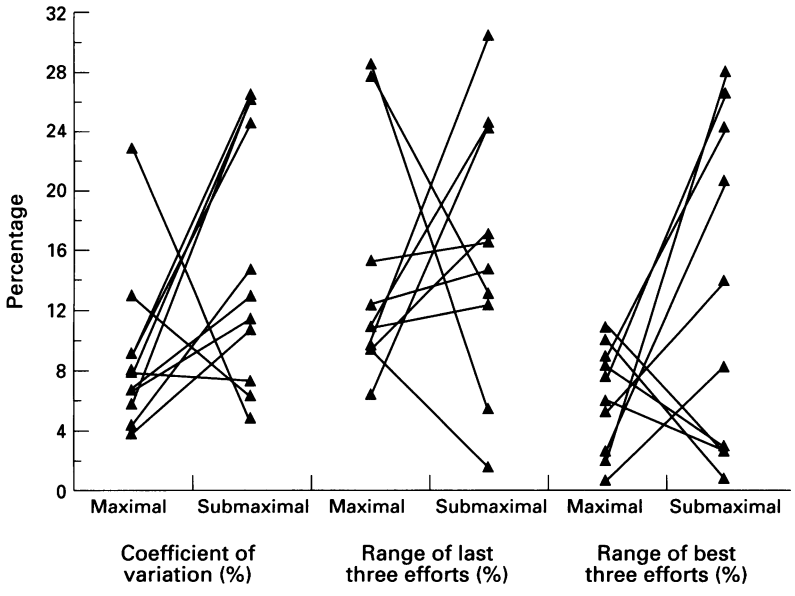
Table 2 Mean (SE) reproducibility of maximal and submaximal inspiratory efforts in 10 study subjects

	Maximal efforts	*Submaximal efforts*	*p*
Coefficient of variation (%)	8·71 (1·75)	14·58 (2·63)	NS
Range (%) (all 9 efforts)	24·58 (4·48)	45·80 (8·39)	NS
Range (%) (last 3 efforts)	14·14 (2·45)	16·17 (2·78)	NS
Range (%) (best 3 efforts)	6·48 (1·12)	13·40 (3·48)	NS

imum. At least one minute of rest was allowed between each effort, and at least five minutes between each group of three efforts.

Pressures were recorded with a carrier demodulator/amplifer (Validyne CD18), with its output low pass filtered at 200 Hz, and digitised at 500 Hz by a 12 bit analog digital converter (Labmaster, Scientific Solutions Inc, Solan, Ohio, USA) driven by a microcomputer (Model 386-20, NEC Corporation, Tokyo, Japan) equipped with appropriate software (Labtech Notebook, Laboratory Technologies Inc, Wilmington, Delaware, USA). Data analysis was carried out using a spreadsheet (Lotus 123, Lotus Development Corp, Cambridge, Massachusetts, USA) and appropriate spreadsheet macros for automated analysis.

Peak negative inspiratory pressure (Pmax) and coefficient of variation of Pmax (CV = 100% × SD/mean) were calculated for each of the sets of nine efforts without visual feedback (maximal or submaximal). In addition, the range of pressure measurements was calculated for all nine efforts, the last three efforts, and the best three efforts in each group (maximal and submaximal). All ranges were expressed as percentages of the means. Data from all 10 subjects were tabulated and mean characteristics of maximal efforts were compared with those of submaximal (50%) efforts using the Student's *t* test for paired data.



Variability of replicate determinations of peak negative inspiratory pressure for maximal and submaximal efforts of 10 normal subjects. The left panel shows the coefficients of variation of all nine efforts; the centre panel shows the ranges of the last three efforts of each type; and the right panel shows the ranges of the best three efforts of each type. All data are expressed as percentages of the means. Although there was a trend toward lesser variability among the maximal efforts, the differences were not significant and there was considerable overlap.

Results

The mean (SE) age of the subjects was 29·0 (0·7) years, height 174·8 (2·5) cm, and weight 73·1 (4·4) kg. The characteristics of the maximal and submaximal efforts are compared in table 1. As expected, the maximal efforts were much stronger than the submaximal efforts. Although there was a trend toward lower coefficients of variation and ranges of Pmax among the maximal than the submaximal efforts (table 2), the differences were not significant and there was no clear separation of maximal from submaximal efforts (figure). In three of the 10 cases the coefficients of variation were higher for maximal than for submaximal efforts, and in four cases the ranges of the best three efforts were higher for maximal than for submaximal efforts. For these four subjects, the ranges of their best three submaximal efforts were substantially less than 5 cm H_2O and less than 5% of their "best" effort – criteria that have been used to validate MIP results.[2589] There was no significant relation between the percentage predicted Pmax values and their coefficients of variation or range, and the order in which the efforts were made also had no significant effect on their coefficient of variation or range.

Discussion

Complete or almost complete activation of diaphragm motor units has been documented during at least some MIP efforts of well motivated normal subjects using the twitch occlusion technique described by Bellemare and Bigland-Ritchie[13] and by Gandevia and McKenzie.[14] Virtually complete activation of phrenic motor units has also been demonstrated among stable, well motivated patients with chronic airways obstruction undergoing rigorous testing in a research environment.[15] However, complete activation is unlikely to occur during routine MIP measurements, at least among patients with chronic airways obstruction,[16] and it is difficult to assure high levels of motivation even of research subjects for studies in which MIP may not be the primary focus. For practical purposes, both in clinical testing[12] and in research,[3–9] reproducibility of triplicate MIP

measurements is usually relied upon to establish that the measured MIP reflects the maximal effort of the inspiratory muscles.

"Reproducibility" often remains undefined[1 3 6 7]; when it is defined, it is usually as a range among the best three efforts of less than 5 cm H_2O or less than 5% of the best effort.[2 9] In a group of normal subjects we have shown that deliberately submaximal efforts are often reproducible enough to meet either definition. Thus, reproducibility of efforts does not prove that the efforts were truly maximal or even that they were close to maximal. This finding is consistent with that of Kroemer and Marras[17] who showed that deliberately submaximal contractions of the elbow flexors could be just as reproducible as maximal contractions.

Since we did not measure MIP by twitch occlusion we cannot be sure that all of our subjects activated their inspiratory muscles maximally during their "maximal" efforts. We may therefore have been comparing the reproducibility of two sets of submaximal efforts. Nevertheless, we have shown that both types of efforts are commonly highly reproducible; if both sets were submaximal, that would only strengthen our argument that reproducibility does not necessarily indicate maximal effort.

Incomplete activation of inspiratory muscles during an MIP manoeuvre probably results, in most cases, from inadequate motivation due to lassitude, pain, inability to understand instructions, or malingering; in some cases it could be due to a non-motivational form of "central fatigue".[18] It could be argued that the ineffectual efforts of poorly motivated patients are not comparable with, and might be less likely to result in, a narrow range of MIP results than the deliberate attempts by capable, cooperative, and motivated subjects to produce 50% of MIP. That is certainly true for grossly uncooperative patients, and our data do not allow us to be sure that the submaximal efforts of our subjects are not artificially reproducible. However, it seems likely that the discomfort evoked by the muscular activity required for MIP efforts has a certain reproducible threshold, or that a patient may be willing to exert a certain reproducible level of effort during MIP attempts. If so, then some patients in effect make deliberately submaximal efforts when asked to produce maximal efforts. If even small numbers of patients or research subjects exhibit this phenomenon, then the presence of reproducibility could not be counted on as an indicator of maximum effort.

Our results have important implications for clinical pulmonary function testing, and particularly for investigations of factors that might influence inspiratory muscle strength. For example, Mier-Jedrzejowicz and associates found reductions in MIP in persons with viral upper respiratory infections, used reproducibility as an indicator of acceptable tests, and concluded that inspiratory muscle weakness is one consequence of viral upper respiratory infections.[3] An alternative explanation of the results, however, would be that the lassitude that is common in viral upper respiratory infections prevented subjects from exerting as strong an effort when they were infected as they did when they were not infected. Our findings show that the observed reproducibility of MIP efforts cannot be used to verify that such efforts were truly maximal.

Most pulmonary function tests are effort dependent, but MIP is especially sensitive to the level of effort exerted. The result of an MIP manoeuvre is, for practical purposes, directly proportional to effort. In contrast, because dynamic compression of airways limits expiratory flow, maximal FEV_1 can be achieved with expiratory muscle contraction efforts well below maximum.[19] Vital capacity manoeuvres do not require rapid flow rates, so their results are relatively less dependent than MIP on maximal inspiratory muscle contraction. Inspiratory muscle strength is therefore particularly at risk of being underestimated from the results of MIP testing. Perhaps this problem helps to explain the higher range of normal values for MIP than for other pulmonary function tests.[12]

We conclude that, unless full activation of the respiratory muscles can be documented by other means such as the twitch occlusion technique of Bellemare and Bigland-Ritchie[13] and Gandevia and McKenzie,[14] or its painless adaptation described by Similowski and colleagues,[20] an MIP result that is less than the predicted normal value, even though reproducible, should not be considered diagnostic of inspiratory muscle weakness. Changes in MIP after the onset of illness or after pharmacological or other treatments, even if reproducible, should not therefore be considered definitive evidence of an effect on inspiratory muscle strength, and the absence of such changes should not be considered definitive evidence against such an effect.

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