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Chest 1997;111;916-921

This information is current as of August 28, 2005

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An Algorithm for Pulmonary Screening of Military Pilots in Israel*

Yehuda A. Schwarz, MD; Jacob Erel, MD; Benjamin Davidson, MD; Yehezkel Caine, MD; and Gerald L. Baum, MD, FCCP

Background: Medical screening is used routinely to qualify and classify candidates for pilot training. The respiratory system assumes even greater importance owing to the increased stress of flying high-performance aircraft in a hostile environment characterized by high altitude, varying acceleration (“G” forces), and the possibility of rapid decompression. Any respiratory dysfunction may threaten the pilot’s health, flight safety, and completion of the mission. Only those candidates with the highest psychophysical score are accepted to undergo special aeromedical screening. Physical suitability is an important factor in the selection and classification of candidates for flight training programs, and pulmonary function testing is central within this screening protocol.

Methods: We developed a respiratory algorithm for this unique screening process. The algorithm represents a practical and efficient approach for large-scale screening of healthy candidates for flight training. The algorithm deals with the major pulmonary health problems encountered in a previously screened healthy population aged 17 to 25 years. If by anamnesis, physical examination results, or baseline spirometry findings there is reason to suspect a respiratory problem that could emerge to endanger the pilot's life, a specially designed evaluation is performed according to the algorithm. We explain, step by step, the basis for each suggested test in order to reach a decision (operational specifications). The pulmonary function studies we recommend are reasonably priced and can be easily and reliably performed by regular medical staff technicians. The major justification for performing pulmonary function studies in a healthy population that has already gone through a preliminary medical screening and has been found fit is to identify occult or latent abnormalities. These abnormalities may have no or minimal clinical expression under ordinary circumstances but, under the stress of flight during the ensuing 5 to 10 years, may produce serious limitation in function.

Results: Two cases, seen in the Air Force Medical Center, are presented to illustrate how the algorithm is implemented. The algorithm has been in use for more than 5 years, and has been applied to the screening of several thousand candidates. Follow-up of the accepted candidates has not revealed any significant defects in the decision-making process.

Conclusion: Use of the algorithm is highly cost-effective since it allows for nonspecialist physicians to carry out pulmonary screening and involves the pulmonary specialist only infrequently, i.e., when a particularly complicated and/or borderline case is encountered. It is our contention that a similar algorithm would be useful in many other settings where large-scale screening is required.

(CHEST 1997; 111:916-21)

Key words: algorithm; pilot training; pulmonary screening

Abbreviations: CXR=chest radiograph; IAFAC=Israeli Air Force Aeromedical Center; OP=operational specifications; PFT=pulmonary function tests; RV=residual volume

Medical screening is routinely used to qualify and classify candidates for a wide variety of training programs in the community at large. Resources, both professional and physical, to carry out such screening programs are always limited, thus making it worthwhile, if not imperative, to use them in the most efficient manner possible. This is particularly true in the field of aviation, owing to the universal problem of screening a large number of candidates to yield the small number who eventually qualify.

In a military setting, the respiratory system assumes even greater importance owing to the increased stress of flying high-performance aircraft. Suitability for flying according to cardiovascular criteria has been thoroughly dealt with,1 but respiratory limiting factors have been less well defined. We...
reviewed the relevant literature and found that no descriptions of routine screening of the respiratory system (US Navy, US Air Force, International Manual of Civil Aviation Medicine, etc.) have provided a clear and specific basis for decision making. As a result, the algorithm described herein was developed and represents, in our opinion, a unique tool for carrying out such screening.

Physical suitability is an important factor in the selection and further classification of participants in different stages of various flight training programs.

Within this screening process, special emphasis should be placed on the respiratory system, including the airways, the lung parenchyma, and the respiratory muscles. This is particularly essential in aviation owing to the hostile environment that includes high altitude, varying acceleration (“G” forces), and the possibility of rapid decompression. Any respiratory dysfunction may threaten the pilot’s health, flight safety, and completion of the mission. The central role of pulmonary function testing (PFT) in this type of screening and the relative scarcity of standardized laboratories dictate the need to use them judiciously, efficiently, and only when results are considered to have significant added value in the decision-making process.

We present this algorithm in detail, and rationalize the tests used as well as the basis for decision making. It was designed to enable nonspecialist physicians to follow the logic of the system and to arrive at a decision concerning a candidate/cadet with less frequent need to involve a pulmonary specialist.

**Materials and Methods**

The Israeli Air Force Aeromedical Center (IAFAC) algorithm, which is presented in Table 1, shows the algorithm for candidates or accepted cadets at the ground training phase, before the beginning of the flight training phase.

Many of the listed decisions are based on accepted practice. Where this is not self-evident, the relevant reported experience that forms the basis of this algorithm will be cited. Obviously, there are situations that require more sophisticated considerations, especially if the disqualified candidate wishes to appeal a decision. These exceptions will require the involvement of the specialist physician.

The studied candidates for flight training had previously undergone the routine medical screening for induction into the Israel Defense Forces. From this basically healthy population, only those with the highest psychophysical score are accepted into the medical screening for air force flight training.

**History and Physical Examination**

**A.** A personal history of asthma or any symptoms suggestive of asthma are of great importance because of the sudden incapacitation\(^1\,^2\) that can result from an asthma attack during flight. This includes imbalance of pressure/flow relationships caused by airways obstruction and the variation of ambient air pressure that can cause abnormal gas exchange. Moreover, overinflation of the lungs secondary to air trapping can result in barotrauma during flight due to sudden ambient pressure change. The history of asthma, even in the absence of current symptoms, is highly suggestive of potential disability, especially under stress.

**OP (Operational Specifications):** The length of the attack-free period is inversely related to the risk of developing further attacks in the immediate future\(^4\,^5\) (the prediction value may reach 0.5). We chose the cutoff point of 5 years based on clinical experience alone, since there are little hard data in the literature that deal specifically with this point (Table 1).

**B.** A family history of either asthma or \(\text{(C) allergy, especially among first-order relatives, is a significant risk factor for the existence of asthma or hyperreactive airways in the subject. In several series, the association approached 50%.}\)\(^6\,^7\) Thus, if such a history is elicited, further testing is imperative.

**D.** In most cases of spontaneous pneumothorax, the morphologic basis of the condition is obscure. The one abnormality, however, that is implicated as a cause is subpleural blebs.\(^8\) It is also known that persons with lung overinflation are more likely to be prone to spontaneous pneumothorax than the general population.\(^9\) Subpleural blebs are more susceptible to rupture when ambient pressure is reduced,\(^11\,^12\) even when they are not large enough to be identified by chest radiograph (CXR) or CT. Spontaneous pneumothorax is associated with a 20 to 60% recurrence rate.\(^10\,^13\,^14\) Up to 80% of recurrent episodes will occur within the first year after the initial episode.\(^10\) It is only after 5 years, however, that the degree of risk returns to that of the general population.\(^10\)

**OP:** Therefore, if 5 years have passed since the last episode, a medical waiver may then be considered on the condition that the chest CT and pulmonary function studies give no hint of subpleural blebs, localized overinflation, generalized overinflation, or airways obstruction (Table 1, I-D-b-b). In borderline cases, the candidate may be further evaluated by hypobaric chamber exposure under a carefully controlled protocol.

**E.** Traumatic pneumothorax is, by definition, not a primary lung problem, but there may be secondary lung damage. This will heal with greater or lesser residual scarring. The major factor limiting flight training is the extent of the trauma, after excluding the likelihood of recurrence of the pneumothorax and residual lung damage.

**OP:** After 1 uneventful year, the chance of recurrence is negligible and, if residual lung damage is minimal or absent, a waiver is recommended (Table 1, I-E-a-1). At only 6 months posttrauma, it is not yet clear whether the healing process has been completed and no decision is possible, but if 6 months to 1 year have passed since the event, then each case may be considered for waiver based on the results of the recommended studies (Table 1, I-E-b-1).

**Chest Examination**

**A.** CXRs, including both posteroanterior and lateral projections, generally will clarify the form and extent of the morphologic abnormality (Table 1, II-A).

**B.** Respiratory infection can artifactually produce findings that may be disqualifying. Its presence on chest auscultation excludes the candidate from undergoing screening.

**OP:** (a) The finding of wheezing on auscultation on relatively mild deep breathing or at the end of a slow full expiration with the mouth open is disqualifying by itself and requires no further workup. The finding of prolonged expiration on normal or mild deep breathing in the absence of respiratory infection requires further investigation, since this may either be a normal variant or the single indication of significant obstructive airways disease.
II. Physical

A. Technicians. Priced and can be easily and reliably performed by regular staff.

B. Infection is suspected, screening should be delayed by at least 6 weeks.

C. Chest deformity

D. Spontaneous pneumothorax

E. Traumatic pneumothorax

III. Anomalous PFTs

A. FVC

B. FEV₁ baseline

C. FEV₁/E ratio

D. FEV₁/B ratio

E. FEV₁/FVC ratio

F. FMF 25–75%/MEF 50%

G. BPT (methacholine)

Table 1—Algorithm for Candidates or Accepted Cadets at the Ground Training Phase Before Beginning the Flight Training Phase*

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*VOL=lung volumes (body plethysmograph); Spiro=spirometry (lung mechanics); B=baseline; E=postexercise; BD=after bronchodilator; BPT=bronchial provocation test (methacholine); E/BD ratio=postexercise/after bronchodilator inhalation ratio; FMF=forced expiratory flow; MEF=mean expiratory flow; Diffusion=diffusion capacity test for carbon monoxide (DLco); N=normal; ABN=abnormal; CD=considered disqualifying; WC=waiver considered; WR=waiver recommended; NW=no waiver.

1Chest CT preferred.

The major justification for performing pulmonary function studies in a healthy population that has already gone through a preliminary medical screening and has been found fit is to identify occult or latent abnormalities. These abnormalities may have no or minimal clinical expression under ordinary circumstances but, under the stress of flight during the ensuing 5 to 10 years, may produce serious limitation in function. In this context, the conditions causing the restrictive defects that may impose an unacceptable risk of disturbed flight performance are minimal diffuse parenchymal disease, musculoskeletal abnormalities, and pleural scarring. The conditions causing obstructive defects with

Wheeze indicates airways obstruction which, in young persons, generally indicates asthma or uncommonly localized airway obstruction, both of which are disqualifying factors. (b) If such an infection is suspected, screening should be delayed by at least 6 weeks.15-17

Pulmonary Function Tests

The pulmonary function studies we recommend are reasonably priced and can be easily and reliably performed by regular staff technicians.
similar implications are occult/latent asthma, major airway obstruction by an occult tumor, isolated overinflation, and early fixed airways obstruction.

Lung volumes as noted in the algorithm (Table 1) refer to two measurements: total lung capacity and residual volume (RV). A reduction of the total lung capacity below 80% with an attendant reduction in RV of similar magnitude generally means a restrictive defect as discussed above. In flight, the added pathophysiological stresses consist of increased perfusion of the lung bases with overdistention of apical alveoli and the occurrence of basal atelectasis. This combined defect decreases the gas exchange membrane. Stress-induced increase in cardiac output leads to critical decrease in RBC transit time through alveolar capillaries, resultant decreased oxygen uptake by the RBCs, and eventually to hypoxemia. These added defects exaggerate the above-noted gas exchange defect.26

A significant increase in RV indicates trapped gas in the lung. There is most often associated significant airways obstruction,19 possibly only at the level of so-called small airways (≤2.0 mm in diameter). An increased RV means impaired intrapulmonary gas mixing and thus reduced capability for oxygenation of the blood.

OP: Persons with increased RV are at greater risk than normal persons for developing spontaneous pneumothorax due to the presence of either generalized emphysema or localized emphysematous bullae.10 Therefore, the finding is a disqualifying one.

A. FVC assessed with the subject sitting quietly is a reliable and reproducible measure of voluntarily controlled lung volume. Performance of this test gives insight into both restrictive and obstructive ventilatory defects.

OP: If the results are ≥80% of the predicted value, the subject is considered normal according to this parameter.

Airway hyperreactivity serves as a marker for the presence of occult/latent asthma20 or as a predictor for the development of clinical asthma.21,22 Moreover, persons with this defect are at greater risk of developing acute airways obstruction when exposed to irritants commonly encountered in the environment surrounding aircraft.

B. FEV1 at rest is a worldwide standard of reduced maximum flow in the large and midsized airways, and is the most commonly used indicator of the presence or absence of an obstructive ventilatory defect.

OP: If there is a reduction in the postexercise FEV1 of 90% may suggest a restrictive defect (Table 1, III-E-a).

C. In cases in which the FEV1 is normal at rest but airway hyperreactivity is suspected, comparison of the baseline FEV1 with the postexercise FEV1 is indicated.23

OP: If there is a reduction in the postexercise FEV1 of <9%, the test result is considered normal.23 If the reduction is >14%, the result is abnormal and disqualifying. A reduction between 9% and 14% indicates the need for further testing (β2-agonist inhalation and lung volume evaluation).

D. Added information is obtained from spirometry after inhalation of a β2-agonist bronchodilator (in our laboratory, metered dose inhaler salbutamol through a spacer).

OP: A percent change of baseline FEV1/β2-agonist FEV1 <9% is normal, >14% is abnormal and disqualifying. While 9% to 14% is equivocal and requires further testing25 (bronchial provocation test with methacholine).

E. FEV1/FVC ratio can signal restrictive or obstructive defects. A ratio >90% may suggest a restrictive defect (Table 1, III-E-a).

OP(s): The individual will be checked for lung volumes and undergo the diffusion capacity test for carbon monoxide.

In contrast, values <80% imply an obstructive ventilatory defect24 (Table 1, III-E-b).

OP: Need for exercise test and β2-agonist inhalation.

Values for FVC and FEV1 may be at opposite extremes of the normal range (ie, FVC high normal and FEV1 low normal), and thus produce a ratio that, by definition, is obstructive but may well not be a valid expression of the subject’s status. If, indeed, this occurs, other previously mentioned tests for the diagnosis of airways obstruction should be factored into the final diagnosis and decision. This obstructive index was also found in normal athletes, due to a discrepancy between large muscle mass and relatively normal bronchial size.27 Our study population is composed of a large number of highly physically fit individuals. Nevertheless, the general experience has been that most persons with this abnormality do prove to have airways obstruction.

F. Measurements of the midvolume maximal flow rate are useful indicators of airflow in the small airways.18 The presence of small airways obstruction identifies an obstructive defect caused by bronchiolitis in early life,28 obstructive bronchiectasis as the result of cigarette smoking,29-31 or more important in our milieu, latent asthma.32

OP: Further differentiation should be based on other indexes of the airways reactivity and several of the other clinical studies that are noted in the algorithm (Table 1, III-G).

G. The methacholine challenge test is the most sensitive indicator of airways hyperreactivity.

OP: If the FEV1 drops <15% after administration of a maximum concentration of 12.5 mg/mL methacholine,33,34 the test result is considered negative and airways hyperreactivity is not present. If the drop is ≥15%, the test result is positive for airways hyperreactivity.

We have chosen this value rather than 20% in order to increase the sensitivity of the test at the expense of specificity. This reflects the importance of excluding anyone with even latent airways obstruction from the stress of combat flight.

The predictive value of the methacholine test for subsequent development of asthma has not been clearly defined in an asymptomatic population. Hopp et al31 and O’Connor et al32 showed a significant predictor value to an abnormal methacholine test in an asymptomatic population. The experience of the Israel Air Force Medical Unit with this test (in an ongoing study) in over 100 asymptomatic cases with no atopy does not validate the hypothesis of an accelerated decline in pulmonary function (study and data gathering still in progress).

It has been suggested that there is greater risk of small airways obstruction in pilots of high-performance aircraft,35 but that work is flawed and emphasizes the need to study the relationship of small airways abnormalities to other environmental and occupational exposures.

Our suggested algorithm includes tests of gas exchange and imaging techniques. The significance and interpretation of these added studies are well established and need no further elaboration in this context.

Case Reports

The following section describes specific illustrative cases seen in the Air Force Medical Center, following the algorithm presented.

Case 1

An 18-year-old candidate for flight training examined at the IAFAC stated that he had had a single episode of acute shortness of breath with pain in his right shoulder approximately 5 1⁄2 years ago (Table 1, I-D-b). The symptoms resolved gradually over the following 36 h. He did not seek medical care at that time. The rest of his medical history was entirely negative. Results of physical examination were normal. Spontaneous pneumothorax was suspected. CXRs were normal. Chest CT and complete PFTs including lung volumes (Table 1, I-D-b-1) ruled out subpleural blebs, localized emphysematous areas, and airways obstruction. It
is known that with a disease-free interval of 5 years or more after a single episode of pneumothorax (albeit not proved in this case but strongly suspected), the likelihood of recurrence is low. A decision to recommend a waiver for flight training was made (Table 1, I-D-b-1-decision). This was based on several considerations: the low probability of recurrence, the fact that all assessments were normal, the fact that although suspected strongly, the episode was not a proved instance of pneumothorax, and the growing need of the system to find qualified pilot candidates. Clearly, if the suspicion had been verified at the time of the episode or if the episode had occurred within 5 years of the candidate’s examination or even if there were an excess number of candidates at the time, this candidate most likely would have been rejected even with normal CXR and PFT results. We wish to emphasize that the final decision in this borderline case could have been modified by an excess in the number of candidates.

Case 2

An asymptomatic candidate aged 17 years was normal on routine physical examination. Auscultation revealed no wheezing or prolonged expiration. Routine spirometry revealed an FEV1/FVC ratio of 71%. FVC and FEV1 were 120% and 104% of predicted value, respectively. The midflow rate was 59% of predicted value. According to the algorithm (Table 1, III-E-b-decision), spirometry carried out postexercise and after salbutamol inhalation was indicated: the results were normal (Table 1, III-C-a-1 and D-a-decision). Usually, at this point, a medical waiver is recommended; this candidate, however, was evaluated when the algorithm was first introduced and thus lung volumes and a methacholine challenge were performed (the results of which were normal—Table 1, III-G-1). The presence of nonreversible airways obstruction (fixed airways obstruction) was established, albeit without evidence of functional disability, and the candidate was recommended for flight training. Currently, >3 years after initial examination, the pilot is flying advanced-technology aircraft without any objective or subjective health problems.

Conclusions

The algorithm represents a practical and efficient approach for further large-scale screening of healthy candidates for flight training. The form of the algorithm is logical, the decision tracks are clear, and the tests required are easily obtainable and subject to quality control. It is our impression that the algorithm deals with the major pulmonary health problems encountered in a previously screened healthy population aged 17 to 25 years. We did not deal with chronic infections or granulomatous diseases because they will have been discovered by induction screening or their importance as modifying circumstances will have been determined by pulmonary consultants.

The algorithm has been in use for >5 years and has been applied to the screening of several thousand candidates. During this time, its usefulness was established and only minor modifications were required. Follow-up of the accepted candidates has not revealed any significant defects in the decision-making process.

Use of the algorithm is highly cost-effective since it allows for nonspecialist physicians to carry out pulmonary screening and involves the pulmonary specialist only infrequently, ie, when a particularly complicated and/or borderline case is encountered. The equipment required is not costly, maintenance is simple, and a technician’s capability is easily tested periodically. It is our contention that the utility of this algorithm for pilot screening is such that a similar algorithm would be useful in many other settings where large-scale screening is required. Modifications of content would be necessary, but the logic flow appears applicable in any medical setting and for any organ system. Moreover, the development and application of such an algorithm is compatible with the approaches reviewed by Woolf36 concerning practice guidelines.

An added benefit of using this algorithm is its potential in research in historical prospective analyses. Thus, the paired advantages of being able to accurately analyze a singular experience in an institutional setting and the collection of data for validation may be realized. Currently the staff of the IAFAC is taking full advantage of these two benefits derived from use of the described algorithm.

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