Pulmonary Function tests - Interpretation and application in clinical practice

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Week 4
Lecture 1

Essential Criteria for a Good Pulmonary Function Testing

I am Dr. Meenakshi, Professor and HOD of the Department of Respiratory Medicine, Chettinad Hospital and Research Institute. Today our topic of presentation will be essential criteria for a good pulmonary function testing. This is a pulmonary function machine, spirometry machine and this is the picture on the left shows a person doing the spirometry and the picture on the right shows the graphs. The top one is a flow volume curve and the bottom one shows the volume time curve. See, spirometry is the most common widely used technique for the assessment of lung function and it provides objective information used for diagnosis, monitoring, disability and impairment evaluations.

Since 2005, when the American Thoracic Society and the European Respiratory Society jointly adopted technical standards for conducting spirometry, improvements in instrumentation and computational capabilities have been consistently made and officially documented in 2021. Spirometry is a physiological test. What does it measure? It measures the maximal volume of air that an individual can inspire and expire with a maximal effort. What are the most relevant measurements we are going to discuss? One is the forced vital capacity that is volume delivered during an expiration made as forcefully and completely as possible starting from the full inspiration.

The next parameter is forced expiratory volume in one second which is the expiratory volume in the first second of a forced vital capacity maneuver. The primary signal measured in spirometry is either volume or flow as a function of time. So, today our objective is to understand the criteria for a good pulmonary function test so that we can utilize all these criteria. These criteria should be scrupulously followed to obtain a good pulmonary function testing. What are the criteria? There are criteria for lab that is a lab setting, there are criteria for the equipment, there are criteria for patients and there are criteria for the test.

Let us see what are the lab requisites. First and foremost is ambient temperature and barometric pressure should be stable. There should not be any fluctuation in the temperature or pressure. Then the time of the day should be recorded. Suppose patient is having suspected infection, this procedure can be postponed to the end of the day.

It should be done in a quiet and comfortable environment. Then other accessories like drinking water, tissues, adjustable chair and nose clips for the maneuver should be made available. The most important thing is hygiene and infection control because you will have to prevent cross contamination between patients, between the operator and the patient and contamination into the environment. So, a fresh mouthpiece is a must. Then hand sanitizer should be given to each new patient.

To avoid operator exposure and cross contamination, hands must be washed immediately after handling the mouthpieces, tubing, breathing valves and interior spirometer surfaces. It is preferred to use in-line filters which are disposable to prevent infection in transmission from one person to another. Then you will have to rule out transmissible infectious diseases to prevent equipment contamination. Then one line regarding bedside PFT. Suppose the patient is not able to attend the lab and is acutely ill, bedside PFT can be done.

That is testing the patients in their own rooms with adequate ventilation, but with appropriate protection for the operator. Then next coming to the criteria for equipment, equipment. See that is a quality assurance for the equipment. This current update is ISO 26782 2009 which was last reviewed in 2021. This spirometric equipment must have a maximum permissible error for accuracy and repeatability which is plus or minus 2.5 percent. For optimal quality control, both volume time and flow volume real time displays are required. Then coming to the calibration, this equipment should be calibrated. What is calibration? It is a process of verifying whether the accuracy of the sensor determine flow volume and the actual flow volume are almost equal. Regular calibration aids in accurate test results. You should recalibrate the spirometer whenever there is a failed calibration verification and also at intervals specified by the manufacturer.

See nowadays pre-calibrated spirometers are available, but that cannot be recalibrated by the operator, but must still undergo a calibration verification. Then this spirpmetry software must include the ability to generate a report of calibrations that includes the results of all verifications, the number of failed calibrations in each session and changes in the calibration factors. This is regarding equipment. Then the criteria for the patient. Coming to the criteria of patient, this following information should be included in the patient's record.

The patient's age, then height, height should be measured without shoes and weight should be recorded to obtain the BMI. If the patient is unable to stand, you can estimate the height by correct arm span equations. Then birth sex, that is gender, should be verified before interpretation. This is very, very important because all the predictive values are based upon gender, height, ethnicity and sex. So, ethnicity correction values should be available.

What do you understand by ethnicity? The patient may be belonging to different parts of the world like they may be black, they may be white people, they may be belonging to the

European or American or Asian. So, ethnicity correction values should be available because interpretation will be based on the correction values. These information should be correct as this has got a significant impact in the interpretation of the test. Then coming to the patients, what are the activities that should be avoided before lung function testing? To avoid acute bronchoconstriction due to smoke inhalation, smoking or vaping or water pipe use should be avoided within one hour before testing. Then to avoid problems in coordination, comprehension and physical ability, consuming intoxicants like alcohol because they may interfere with the performance of the test.

It should be avoided within eight hours before testing. Then to avoid potential exercise induced bronchoconstriction, performing vigorous exercise within one hour of the test should be avoided. To avoid external restrictions on lung function, wearing clothes that substantially restricts the full chest and abdominal expansion should be avoided. They should be advised to wear loose clothes. Then coming to the procedure, so test procedure depends on the preparing the patient, instruct and demonstrate the test and perform the manual.

How do you prepare the patient? As already told, you should have a hand sanitizer for the patient. Then confirm the patient identification as already told, age, birth, sex, ethnicity, etc. measure weight and height without shoes. And also you should ask about recent activities, any medication they are using, any relative contraindications. This is very, very important.

Any relative contraindications should be noted and you should also note the respiratory symptoms and other clinical symptoms you should be recording. Then after noting down all these details, you should instruct and demonstrate the test. You should instruct about the position of the mouthpiece and nose clip. Actually the mouthpiece should be around, should be sealed around the lip without any leak. The correct posture is the head is slightly elevated.

You should inspire rapidly until completely full, then expire with the maximal effort until completely empty, then inspire with the maximal effort until completely full. And the most important thing is confirm that the patient understands the instructions. Maybe it will be better preferred that this should be in the patient's own language and the patient is also willing to comply. Then performing the maneuver. See after having the patient assume the correct posture with a nose clip, the mouthpiece in mouth and closed lips around the mouth, ask the patient to breathe normally.

Then inspire completely and rapidly with a pass of less than 2 seconds at total lung capacity. Expire with the maximal effort until no air can be expelled while maintaining an upright posture. This is the expiratory loop. Expire with the maximal effort. This is the expiratory loop and this is the inspiratory loop.

Then after full expiration, inspire with the maximal effort until completely full. Repeat these instructions as necessary and coaching in between is very, very important. You should coach them vigorously because some patients may not be able to do the full maneuver properly. Then you should repeat the maneuver for a minimum of three maneuvers, but usually not more than eight for adults and not more than six for children. Then check FEV1 and FEC repeatability and perform more maneuvers as necessary.

See by maximal inspiration and peak expiratory flow. Actually, reduction in the peak expiratory flow on FEV1 has been shown and the inspiration is slow. Initial inspiration should be as rapid and as fast as possible. If the inspiration is slow, then there will be reduction in the peak expiratory flow and the forced expiratory volume in one second. Another thing is if there is a pass of 4 to 6 seconds at the total lung capacity before beginning expiration, then also there will be reduction in peak expiratory flow.

It is therefore important that the preceding inspiration, you cannot be seeing the preceding inspiration here because the curve starts with the expiration. So, if the preceding inspiration is being rapid and any pass at full inspiration should be minimal, it should be less than 2 seconds. Then hesitation time, that is the time from the point of maximal inspiration to the time 0. Time 0 is here from maximal inspiration and the patient starts to expire. So, that time should be 2 seconds or less.

Then this peak expiratory flow should be achieved with a short price and occur close to time 0. This is time 0 when he starts expiring, he should have a short price and it should occur close to the time 0 and the rise time from 10% to 90% of the peak flow should be less than 150 milliseconds. But in a patient with upper airway obstruction, this can be greater. Then first you inspire maximum inspiration, then expire, this is expiratory loop, then again you inspire to the full capacity, total lung capacity. So, this maximum inspiration after expiration, that is a measure of the forced inspiratory vital capacity, FIVC.

It is a maximal effort to return to the total lung capacity to complete the flow volume loop. Comparison of the forced inspiratory vital capacity and forced vital capacity that it provide a feedback to the operator on whether the patient began the forced expiration after from full inflation. If the maximal inspiration after the end of forced expiration, that is a maximal inspiration at the end of the forced expiration is greater than the forced vital capacity, then the difference between the forced inspiratory vital capacity and the forced vital capacity must be 100 ml or 5% of the forced vital capacity whichever is greater. Then coming to the acceptability. The spirometry actually criteria for the test is, it should be acceptable, it should be repeatable and reproducible.

Then it is in the latest 80s criteria they have said some of the criteria could be adjusted so that it can be usable in case of patients where they are not able to perform and in some clinical practice. So, there is acceptability criteria, reproducibility criteria that is

repeatability criteria and also usability criteria. When will you say the spirometry is acceptable? Before interpretation, the spirometry graph should be acceptable. When will you say the spirometry graph is acceptable? First let us go to the normal graph. So, this is the expiratory loop, this is the inspiratory loop.

See in a normal spirometric graph which is performed correctly there will be instant start of exhalation here this is a time 0 instantaneous start of the exhalation there is a rapid rise to the peak flow then there is a sharp peak occurring early in exhalation. Peak should be very early in exhalation. Then there is a smooth continuous fall in flow without interruptions then the gradual fall then there is a smooth continuous inhalation to the total lung capacity. So, this is a reproducible shape. Suppose this is another curve I will show you, see here instead of a instantaneous start of exhalation there is a very slow start.

Then there is a instead of a sharp rise in flow here there is a slow rise in flow here. Then instead of a sharp peak occurring early in exhalation this peak is occurring late in exhalation. Then here there is a smooth continuous fall without any interruptions, here there is a erratic flow can you see this erratic flow this could be because the patient has coughed or there is a vocal cord dysfunction or there may be a glottis closure. Then again incomplete inhalation see here inhalation is complete here inhalation is incomplete. Then one more thing is there that is good start should be there I told you good start should be there this back extrapolated extrapolated volume that is the volume of gas that has already been expired from the maximum lung volume to time 0 and is included in that this will be included in the FEV1 FVC measurements.

See this one is here I will show you here see this is the volume time curve this is also the volume time curve here it has been started at 0 the patient has started expiring at 0. Here even before 0 the patient has started expiring, so this is the back extrapolated volume. So, this one here this is a back extrapolated volume, so this should be less than 5 percent of the forced vital capacity or 100 ml. As I have told you so this should be free from all the artifacts that is cough during the first second of exhalation especially whenever you are measuring FEV1 there should not be any cough during the first second of exhalation. Then glottis closure early termination of early termination submaximal effort leak then there may be obstructed mouthpiece also obstructed mouthpiece then the values may not be correct.

Then this shows satisfactory exhalation, exhalation should be satisfactory that is expiratory time, the total expiratory time ideally it should be more than 15 seconds. Then expiratory plateau should be less than or equal to 25 ml in the last second of expiration the last second of expiration this expiratory plateau should be here this last second of expiration that plateau should be less than 25 ml. So, these are all the within maneuver acceptability criteria. Now, I told you one more thing going to the repeatability criteria actually whenever the patient is doing a spirometry, initially he may not be able to generate a good spirometric graph.

So, you can repeat the graph. So, how many times you can repeat, I have already told you minimum will be 3 acceptable graphs if the patient is not able to do then maximum will be 8 acceptable graphs 8 times he can repeat for children they can repeat up to 6 times. So, what is the criteria for a repeatability, when will you say that repeated graph is correct for interpretation see when children in adult aged more than 6 years the difference between the 2 largest forced vital capacity values must be less than 150 ml that is 0.150 liter for a repeatable to accept that as a that graph for interpretation. Similarly, the difference between the 2 largest forced expiratory volume in 1 second values must be less than 0.50 ml per children that is age less than 6 years the difference between the 2 largest forced vital capacity values must be 100 ml or 10 percent of the highest value whichever is greater and the difference between the 2 largest forced expiratory volume in 1 second must be less than 100 ml or 10 percent of the highest value whichever is greater this is very important for repeatability unless this criteria is there that graph cannot be accepted.

A short note on bronchodilator responsive testing what is bronchodilator responsive testing it is to determine the degree of improvement of air flow in response to the bronchodilator administration this is measured as changes in forced expiratory volume 1 and forced vital capacity. If the aim of the test is to determine whether the patient's pyrometric lung function can be improved with therapy in addition to their regular medication patient will be having a regular medication you want to add on some drugs some medications and you want to see the improvement then you need not withhold the bronchodilators. So, you can continue with their regular medications but if the test is used for diagnosis then you need to withhold the bronchodilators. So, how much time is needed to withhold, how long you should withhold the bronchodilators, see bronchodilator withholding times for SAMA that is short-acting beta agonist like albuterol or salbutamol withholding time is 4 to 6 hours you will have to withhold the medications for 4 to 6 hours. For SAMA that is short-acting muscarinic antagonist like ipratopium bromide you will have to withhold medications for 12 hours.

For long-acting broncho beta agonist you will have to like formoterol and salmeterol you will have to withhold for 24 hours. For ultra long-acting beta agonist like indacaterol, vilanterol or olodaterol you will have to withhold for 36 hours. Then for LAMAs that is long-acting muscarinic antagonist like tiotropium, umeclidinium, aclidinium or glycopyrronium withholding time is 36 to 48 hours. Then all these spirometric session the latest ATS guidelines here is ATS guidelines they say you can grade the quality of the session grade the quality of the spirometric session. So, how will you grade there are grading systems for forced expiratory volume in 1 second and forced vital capacity.

Grade A many will say this pyrometry is grade A see it depends on the number of measurements and repeatability. Repeatability for those more than 6 years and those less than 6 years. So, grade A is there are more than 3 acceptable graphs and the repeatability criteria is within 150 ml that is grade A for more than 6 years, for less than 6 years it is

within 100 ml. Then grade B grade B is 2 acceptable graphs are there then the repeatability criteria similarly within 150 ml for age more than 6 years and 100 ml for age less than 6 years. Grade C that is more than or equal to 2 acceptable graphs are there, but the repeatability is 200 ml.

See initially A and B within 100 ml 150 ml the repeatability criteria within the largest of the difference between largest FVC and largest FEV1 were 150 ml, but here in grade C it is 200 ml. For children less than 6 years it is 150 ml. Then grade D is more than 2 acceptable graphs are there, but again there in the repeatability criteria the difference between the two largest graphs will be 250 ml for age more than 6 years and 200 ml for children age less than 6 years. Grade E grade E is again 2 acceptable curves are there again the repeatability it is 250 ml or 1 acceptable curve is there if 1 acceptable curve is there it is not accepted. Then U is 0 acceptable curve and 1 usable curve is there F is 0 acceptable and 0 usable curve.

Then again finally going to acceptability and usability criteria. See usability criteria I told you that usability sometimes the curve may not be acceptable as we had said that for the curve to be acceptable it should not have any artifact all those factors are there, but still in case the patient is not able to perform or in certain clinical situations you can still use the curve. So, what are the criteria for acceptability and what are the criteria for usability. This is the same which I have told I will be again repeating the same the back extrapolated volume should be less than 5 percent of the forced vital capacity or 100 ml which is greater. So, this is a first criteria this should be there for acceptability and for usability this is required.

Then faulty zero flow setting that is also required for all acceptability and usability these criteria are separate for FEV1 and FVC that you should note. So, cough in the first second of expiration since FEV1 depends on the first second of expiration this criteria should be there for FEV1 measurement, but that is not needed for FVC in acceptability and also for usability this is not needed. No glottic closure in the first second of expiration yes because we are going to look at the values for the first second of expiration. So, for calculating FEV1 this is needed this is required for FVC also this is required similarly for usability also this is required. Must have no glottic closure after the first second of expiration.

So, once after the first second of expiration is needed for FEV1 because we are going to measure the measurements in the first second of expiration. So, that is not needed for acceptability, but for forced vital capacity that is needed, but for usability these two are not needed that is glottic closure after once even if glottic closure is there after one second of expiration you can use the curve to come to some conclusion. Then end of forced expiratory indicators whenever there is a end of forced expiration I told you that expiratory plateau should be less than 0.025 liters in the last one second of expiration. So, for FEV1 because

FEV1 is calculated in the first second that is not required for accepting in FEV1, but for FVC measurement that is needed, but for usability this is not needed for usability.

Then FVC expiratory time more than 15 seconds then FVC is within the repeatability tolerance of or is greater than the largest prior observed FVC. So, all these criteria that is these are called the end of forced expiratory indicators they are all needed for calculation of forced vital capacity, but not for calculation of FEV1, but for usable criteria these are not needed even these are present you can use the curve. Then must have no evidence of obstructed mouthpiece or spirometer yes that is required because there should not be any obstruction by of the mouthpiece. So, for acceptability criteria for FEV1 and FVC, but even there is obstruction you can use it for usability criteria is there you can utilize that curve to come to some conclusions. Leak must have no evidence of leak, leak is from the mouth around the mouth yes it is required for acceptability for forced volume 1 and then forced vital capacity, but that is not required for usability criteria.

If the maximum inspiration after the end of forced expression is greater than FVC, I told you then the difference that is the forced inspiratory vital capacity minus forced vital capacity must be less than 100 ml or 5 percent of the forced vital capacity whichever is greater. These criteria should be available for acceptability, but this is not required for usability. So, finally to conclude actually these criteria should be scrupulously followed. So, criteria there are criteria for lab, lab is a place where you do the test then there are criteria for the patient, there are criteria for the equipment, there are criteria for the test. So, all these criteria should be scrupulously followed to get a good pulmonary function testing.

Any PFT report should be verified with calibration details and background clinical details of the patient this is very very important all background clinical details of the patient should be there. Then acceptability of the PFT report should be verified. Then interpretation of pulmonary function abnormalities they should always be as per the existing guidelines and norms. These are my references I have taken the references from American Thoracic Society and European Respiratory Society technical statement. Then technical standards on interpretive strategies for routine lung function test 2021. Thank you.