SELF-ADMINISTERED CARDIOPULMONARY RESUSCITATION BY COUGH-INDUCED CARDIAC COMPRESSION

By J. MICHAEL CRILEY, M.D., AND (BY INVITATION) ARNOLD H. BLAUFUSS, M.D. AND GRAY L. KISSEL, M.D.

TORRANCE

Ventricular fibrillation is the most common form of sudden cardiac arrest and death. If it is treated promptly, this otherwise fatal rhythm disturbance can be safely and effectively reversed. Unfortunately, most episodes of apparent ventricular fibrillation are not immediately witnessed by trained personnel, and the outcome is usually fatal.

When ventricular fibrillation occurs in the cardiac catheterization laboratory, either with manipulation of the catheter or following injection of contrast medium in heart or coronary arteries, the rhythm disturbance is usually recognized immediately, and through application of external cardiac massage and electrical defibrillation,[1] the vast majority of these patients recover completely.

In the past 4 years, 8 episodes of ventricular fibrillation were observed and recorded during the performance of coronary arteriography in the cardiac catheterization laboratory at Harbor General Hospital. It was noted in 3 of these patients that forceful, abrupt, rhythmic coughing constituted a form of "cardiac massage," and sustained consciousness until a defibrillating shock could be delivered. This cough-induced cardiopulmonary resuscitation has several potential advantages over external chest compression CPR in the catheterization laboratory setting, and may be applicable to other situations where arrhythmias are detected before loss of consciousness occurs.

Methods and Procedures

Coronary arteriography was performed utilizing percutaneous transfemoral techniques with preformed catheters.[2] Constant electrocardio-

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From the Departments of Medicine and Radiological Sciences, the University of California, Los Angeles School of Medicine, Harbor General Hospital Campus, Torrance, California.

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Requests for reprints may be sent to: J. Michael Criley, M.D., Chief, Division of Cardiology, Harbor General Hospital, 1000 Carson Street, Torrance, California.

graphic and catheter tip pressure monitoring was employed throughout the performance of the procedure. During the manual injections of contrast medium (76% Meglumine & Na Diatrizoate, 5 to 8 ml in 2-3 seconds), catheter tip pressure was momentarily discontinued, but resumed immediately upon completion of the injection. The patient was instructed to cough several times immediately after completion of each injection, as suggested by Sones,[3] particularly if bradycardia or hypotension resulted from the contrast injection.

In instances where ventricular fibrillation occurred, usually within a few seconds after completion of the injection, 1-3 external d.c. countershocks were delivered to restore a supraventricular rhythm.

Since the patients developing fibrillation were suspended in a rotary angiographic cradle, and encumbered by straps, sterile drapes, and angiographic apparatus, variable delays in initiating defibrillation were frequently encountered, and external chest compression (closed chest cardiac massage)[1] was employed for 21-45 seconds.

Patients who were able to continue to cough after the onset of ventricular fibrillation, were encouraged to cough forcefully every 1-3 seconds until the defibrillator could be brought into position.

In all cases, continuous recordings of electrocardiogram and arterial pressure were made from the initiation of angiographic injection until normal rhythm and pressure were restored.

Results

All patients converted to sinus rhythm or a life-sustaining supraventricular rhythm, and all survived to leave the hospital.

The mean systolic aortic pressure response to external cardiac massage (Table 1) was 60.7 $\pm$ 5.1 in the 7 patients in whom this technique was employed, possibly reflecting a less than optimal chest compression because of the oblique position of the patient and the padded rotating cradle. Two patients sustained rib fractures and had persistent pain and disability.

In contrast, the mean systolic aortic pressure response to cough (Figure 1, Table I) was significantly higher (139.7 $\pm$ 3.8, p. $<$ .001) than to external cardiac massage even in the same individuals. The patients who continued to cough effectively were encouraged to do so until the defibrillator could be activated, resulting in periods of cough-sustained consciousness of 24, 29, and 39 seconds. No attempt was made to prolong the period between onset of fibrillation and delivery of countershock because the desirability of defibrillating as soon as possible. It appeared as if each patient could have continued to cough for a longer period if

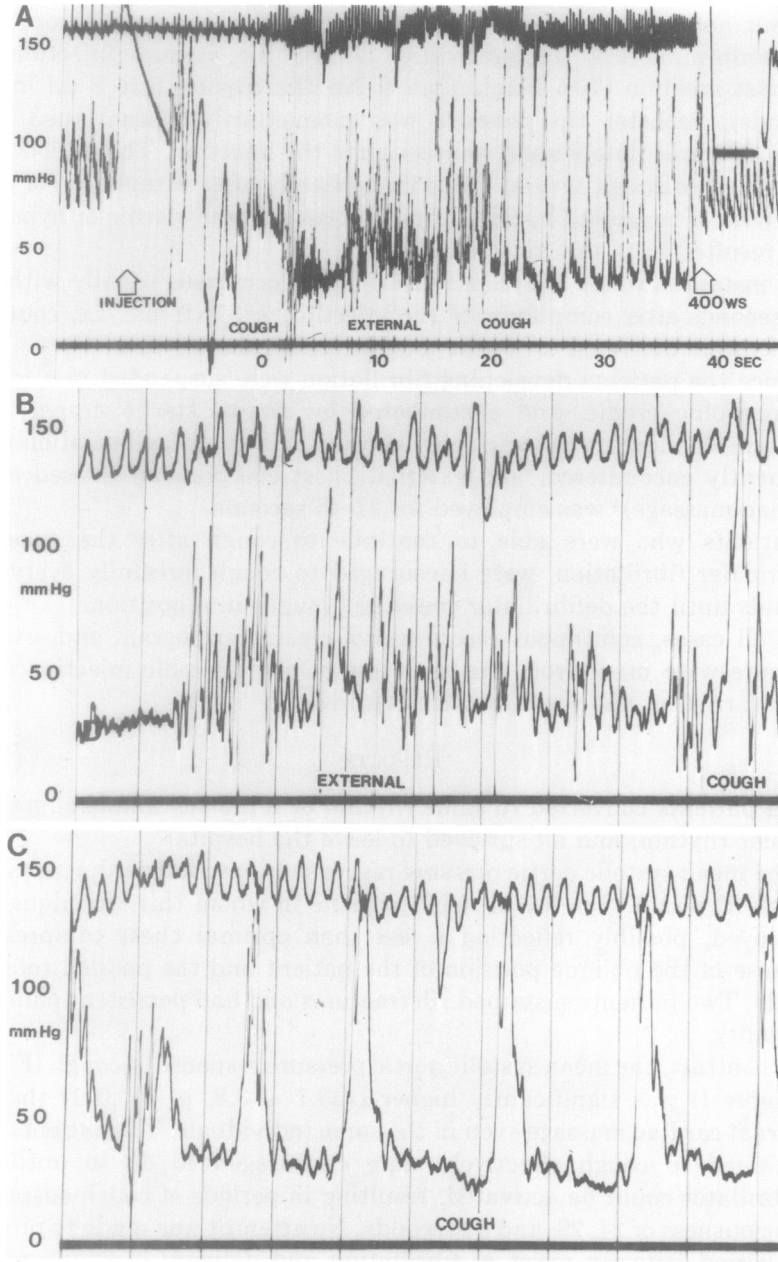

FIG. 1. Electrocardiogram and aortic pressure in patient H.B., a 45 year old white male with diffuse coronary artery disease and 3 saphenous vein bypass grafts. A right coronary

TABLE 1

A Comparison of Cough Induced Cardiac Compression and External Cardiac Massage in Patients Developing Ventricular Fibrillation During Coronary Arteriographic Studies

Patient	Age	Sex	Diagnosis	Duration of Ventricular Fibrillation	Average Peak Aortic Pressure During Cough Induced Compression	Average Peak Aortic Pressure External Massage
			Cough Induced Cardiac Compression			
D.S.	50	M	Postop. CAD and RHD with prosthetic aortic valve and mitral disease	24 sec.	133 mm Hg	—
M.C.	45	M	Postop. CAD	29	146	75 mm Hg
H.B.	45	M	Postop. CAD	39	140	73
			External Cardiac Massage			
M.S.	45	F	Chest pain with normal coronary arteriogram	34	—	42
M.B.	56	F	RHD with mitral stenosis	21	—	55
S.B.	75	F	Prinzmetal's variant angina	28	—	73
B.O.	49	F	Chest pain with normal coronary arteriogram	30	—	60
S.P.	56	M	Cardiomyopathy	45	—	47
	Mean ± S.E.			31.3 ± 2.8	139.7 ± 3.8	60.7 ± 5.1 ($p < .001$)

Abbreviations: Postop. CAD = postoperative coronary artery disease with saphenous vein bypass graft, RHD = rheumatic heart disease.

artery injection was followed by the onset of ventricular fibrillation. *A*. Compressed record of the coronary arterial injection, onset of ventricular fibrillation (at time 0), followed by external massage, cough-induced cardiac compression, and defibrillation with 400 Watt-Seconds countershock. *B*. Expanded record demonstrating ventricular fibrillation with poor aortic pressure response to external massage, and onset of cough-induced cardiac massage. *C*. Expanded record demonstrating ventricular fibrillation and improved aortic pressure response to cough-induced massage. The patient remained conscious and alert for 39 seconds after the onset of ventricular fibrillation. (Time lines = 1 second.)

necessary, since all 4 were able to respond to the command to cough, and had no diminution in the forces of the cough over the periods of time observed.

Discussion

A cough is produced by closing the glottis, followed by a strong contraction of the respiratory muscles (diaphram and intercostal muscles) which rapidly increases the intrathoracic pressure, which results in the explosive discharge of airway contents when the glottis is re-opened. Since the heart is within the thoracic cavity, it is subjected to the same rapid rise in pressure as the lungs, and it is postulated that this compressive force propels blood forward because of the presence of valves in the heart. Although all cardiac chambers and great vessels are subjected to this rapid increase and release of pressure during cough, the presence of a competent aortic valve and peripheral vascular tone maintain a higher pressure in the aorta between coughs (Figure 2). Conventional external cardiac massage also causes the atrial pressure to rise to a more-or-less equal degree to the aortic pressure during compression.[4]

The presence of arterial pulse waves does not necessarily prove that blood is being propelled forward, and admittedly there was no attempt to measure cardiac output during ventricular fibrillation in these cases. However, the maintenance of a conscious state for periods up to 39 seconds after the onset of ventricular fibrillation suggests that adequate cerebral blood flow was maintained.

There are several potential advantages in cough-induced cardiac compression, as compared to external massage, in situations where it can be successfully employed: 1) It is self-performed, and therefore permits laboratory personnel to turn their full attention to preparing and using the defibrillator; 2) Because a breath is taken between each cough, cardio-*pulmonary* resuscitation is delivered; 3) The hazards of rib or sternal fracture, and dislodgement or damage to a prosthetic valve or adjacent myocardium[5-10] are avoided; 4) It can be performed by the patient in any position and on any surface, and does not require a firm surface as does effective external chest compression.

There are limitations to the usefulness of cough-induced cardiac compression: 1) Certain individuals cannot perform an adequate cough or have long paroxysms of coughing which is ineffective; 2) Some anatomical abnormalities may preclude adequate cough, for example extreme obesity and umbilical hernia; 3) Unless coughing is initiated before or immediately after the onset of fibrillation, unconsciousness will occur.

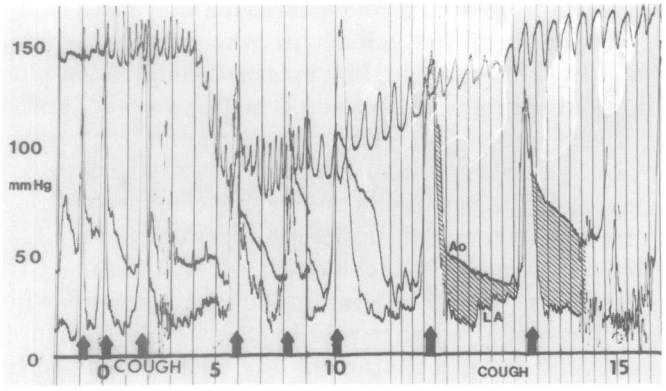

FIG. 2. Electrocardiogram, aortic (Ao) and left atrial (LA) pressure in D.S., a 50 year old male with diffuse coronary artery disease, an occluded saphenous vein bypass graft, prosthetic aortic valve, and mixed mitral valve disease. Following coronary arteriographic injection in the right coronary artery (not shown) the patient was asked to cough 3 times. Ventricular fibrillation occurred between the second and third cough, and because of a good pressure response and the patient's state of maintained consciousness, he was asked to cough every few seconds until a defibrillating shock was delivered 24 seconds later (not shown). The aortic and left atrial pressure rose to 130–150 mm Hg with each cough but the aortic pressure remained higher (shaded area) during relaxation between coughs due to the competent (prosthetic) aortic valve and the peripheral vascular resistance. The recorder speed was increased from 10 to 25 mm/sec. 10 seconds after the onset of ventricular fibrillation. (Time lines on left = 1 sec., on right = 0.2 seconds.)

In addition to its usefulness in ventricular fibrillation, cough-induced cardiac compression has been documented to sustain consciousness during prolonged asystole either by inducing ventricular depolarization comparable to a "chest thump," or by expressing blood from the arrested heart without depolarization.

Although the current cases of cough-induced cardiac compression occurred in a catheterization laboratory, the technique may also be useful in a Cardiac Care Unit (CCU) where the mattress on the bed renders external chest compression ineffective. Unfortunately, it is unusual for the patient to recognize that he is losing consciousness when ventricular fibrillation begins, otherwise the technique might permit a lone fibrillating patient to maintain consciousness while seeking assistance.

SUMMARY AND CONCLUSIONS

Repeated rhythmic (every 1–3 sec.) coughs were documented to maintain consciousness up to 39 seconds in 3 patients developing ventricular fibrillation during coronary arteriography. The arterial

pressure wave resulting from a cough exceeded that induced by external chest compression in 2 individuals in whom both techniques were employed and in 5 others treated by external compression alone.

Cough-induced cardiac compression is self-performed, and compared to external chest compression is less likely to traumatize the chest wall or heart and can be performed in any position on any surface.

It is recommended that patients undergoing coronary arteriography be previously trained to cough abruptly and repeatedly every 1–3 seconds. The potential for utilizing this technique in other areas (i.e., CCU, home) is less favorable than in catheterization-induced ventricular fibrillation, but it might be employed successfully in patients with premonitory symptoms of ventricular arrhythmias or Stokes-Adams seizures. The prior training of high risk individuals (and their spouses) to induce effective coughing in the victim might be lifesaving.

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DISCUSSION

DR. ROBERT WHALEN (Durham): I think this is a beautiful example of looking at a classic clinical observation in a laboratory and demonstrating the underlying physiology behind

the observation. I would like to share with you Dr. Sones' perhaps less erudite explanation which he gave me to explain the reason why he made patients cough after an injection of contrast media. I think Mike may know the story well since both he and I spent time with Dr. Sones in his laboratory. When I went there years ago to observe Dr. Sones' technique he would always say to the patient, "Now cough, cough, cough," after he finished each injection into a coronary artery. After watching about seven or eight cases in a day and hearing Dr. Sones repeatedly command the patient to cough I could not understand why he used this procedure.

He said his decision to have patients cough stemmed from an experience he had had many years ago when he was working with a new piece of x-ray equipment that required the patient to be on one floor and the x-ray equipment, as well as the viewing mirror, to be on a level one floor below the patient. The catheters would be placed in the appropriate cardiac chambers and then Dr. Sones would climb down a stairway or ladder to the lower level to activate the x-ray equipment and observe the injection. One day after placing a catheter in the left ventricle and activating the injector he observed the catheter pop from the left ventricle into the aortic root and then into the left coronary artery, eventually delivering a large amount of contrast media directly into the left anterior descending coronary artery. He was horrified to see the bolus of dye injected directly into the coronary artery and rushed up the stairway to observe the patient's response. When he arrived on the second level, to his surprise the only thing that seemed to be happening was that the patient was coughing and there had been no untoward physiologic effect. Dr. Sones told me that, from that experience, he decided that coughing must have done something to protect this man from the deleterious effects of injecting contrast media directly into a coronary artery so from that time on he would have all of his patients cough immediately after injection into the coronary artery.

DR. IRVING WRIGHT (New York): I can see the great advantage of this approach when the patient is securely attached to all of your equipment. The question I now ask is as follows: with your new experience and full knowledge of the disadvantages of the usual procedures used for resuscitation, assuming that the patient is free and clear of all impedimenta, which method would you elect to use first, the former more or less standard anterior compression of the chest, forcing the patient to breath but possibly fracturing a few ribs or the more gentle cough technic without the fractured ribs? Which do you start with now?

DR. CRILEY: If we have a conscious patient, we ask him to cough, and if he coughs well and maintains consciousness, we then turn our full attention to getting a defibrillator ready, or getting the electrocardiogram on the screen and find out what is going on. I didn't have time to mention, but it will come out in the manuscript, that we have a significant number of rib fractures in the patients that we did external compression and CPR on. The cough patients had no complications.

DR. ARNOLD WEISSLER (Detroit): I want to congratulate Mike on a very interesting presentation. I guess we can now call the maneuver cough desyncope. Perhaps the external artificial heart we have been looking for is really in the chest and I wonder whether we might consider using the diaphragm or the thoracic wall to sustain the circulation in patients with prolonged hypotension in shock states. Perhaps if we could stimulate the diaphragm externally or through the mechanism of cough, we could actually sustain circulation for prolonged periods of time without depending on the patient's central nervous system to do this.

DR. CRILEY: I believe there have been some experimental attempts at wrapping slings of diaphragmatic muscles around the heart and stimulating it in an attempt to get an internal cardiac assist.

DR. STUART BONDURANT, JR. (Albany): May I be permitted to comment on the last question, Mike and Mr. President. There have been estimates of the maximum energy that

could be generated by using all the respiratory muscle and the diaphragm as well. And it is true that you can generate enough energy to sustain the circulation for a short period of time, but the mechanical disadvantage of these muscles, as well as the mass of the muscles, suggests that they would have to be hypertrophied significantly in order to sustain arterial pressure levels over a long period of time. So, it looks like it is not going to work indefinitely. I do think this is a delightful contribution and observation that you have made, and I wonder if we should be bold enough to tamper with nature a little bit in view of the fact that the primordial purpose of the cough rests on a little different basis in the sense that it is to create a very high flow rate over short periods of time. To sustain the circulation, one wants to produce a volume change by virtue of the cardiac compression, and this takes more time. The cough is a great way of producing a peak pressure over a very short period of time. I was wondering if one could obtain more effective cardiac compression by modifying the duration that pressure is maintained as well as the height of the pressure. For example, is a long cough more effective than a short one. Have you have been able to notice any difference in the pattern of cough in different people as a determinant of the effectiveness with which the maneuver can maintain the circulation?

DR. CRILEY: I think your comments are appropriate. In regard to hypertrophy of the respiratory muscles, it is of interest that all three of the patients were post-operative patients, and as anybody knows who has been visiting a post-operative thoracic surgical unit, there are some very masochistic nurses who go around and make these people cough. Despite pain and discomfort and everything else, they are taught to cough on demand and they cough very effectively or else something is done to them, like a long tube goes down their throat and tickles them until they do cough. They get to be very good coughers. It may very well be that the secret of their success was the fact that they were post-operative patients and had been taught to cough. But is has worked in areas out of the catheterization laboratory where the effects on pressure have not been as well documented so I did not show them today. I think it could be kept up for some length of time, and I hope that any of us who arrests at home that it at least gets us to the telephone, allows us to call a doctor and we hope that the doctor doesn't come and give us cough medicine.

DR. FRANCIS WOOD (Philadelphia): It just occurred to me while listening to this most interesting, delightful and useful paper that there is another maneuver that people could make. It may even produce more intrathoracic pressure, and that is a sneeze. And it might also be able to be produced in a person who actually partly lost consciousness and could not cough. Have you tried that at all?

DR. CRILEY: That's a very astute observation, Dr. Wood. There was a patient who went into prolonged asystole and did sneeze and got effective pressures, much better pressure than from a cough, as you point out. Whether you can sneeze on command or whether we should give snuff, remains to be seen.

DR. VERNON KNIGHT (Houston): I wanted to ask if there is a possibility that you could supplement the coughing with chest pressure, perhaps not at the rib-breaking level, but I would think you could coordinate and you might top off the pressure that way.

DR. CRILEY: That is a good thought that we have not tried.