EVALUATION OF CARDIOPULMONARY RESUSCITATION TECHNIQUES IN MICROGRAVITY

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PURPOSE:

To investigate cardiopulmonary resuscitation (CPR) techniques in microgravity with specific application to planned medical capabilities for Space Station Freedom (SSF.)

OBJECTIVES:

- Evaluate CPR using the variety of techniques that have been envisioned as possible aboard SSF, including utilizing the medical restraint system (MRS), a flat surface, and free-floating.
- Compare the effectiveness of the studied techniques in both subjective and measureable ways.
- Provide additional information on interfaces and requirements that will assist in current planning and design of medical equipment and facilities for SSF.
- Specifically evaluate the use of a cardiac compression assist device (CCAD) as a means of increasing crew mechanical efficiency in 0-G and as a way to reduce fatigue while performing CPR.
- Begin to establish operational protocols for the performance of basic life support aboard SSF.

OVERVIEW:

A KC-135 parabolic flight test was performed on May 4, 1990 with the goal of evaluating and quantifying the efficacy of different types of microgravity CPR techniques. The flight followed the standard 40 parabola profile with 20-25 seconds of near-zero gravity in each parabola. Three experimenters were involved in the study. Each one was chosen for their clinical background, certification and practical experience in basic and advanced life support, and their experience in prior KC-135 parabolic flight.

The CPR evaluation was performed using a standard training mannequin (recording resusci-Annie) which was used in practice prior to the actual flight. Aboard the KC-135, the prototype medical restraint system (MRS) for the SSF Health Maintenance Facility (HMF) was used for part of the study. Standard patient and crew restraints were used for interface with the MRS. During the portion of the study where CPR was performed without the MRS, a set of straps for crew restraint similar to those currently employed for the Space Shuttle program were used. The entire study was recorded via still camera and video.

The sequence for the study was as follows:

- 1-gravity (1-G) one-man and two-man CPR using MRS aboard KC-135 to establish baseline.
- 0-G one-man and two-man CPR using MRS in traditional method.
- 0-G two-man CPR using patient straddle technique
- 0-G two-man CPR using MRS with cardiac compression assist device (CCAD) prototype.
- 1-G one-man and two-man CPR using the KC-135 floor (without MRS) to establish baseline.
- 0-G one-man and two-man CPR using KC-135 floor and variety of restraint positions (lateral and patient straddle).
- 0-G one-man and two-man CPR during free float (using Heimlich-type technique.)

The major conclusions resulting from the study include:

- A reaffirming of the fatiguing nature of performing CPR in 0-G and of the difficulting in attempting CPR without adequate patient and rescuer restraint.
- With proper training, restraints and experience (including 0-G) it appears possible to provide adequate CPR using a variety of techniques and positions.
- A properly designed CCAD could have a definite role in improving the rescuer's ability to provide effective CPR in 0-G especially over extended periods of time.

BACKGROUND:

The possibility of sudden cardiac death aboard Space Station Freedom, although remote, should be considered and prepared for as much as reasonable resources will allow. With the initiation of prolonged stays in microgravity it is anticipated that there will be some degree of fluid and electrolyte changes and cardiovascular deconditioning in the crew. Coupled with the chance of trauma, burns or decompression sickness, the risk of a significant cardiac insult or arrythmia becomes one that warrants preparation.

Historically through the current Space Shuttle program, the degree of emergency cardiac care available consisted of Basic Life Support (BLS). BLS either (1) prevents circulatory or respiratory arrest through prompt intervention and early entry into higher levels of medical care or (2) externally supports the circulation and breathing of a victim of cardiac and/or respiratory arrest through CPR. CPR that is performed properly and promptly can give victims the time to receive treatment by advanced medical techniques. With the SSF HMF, for the first time in the US space program, resources are being planned that will provide the capabilities to carry on from BLS into advanced life support (ALS).

To maximize chances of survival, the delay from onset of cardiac arrest until CPR and definitive care should be kept as short as possible, ideally to less than 4 and 8 minutes, respectively. The outcome for cardiac arrest, whether or not CPR has been applied, is dismal if ALS is delayed beyond 8 minutes. CPR should be initiated only when a defibrillator is not immediately at hand or after initial shocks have failed to restore spontaneous circulation.

The Space Shuttle program currently employs a system for performing CPR that has been tested on manikins aboard KC-135 by physicians and physician-astronauts. (No formal documentation of this testing is available other than video tapes of the flights.) This system has also been evaluated informally during actual Shuttle flight. The Shuttle CPR system consists of a standard anesthesia breathing mask attached to a pressurized oxygen system that will initiate air flow with a simple trigger mechanism. It requires that mannual airway positioning be accomplished with each breath. The actual performance of external cardiac compression is assisted through use of straps to secure the patient to a flat surface and an adjustable waist harness to secure the rescuer in close proximity to the patient. As with all restraint mechanisms, time is required to utilize them properly and is dependent upon operator familiarity.

Concerns reported about the Shuttle CPR system focus around the rapidly fatiguing nature of the system, the awkwardness of the rescuer positioning, and the lack of any advanced life support resources to follow-up with.

The SSF Health Maintenance Facility is currently planned to include portable monitoring, defibrillation, external cardiac pacing, IV fluids and medications consistent with American Heart Association Advanced Cardiac Life Support (ACLS) standards. Resources will also be provided for airway stabilization, intubation and mechanical ventilation.

With these advanced medical resources available, it is more imperative than ever that the techniques and protocols for adequate CPR in microgravity be established in order to lay the foundation for effective ACLS should ever the need arise.

MATERIALS:

- Recording Resusci-Annie (standard CPR mannequin)
- Medical Restraint System for SSF HMF (prototype)
- Cardiac Compression Assist Device (CCAD) (prototype)
- Straps for mannequin and rescuer restraint
- Photography and other recording materials

PERSONNEL AND SUPPORT:

- 3 investigators and 1 recorder

- Video recording performed by recorder, still photography performed by non-dedicated NASA photographer.

TEST PROTOCOL:

All procedures were performed first in the HMF ground lab for familiarization.

CPR using the MRS
Mannequin is strapped to the flat MRS in a supine position with the MRS positioned at just below waist height for the operators. Operators are initially restrained using foot loops attached to the floor grid and with waist restraint straps attached to the edge of the MRS.

- *MRS CPR in 1-G*
  Prior to the 0-G parabolas, one and two-man CPR is performed and recorded to establish baseline measurements.

- *MRS CPR in 0-G*
  With operator positioned at side of mannequin in the tradional CPR location, perform one-man CPR. Second operator joins and performs respirations while first operator continues chest compressions. (Each operator has opportunity to try various skills.)

- *Straddle MRS CPR in 0-G*
  With mannequin still strapped to MRS, operator approaches MRS without using restraints and positions himself by straddling MRS at the manikin's thighs and by holding on to the edge with one hand at the level of the manikin's sternum. Chest compressions are performed by applying pressure with the single free hand in proper sternum position (using the restraining hand for leverage.)

CPR with CCAD
With mannequin still strapped to MRS, attach prototype CCAD to edge of MRS at right of manikin's sternum. One operator continues ventilation while second operator uses lever system of CCAD to perform external cardiac compression.

CPR using floor of KC-135
Strap mannequin to floor of KC-135 and perform CPR using a variety of

positions and restraint techniques.

- *Floor CPR in 1-G* — perform one and two-man CPR during 1-G portion of flight to establish baseline measurements.

- *Floor CPR in 0-G in side position* — perform one and two-man CPR with the chest compressions given from the side of the mannequin using waist harness restraints similar to the current Shuttle system.

- *Floor CPR in 0-G in straddle position* — perform two-man CPR with chest compressions performed by the operator straddling the mannikins thighs. Attempt to find best restraint arrangement. Compare two-handed to one-handed chest compressions.

CPR Free-Floating
loosely restrain one of the operators to the floor of the KC-135 and allow that operator to manually maintain control of the free-floating mannequin.

- *One-man CPR Free-Floating*.position the mannequin as if performing a Heimlich maneuver but position the hands properly to perform external cardiac compressions. In proper sequence with the compressions ventilate the patient by acquiring control of the head/neck and airway, then return to chest compressions.

- *Two-man CPR Free-Floating* - with the first operator and mannequin positioned as before, have the second operator assist by giving the respirations while unrestrained.

RESULTS:

1. MRS CPR in 1-G (Fig. 1 and Fig. 2) – As in the ground lab, effective CPR using the MRS was fairly simple and straight forward. No difficulties or complications occurred in 1-G aboard the KC-135 as opposed to in the ground lab.

2. MRS CPR in 0-G (Fig. 3, Fig. 4 and Photo 1) – Effective CPR was accomplished using the MRS with the standard technique. Since the operators required restraint to the MRS, there was increase time delay in changing from chest compression to ventilation during the one-man effort. Since body weight was not a factor in delivering the cardiac compressions, it was necessary to lower the MRS to a height equal to mid-thigh to obtain the most efficient leverage for cardiac compresssion.

(In 1-G much of the force for cardiac compression comes from the rescuer's body weight. Therefore, with no gravity and no body weight, all the force must be delivered through use of the rescuer's muscles. With the table lowered, the leverage and the the larger muscles of the abdomen and thighs could be used to assist in delivering compressions, as opposed to relying solely on the arm and shoulder muscles with the MRS at the standard height.)

3. **Straddle MRS CPR in 0-G** (Fig. 5, Fig. 6 and photo 2) – The straddle technique proved to be quite effective in delivering rapid and reliable cardiac compressions. By grasping the edge of the MRS with one hand, the rescuer could use his complete upper body as a fulcrum to deliver compressions through the other hand (keeping the arm locked in a fully-extended position.) Hand position over the sternum did not appear to be a problem.

4. **CPR with CCAD** (Fig.s 7,8,9 and photo's 3 and 4) – It was readily noticed in the previous techniques that the rescuer performing chest compressions became fatigued quite rapidly due to having to rely solely on muscle strength and endurance (in the absence of gravity.) It was also noticed that having to be restrained next to the mannequin to perform standard two-handed chest compressions made it difficult to perform the alternating compressions and ventilation in one-man CPR (although not impossible.) The CCAD prototype made it possible to perform the cardiac compressions while using only one hand. This leverage system not only reduced fatigue and made it more likely that CPR could be continued for prolonged effort by the same individual, but if freed up the rescuer's other hand to perform airway stabilization and ventilation using a bag-mask system.

   The difficulties encountered with the CCAD prototype centered mainly on the awkwardness of maintaining the pad's contact with the manikin's chest. This resulted in the need to frequently reposition the lever pad to maintain proper sternum alignment. In the absence of gravity, the pad tended to float free from the chest between compressions unless the operator maintained a certain amount of sternal pressure with it throughout the cycle. In doing so, the recordings indicated that there was not always complete relaxation of the thoracic pressure in between compressions.

   The bouncing nature of the CCAD also tended to move the mannequin around on the MRS even with the restraining straps. The movement was not a lot, but it was enough to require the operator giving ventilations to reposition the head/neck and airway frequently.

- *Floor CPR in 1-G* (Fig. 10 and 11) – There was no difficulty performing standard CPR in 1-G with the mannequin strapped to the floor of the KC-135.

- *Floor CPR in 0-G in side position* (Fig 13, 15 and photo 5) – It was possible to perform adequate CPR on the floor in the standard position using the shuttle strap system. However, this proved to be the most fatiguing of all the techniques. It was difficult to find the best alignment of the straps to enable efficient leverage and use of the body muscles. It was also quite hard on the knees.

- *Floor CPR in 0-G in straddle position* (Fig 12, 14 and photos 6-10) – A variety of techniques were attempted using different angles and combinations of restraints. Most efficient was placing a restraint strap across the calves in addition to the waist straps (photo 6) but this took longer to set up. Using one hand as restraint and one hand for compression was also effective and less fatiguing (photo 7 and 8). Overall this method was fairly equivalent to the floor-side technique, was more tiring than others, and the exact technique of preference varied between the different operators.

- *One-Man CPR Free Floating* (Fig 16 and 17, Photo 11 and 12) – Once the hand positioning was established this method proved to be equally effective as standard techniques. It required a greater amount of physical effort but was less fatiguing in other ways (less strain on the back and hamstrings.) Control of the unrestrained mannequin was achieved without great difficulty, and as long as contact was maintained, it was simple to establish head/neck and airway control for delivery of ventilations. Giving ventilation this way created minimal stability of the neck and clearly would be inappropriate for any patient with possible head or neck injury.

- *Two-Man CPR Free-Floating* (Fig 18, Photo 13 and 14) – With one operator controlling the patient and giving chest compressions, the second operator was able to assist with adequate ventilations. Some team work and coordination was required, but within a few practice sessions this method was accomlished with good efficiency. Less strain on the patients neck was delivered with the two-man method because the first operator always provided a stable support of the mannequin with his own body as a stabilizing surface.

DISCUSSION:

The key concerns in providing effective CPR are those of quick response and adequate technique. Both of these issues are especially challenging in the zero-gravity environment. First of all, it is imperative to stabilize the patient to establish an airway and restrain him or her against a firm surface in order to administer cardiac compressions. To accomplish these tasks in a rapid manner the SSF crew will have to be very familiar with CPR principles and acquainted with optional methods that can be adapted to the variety of locations and situations that might occur aboard Space Station Freedom. This study has shown that all of the methods tested were able to produce effective results on the mannequin, especially after brief practice and orientation to the new positions. It is conceivable that several of these methods might be employed in any given scenario as the situation progresses from initial discovery of the victim, to provision of restraints, throughrelocation to the MRS at the Health Maintenance Facility. Therefore it seems prudent to include a variety of methods in crew training to allow for greater flexibility in emergency response.

In the majority of the medical studies done on the KC-135 it has become abundantly clear that the need for adequate and adaptable restraint for both the patient and medical officer(s) is a priority. This point holds true for administration of CPR as well. However, this study demonstrated that it appears feasible to perform CPR for limited periods while free-floating using a Heimlich-type position for patient stabilization and cardiac compressions. This situation may be encountered during initial contact with the victim while awaiting provision of restraints or relocation to the HMF.

One other significant concern revisited in this study is that of operator fatigue while performing CPR. Fatigue is reached quite rapdily in 0-G due to the lack of weight for force and due to the sole reliance on muscle strength. All of the operators tired in a matter of a few minutes, and this occurred in fit individuals who have not been deconditioned due to prolonged spaceflight. With the provision of ACLS resources on SSF, it is critical to be able to support the patient with CPR for prolonged periods while the advanced techniques have time to create effect. Therefore it was interesting to see the possible uses of a prototype Cardiac Compression Assist Device. The concept of a CCAD appeared to be very valuable in increasing the mechanical efficiency of cardiac compressions, thereby reducing fatigue. A secondary benefit was realized of leaving one hand free that could be used to administer ventilation with the bag/mask, thus freeing up the second crewmember for other medical tasks. There were some problems with the prototype used especially in maintaining adequate contact and position with the patient's sternum. These issues would benefit from further investigation.

Overall this evaluation of cardiopulmonary resuscitation techniques in microgravity reaffirmed the concerns about operator fatigue and the need for adequate restraint, demonstrated that a variety of CPR methods and positions appear feasible for SSF, and illustrated the potential benefits of a cardiac compression assist device to increase mechanical efficiency.

RECOMMENDATIONS:

- It is recommended that prototypes for a CCAD be included in further evaluation and developmental effort. A CCAD should be considered strongly as a component of the emergency medical equipment for SSF. Adequate testing would be required to assure compliance with American Heart Association standards and patient safety issues.

- It is recommended that the crew receive CPR training that includes familiarization with the variety of methods and positions that could be adapted for SSF scenarios.

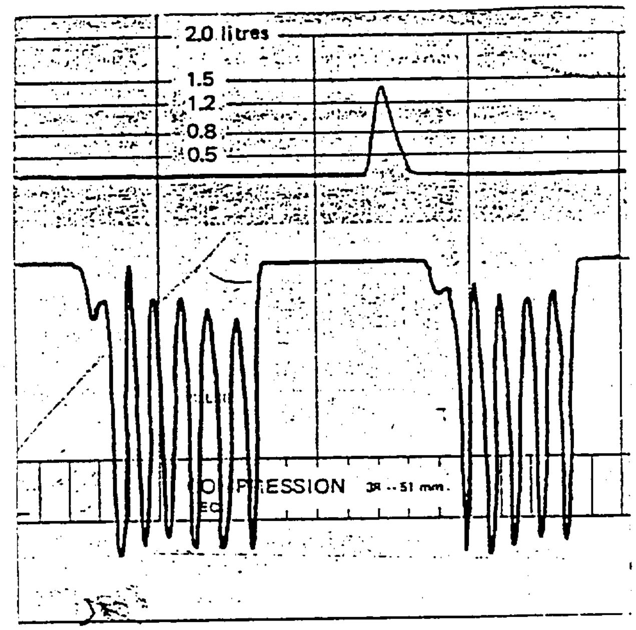


Figure 1.

One-man CPR using the MRS in 1-g during flight.

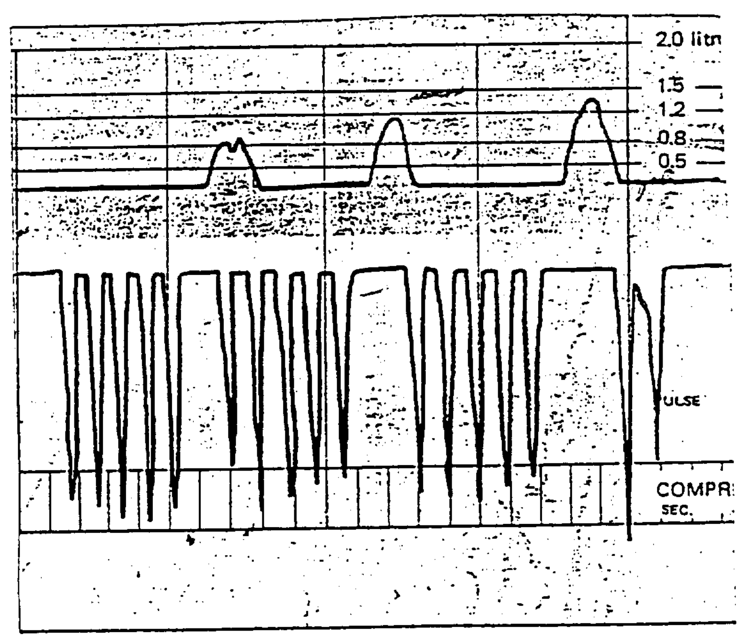


Figure 2.

Two-man CPR using the MRS in 1-g during flight.

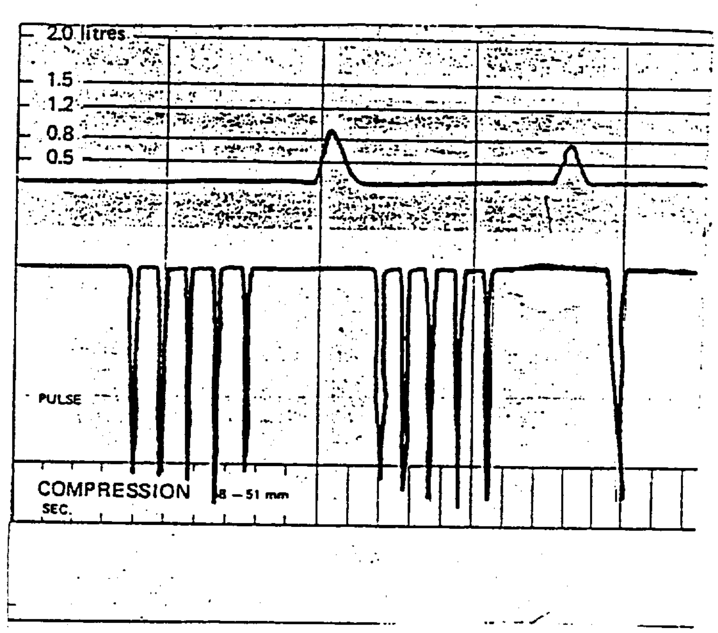


Figure 3.

One-man CPR using the MRS in 0-g. Notice the slight delay in giving ventilations after stopping chest compressions.

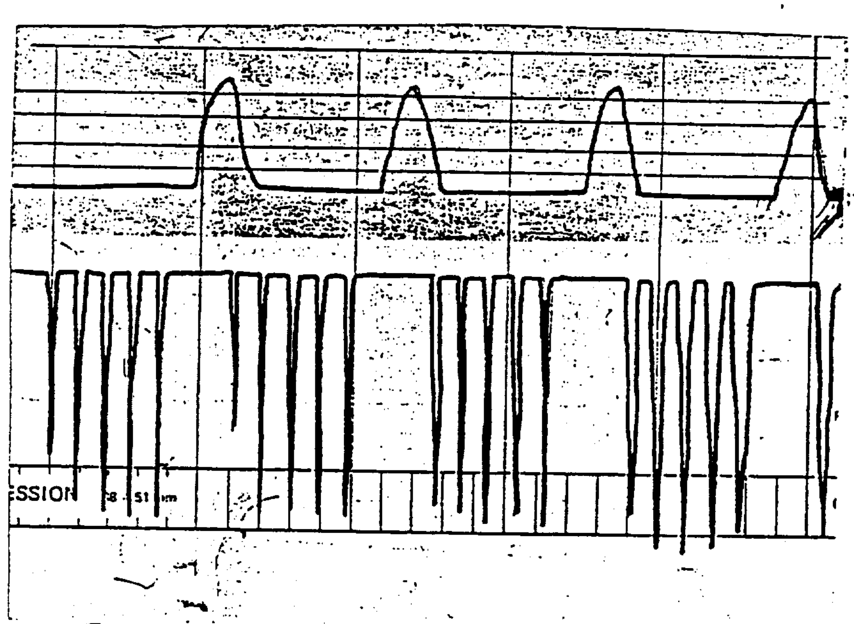


Figure 4.

Two-man CPR using the MRS in 0-g during flight.

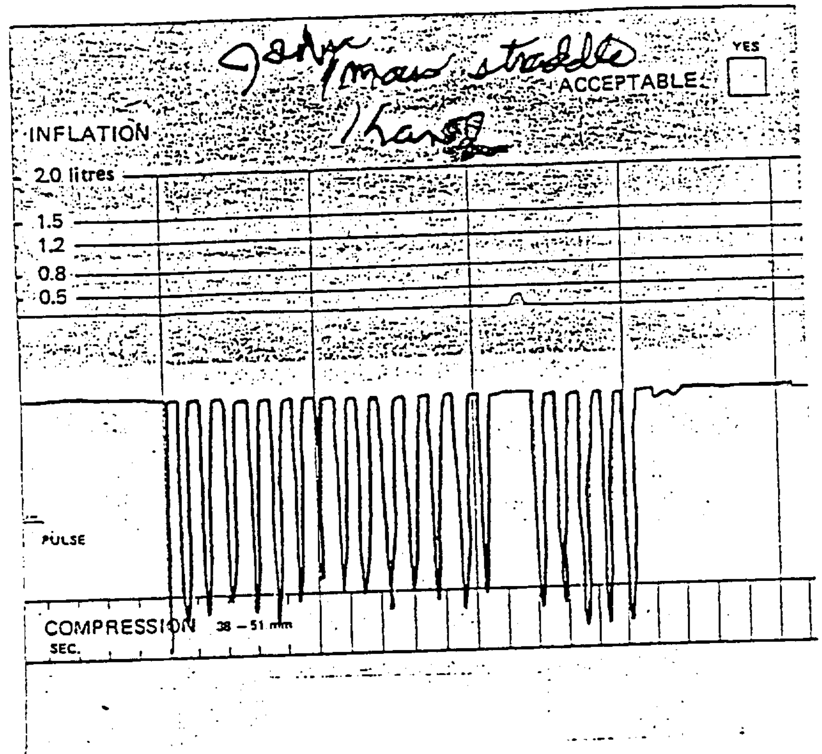


Figure 5.

Chest compressions in 0-g while straddling the MRS.

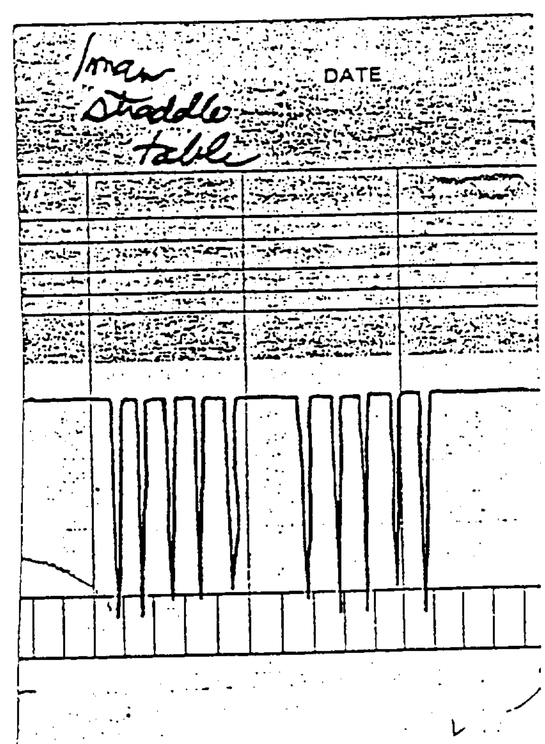


Figure 6.

Chest compressions in 0-g while straddling the MRS

Figure 7. CPR using the Cardiac Compression Assist Device attached to the MRS during 0-g.

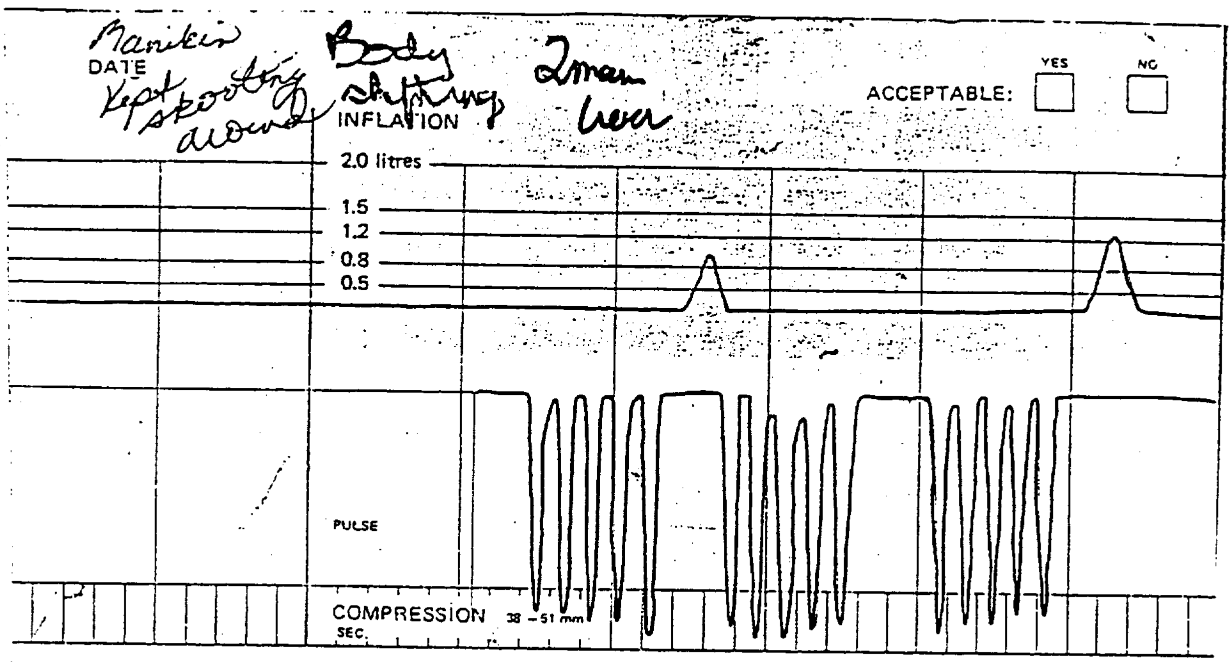


Figure 8. CPR using the Cardiac Compression Assist Device attached to the MRS during 0-g. Notice the incomplete thoracic relaxation in order to keep the CCAD from changing position.

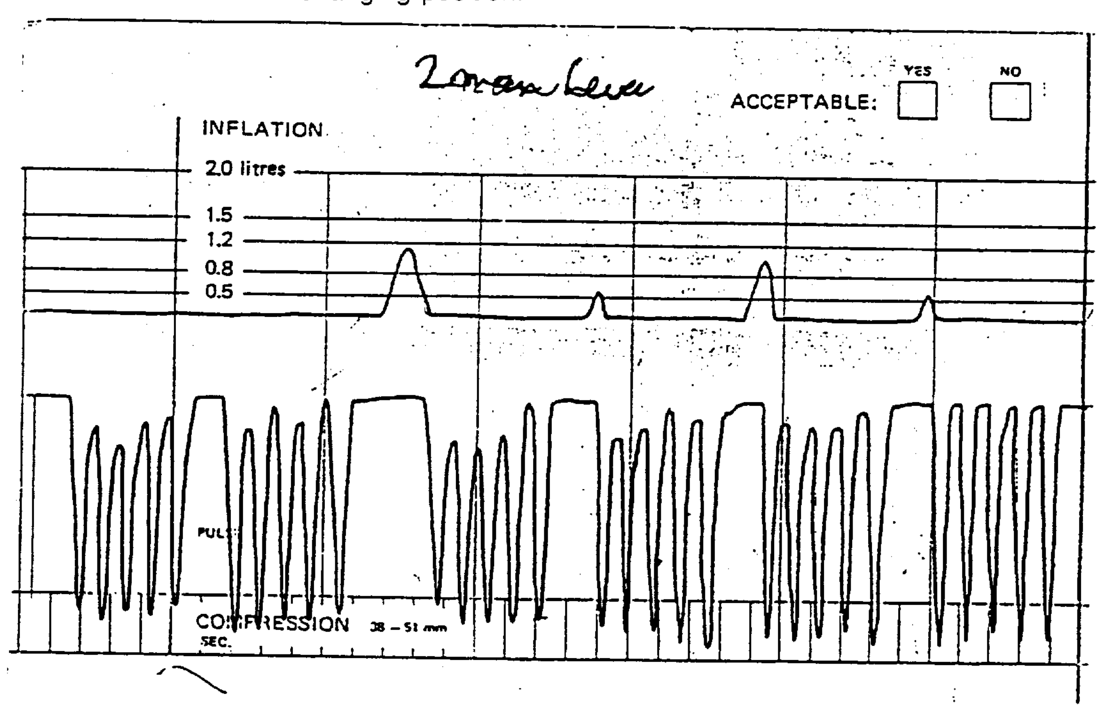
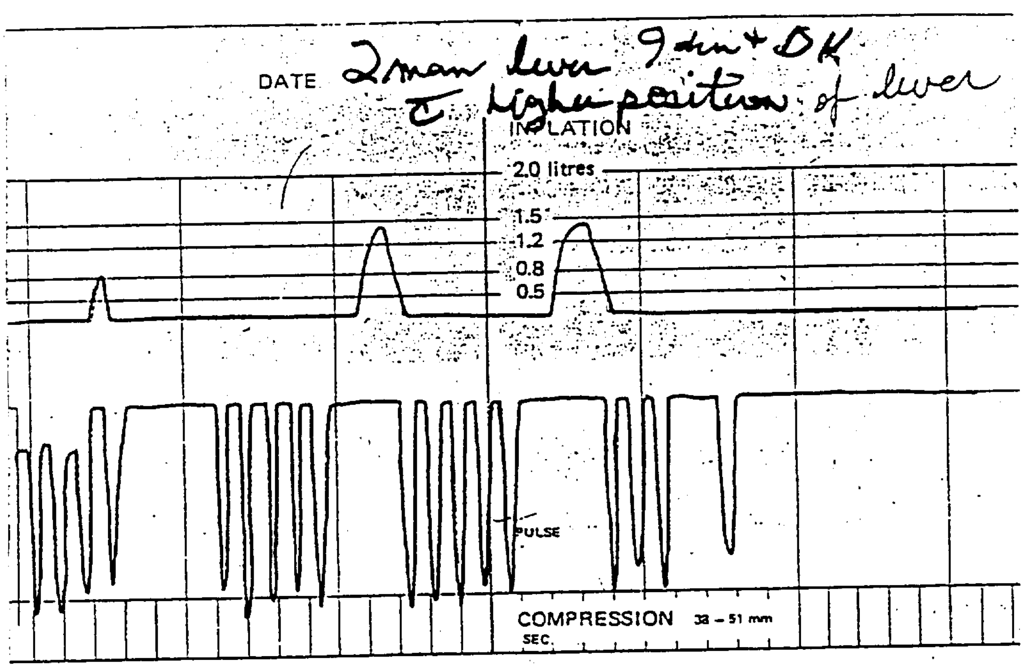


Figure 9. CPR using the Cardiac Compression Assist Device attached to the MRS during 0-g.



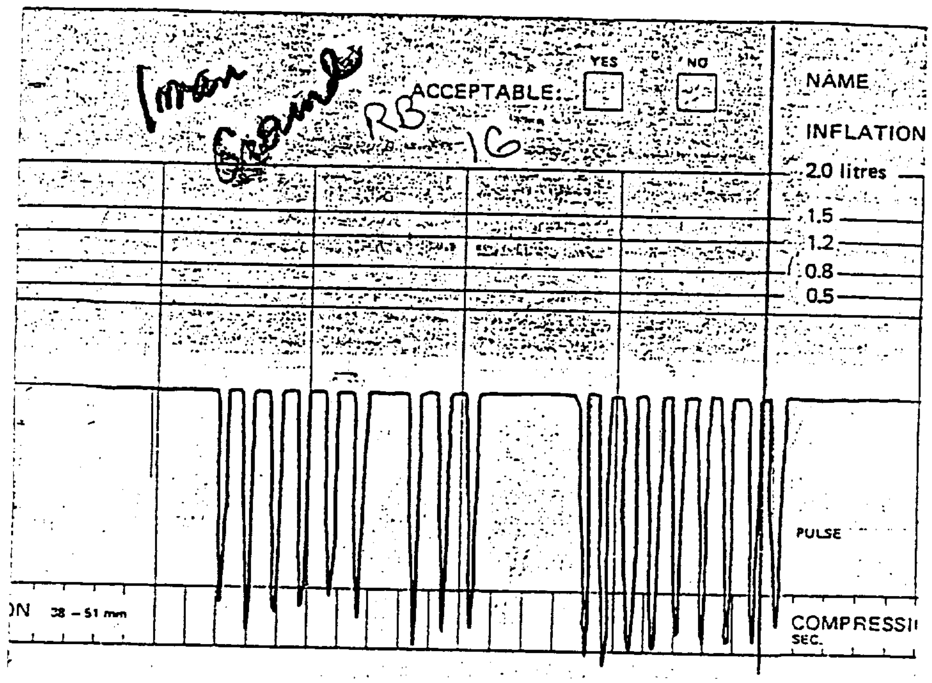


Figure 10.

Chest compressions with the mannequin on the KC-135 floor during 1-g

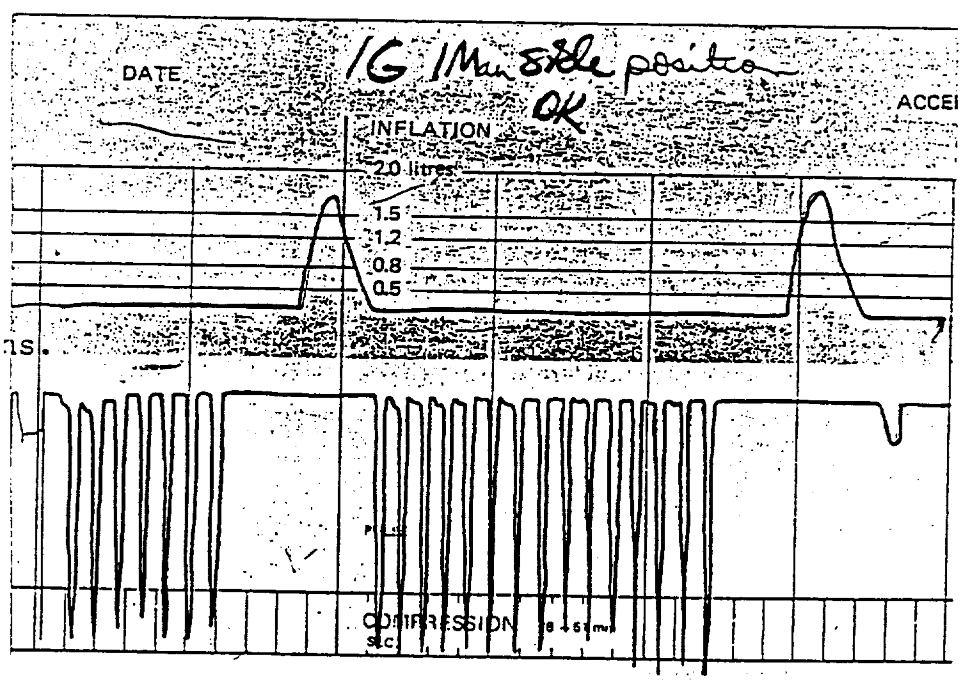


Figure 11.

1-g CPR on the KC-135 floor using the standard side position for chest compressions.

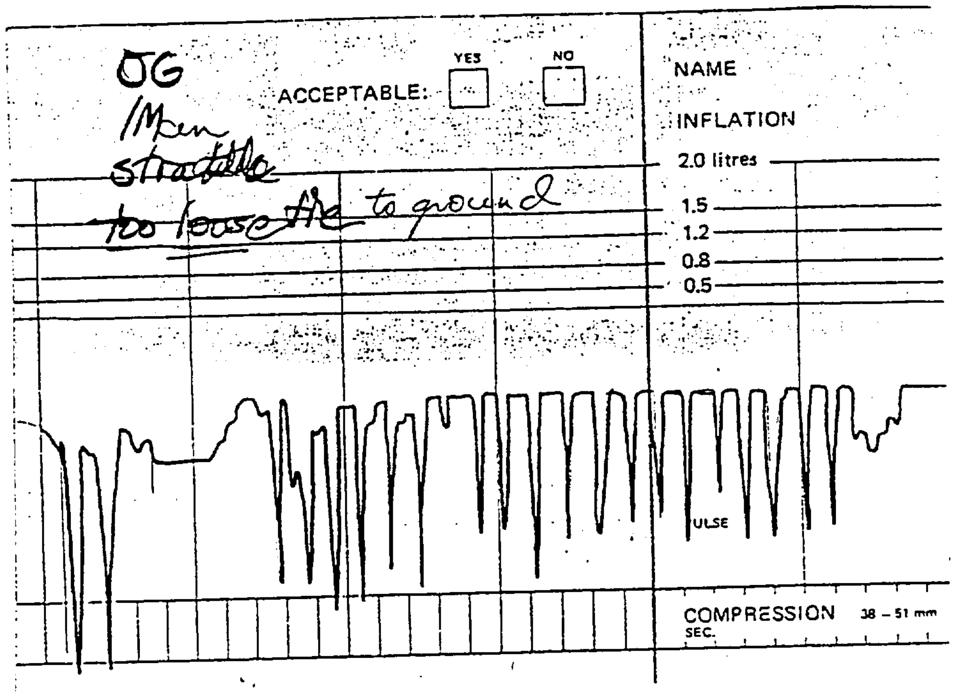


Figure 12.

0-g CPR on KC-135 floor. Difficult chest compressions because of restraint straps being poorly positioned.

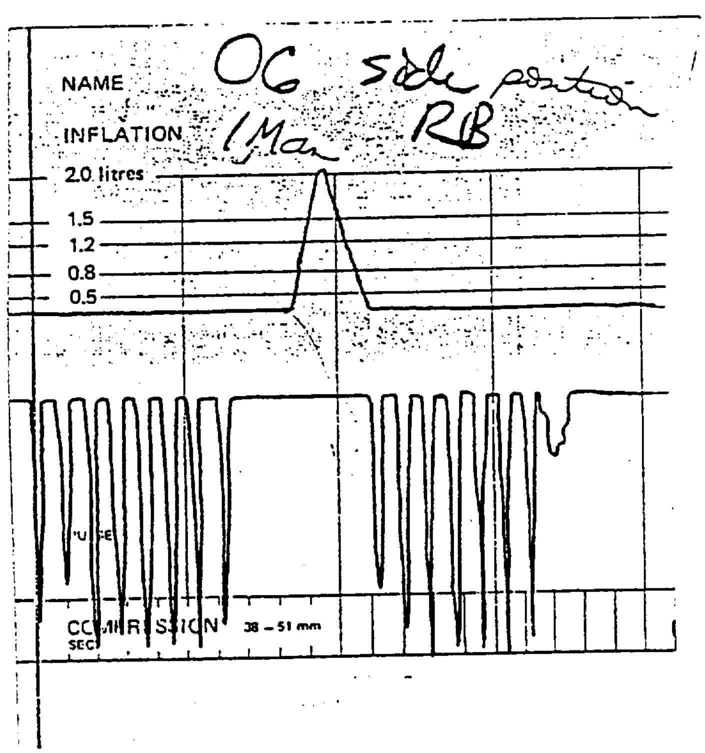


Figure 13.

0-g CPR on KC-135 floor with chest compressions given from the standard side position.

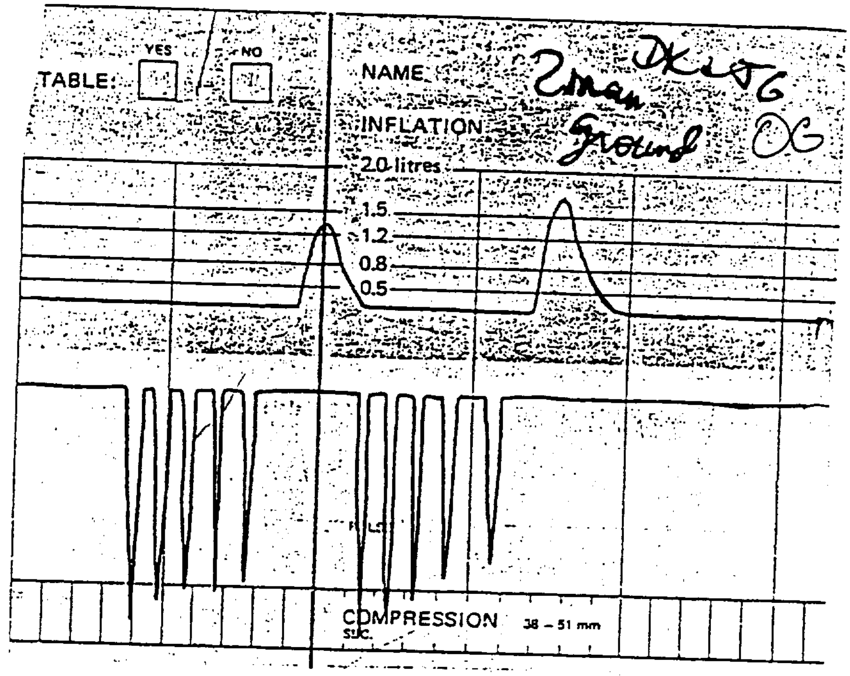


Figure 14.

0-g CPR on KC-135 floor using two-man technique. Chest compressions given from the straddle position.

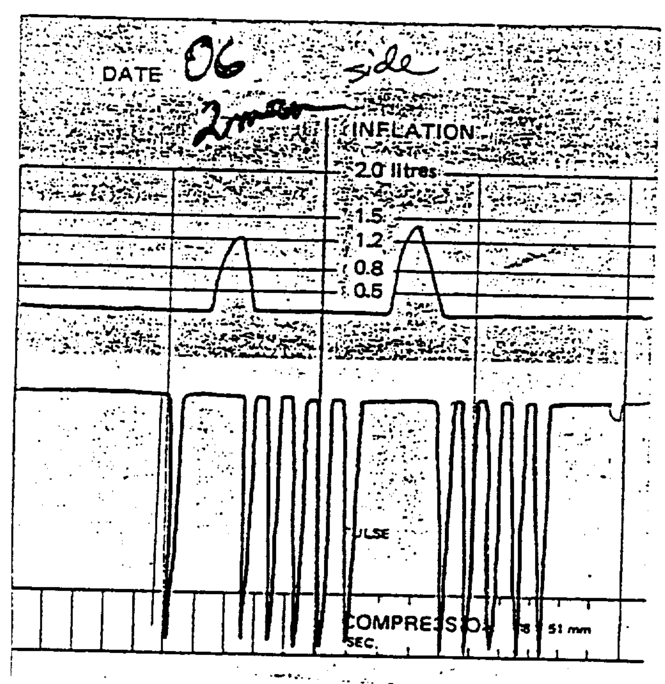


Figure 15

0-g CPR on KC-135 floor using two-man technique. Chest compressions given from the standard side position.

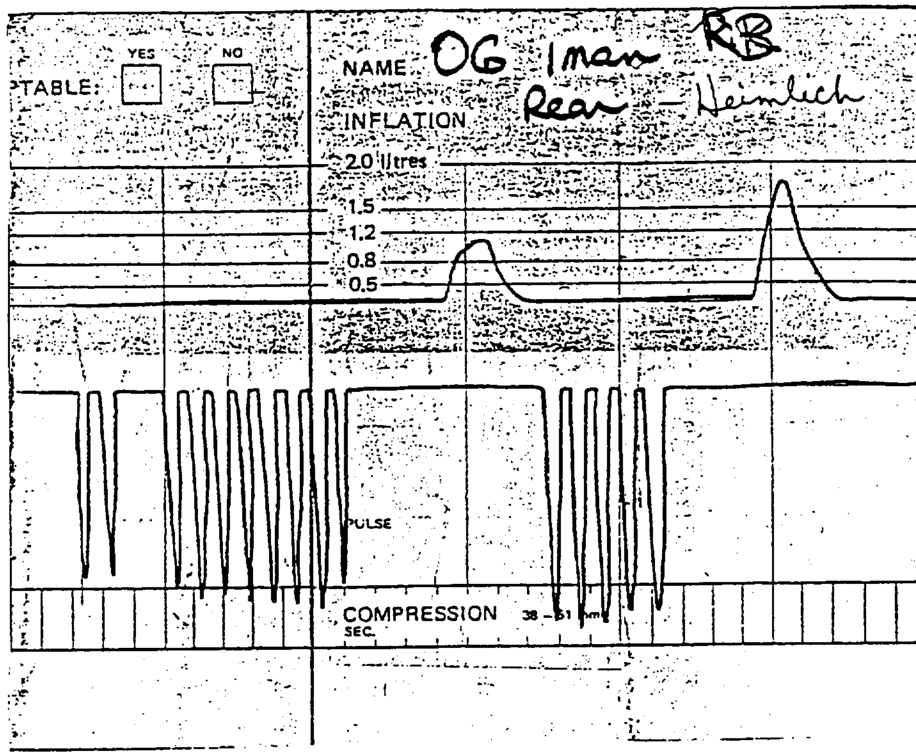


Figure 16.

0-g CPR by one man
using the Heimlich position.

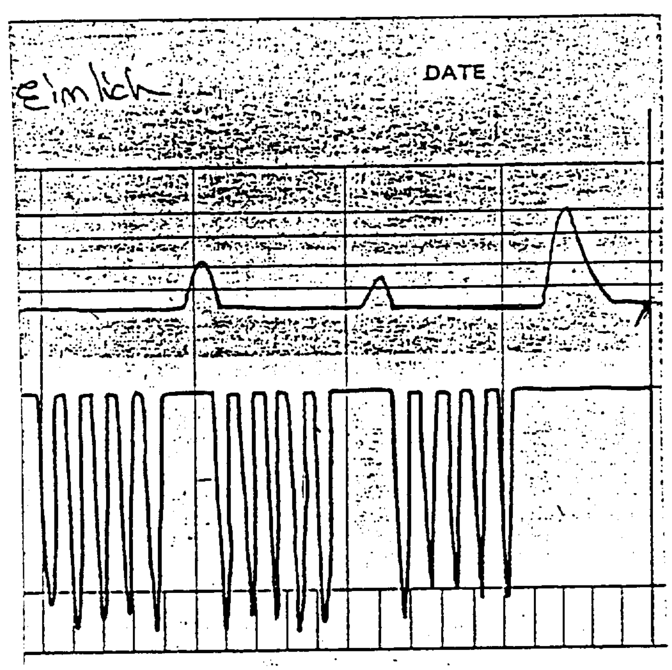


Figure 17.

0-g CPR by one man
using the Heimlich position.
Notice the improved ventilation
with practice.

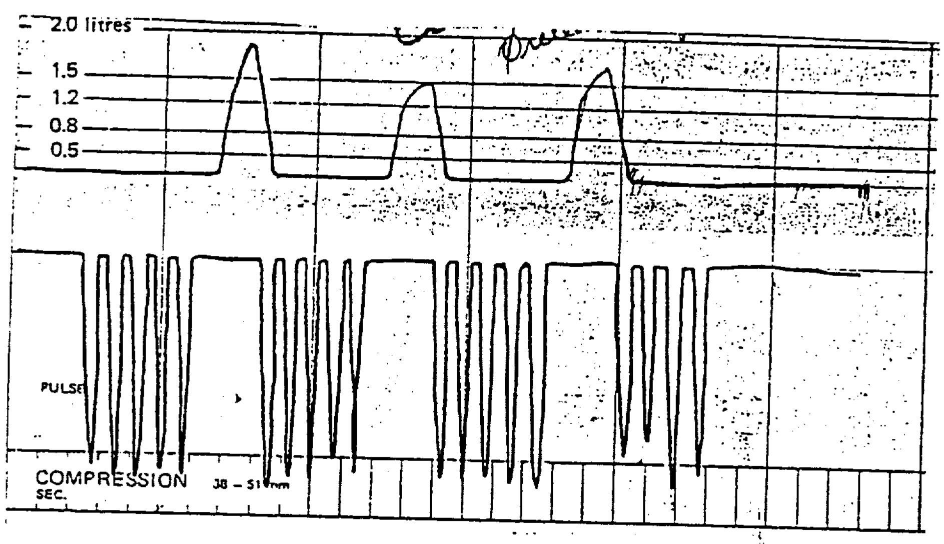


Figure 18. 0-g two-man CPR with chest compressions performed in the Heimlich position and ventilations performed by an unrestrained operator.

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