American Journal of Emergency Medicine 33 (2015) 1350–1353

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Original Contribution

Motion analysis of cardiopulmonary resuscitation☆

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ARTICLE INFO

Article history:
Received 1 March 2015
Received in revised form 23 July 2015
Accepted 25 July 2015

ABSTRACT

Objective: Some cardiopulmonary resuscitation (CPR) monitoring devices were released in recent years. Some of them are motion sensors. There are no guidelines were to position future or present sensors during CPR. We evaluate the possible influence of the location of motion sensors by a high-speed camera during a CPR on a manikin.
Material and methods: We performed a motion analysis by a high-speed camera during chest compression (CC) on a manikin to quantify chest inhomogeneous displacements and rescuer motion.
Results: Midline chest was found to have an inhomogeneous depth during CC (19 mm for the upper sternum, 27 mm for the middle of the sternum, and 47 mm for the xiphoid). Rescuer anatomy has a complex motion.
Conclusion: The direct application of the sensor under the hand performing CC seems to be the more accurate solution if the device allows it.

1. Introduction

Chest compression (CC) is one of the most important factors in cardiopulmonary resuscitation (CPR). Several parameters should be analyzed during CC: compression depth, full decompression, hand position, and frequency. According to the 2010 *European Resuscitation Council Guidelines for Cardiopulmonary Resuscitation* [1], an efficient CC requires 5- to 6-cm depth at a rate of 100 compressions per minute, with full chest recoil, and minimal interruptions[1]. Little is said about where this depth is actually reached.

Several audio and visual feedback devices have been developed to assess CPR quality[2,3]. These devices measure either the pressure or movement with an accelerometer or analyze impedance changes. Some of the accelerometer-based devices use only the acceleration without retrieving the actual position. For some of the sensors, there is an algorithm to retrieve position from accelerometer data. However, the literature lacks validation studies of these devices on test benches, and there is no comparison between them, although there is a growing interest around their clinical applications [4–9]. Devices using position sensors are under development. Applications using mobile phone inertial unit have been proposed [10]. It is still unclear where these devices must be positioned to retrieve chest recoil. Some of these devices could be placed directly under the hand performing the CC. This position ensures probably a good accuracy but could harm the chest skin or impair CC, and it is not conceivable for mobile phone devices. One could imagine putting the device on the upper chest or attaching it to the rescuer anatomy (wrist, elbow, or shoulder). But there is no guarantee that the motion recorded by a distant sensor is correlated to CC. On other hand, the chest distortion is unlikely to be homogeneous during CC. There is not in the literature quantification of this inhomogeneity. Also, to the best of our knowledge, there is no CPR motion analysis published. Thus, monitoring CPR depth is challenging: the thoracic cage motion is probably not homogeneous, and the rescuer is not fixed to the patient and has a certain degree of liberty. It is therefore important to study CC dynamics to use monitoring devices.

In this work, we performed a motion analysis by a high-speed camera during CC on a manikin. The purpose of the study is 2-fold:

–We studied the motion of different parts of manikin thoracic cage during CC to better understand distortion and relative motion of the different parts of the thorax.

–We studied the motion of the rescuer performing CC and more particularly the amplitude of the different segments of limb motion.

2. Material and methods

2.1. Motion analysis and accelerometer validation during CPR

We performed a series of CCs. The manikin used was a standard manikin for CPR training (Ambu Man; Ambu A/S, Ballerup, Germany). The experimenters (4 persons: 1 woman and 3 men, all with average weight and height) performing the compressions and the manikin were equipped with miniature infrared active markers to capture the

☆ Conflict of interest: The authors do not have any conflict of interest.

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http://dx.doi.org/10.1016/j.ajem.2015.07.051
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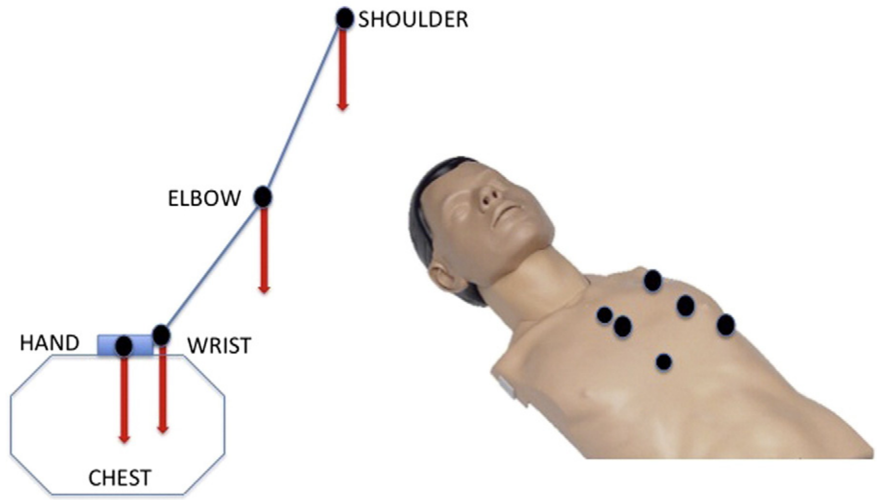

Fig. 1. Placement of infrared markers (black dots) during CC on the rescuer and on the manikin.

motion (Fig. 1). For the manikin, the markers were located on left eighth costal interspace, one on the left nipple, one on the left acromion, one under the xiphoid, one under the Louis angle, and the last one on the sternum's center. Markers on the experimenter were positioned on the metacarpophalangeal joint of the lower hand, on the ulnar stiloid, one on the lateral condyle of the humerus, and the last on the greater tuberosity of humerus. Experimenters performed a total of 100 CCs (1 minute). The rescuers were asked to perform a standard CC following European Resuscitation Council guidelines, and target depth was given by the manikin mechanical indicator (green area between 5 and 6 cm).

A Codamotion system (Charnwood Dynamics Ltd, Rothley, Leicestershire, UK) was used to measure and analyze the movement by means of infrared active markers. An orthonormal coordinate system was defined by 3 fixed markers. The motion capture was performed by ODIN software (Charnwood Dynamics Ltd). Hardware data acquisition was set to 100 Hz, leading to an effective data acquisition rate of 50 Hz. The measurement accuracy is 0.05 mm.

For each CPR series, we computed the average displacement amplitude for each Codamotion marker's location. We computed also the angle formed by the arm and the forearm using the Codamotion system using wrist, elbow, and shoulder markers.

2.2. Data processing and statistical analysis

Data visualization and treatment were performed using Matlab software (MathWorks, Natick, MA). SigmaStat 3.5 (Systat Software/Cranes Software, Chicago, IL) was used for statistical analysis. Each measured variable value is further expressed as its mean value with its corresponding standard deviation interval. A linear regression looking for a correlation between the recorded motions of each part of the anatomy of the experimenter and their possible relation was performed.

3. Results

3.1. Position measurements using Codamotion system

One motion-capture video performed by the Codamotion system can be found in the electronic supplementary file. The average angle between the arm and the forearm was found to be equal to $5° \pm 2°$ for all the compression series. Fig. 2 shows the motion capture during a CPR for different locations. Displacements of the various markers are given in Table 1. Fig. 3 summarizes the displacement on the manikin and shows the different displacements along the midchest line.

Fig. 4 shows the position recorded for the sternum hand, elbow, and shoulder markers vs the wrist position. There is a linear correlation between the position of the wrist and the 3 other markers. The correlation is less strong with the hand.

Table 2 gives the mean displacement of each location and the linear correlation of the displacement of the considered marker vs the wrist position. The relations between the positions of the markers are not simple offsets. The case of the sternum marker is particular: the motion of the upper sternum is poorly correlated to the hand motion. The average vertical displacement is 19.0 ± 0.6 mm. This displacement is well below displacements recorded for the hand and the xyphoid displacements.

The ulnar styloid of the left hand had a similar displacement than the xyphoid (47 ± 3 vs 48 ± 7 mm, $P = .08$). The fifth metacarpophalangeal of the same hand was closer to the midsternum displacement (27 ± 3 vs 32 ± 3 mm, $P < .05$).

4. Discussion

There are some new technological means to investigate the CPR depth, but motion analysis is probably more straightforward. One main issue with the use of motion sensors is where to position the

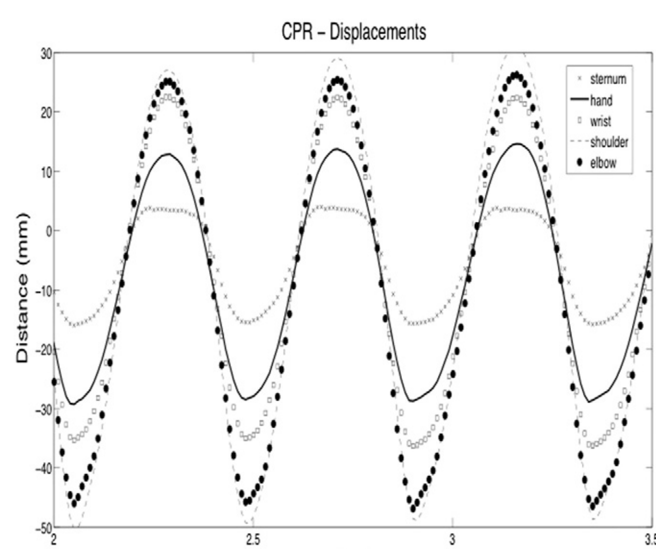

Fig. 2. High-speed camera measured the motions of different body or patient locations during 4 cycles of CPR (dashed: shoulder, x: upper sternum, plain line: hand, square: wrist, point: elbow).