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Theoretical personalized optimum chest compression point can be determined using posteroanterior chest radiography

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ABSTRACT

Aim: Cardiopulmonary resuscitation guidelines suggest the lower sternal half be compressed. However, stroke volume has been assumed to be maximized by compressing the 'point' (P_max.LV) beneath which the left ventricle (LV) is at its maximum diameter. Identifying 'personalized' P_max.LV on computed tomography (CT), we derived and validated rules to estimate P_max.LV using posteroanterior chest radiography (chest_PA).
Methods: A retrospective, cross-sectional study was performed with non-cardiac arrest (CA) adults who underwent chest_PA and CT within 1h (derivation:validation = 3:2). On chest_PA, we defined CD (cardiac diameter), RB (distance from right cardiac border to midline) and CH (cardiac height, from carina to uppermost point of left hemi-diaphragm). Setting P_zero (0, 0) at the midpoint of xiphisternal joint and designating leftward and upward directions as positive on x and y axes, we located P_max.LV (x_max.LV, y_max.LV). Mathematically, followings were inferable: x_max.LV = α_0*CD-RB; y_max.LV = $ß_0$*CH + γ_0. (α_0: mean of (x_max.LV + RB)/CD; $ß_0$, γ_0: representative coefficient and constant of linear regression model, respectively). We investigated their feasibility by applying them to in-hospital (IHCA) and out-of-hospital CA (OHCA) adults.
RESULTS: Among 266 (57.6 ± 16.4 years, 120 females), followings were derived: x_max.LV = 0.664*CD-RB; y_max.LV = 40 − 0.356*CH. Estimated P_max.LV was closer to the reference than other candidates and thus validated: 15 ± 9 vs 17 ± 10 (averaged P_max.LV, $p = 0.025$); 76 ± 13, 54 ± 11 and 63 ± 13 mm (3 equidistant points as per guidelines, all $p < 0.001$). Among IHCA and OHCA patients, 70.7% (106/150) and 38.0% (57/150) had previous chest_PA with measurable parameters to estimate P_max.LV.
CONCLUSION: Personalized P_max.LV, which is potentially superior to the lower sternal half and feasible in CA, is estimable with chest_PA.

Introduction

Current cardiopulmonary resuscitation (CPR) guidelines suggest a wide 'range' of the lower sternal half (about 9 cm long) to compress [1–4]. However, stroke volume (SV), the key point to successful CPR, has been assumed to be maximized by compressing the optimum 'point' (P_max.LV) beneath which the left ventricle (LV) is at its maximum diameter [4–10]. With this rationale, investigators have challenged those guidelines.

At the top of the lower sternal half, most people have their aorta (vs. LV) compressed [3–6,10]. Although compression at the bottom allows their LV to be compressed, this might injure the upper abdominal organs (liver, stomach or spleen) [11,12]. These tradeoffs raise the need to identify the 'personalized' P_max.LV to maximize SV while minimizing complications rather than suboptimal SV with compressing anywhere along the lower sternal half. In one study performed among 34 cardiac arrest (CA) victims with trans-oesophageal echocardiography, compressing 1 cm away from P_max.LV reduced SV by 4 cm [3], which could be critical in CA [5]. Additionally, many critically-ill patients have altered cardiopulmonary structures beyond the scope of CPR guidelines and need identification of personalized P_max.LV more urgently.

Recently, we developed a 3-dimensional coordinate system on computed tomography (CT) to exactly locate P_max.LV [3]. However, CT-guided navigation to identify P_max.LV is not routinely performed and takes enormous time. However, most inpatients, including in-hospital cardiac arrest (IHCA) patients, have posteroanterior chest x-ray (chest_PA) performed on admission. Many out-of-hospital CA (OHCA) patients would have had one performed previously when transferred to the nearest hospital. If P_max.LV can be determined with chest_PA, it

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might then be possible for CA patients to receive 'personalized' optimum chest compression.

This study aimed to mathematically derive and validate simple rules to estimate P_max.LV identified on chest CT (P_max.LV (CT_reference) with parameters easily measured on chest_PA. We also investigated their feasibility in cases with altered cardiopulmonary structures and actual CA patients.

Methods

Design, setting and participant

A retrospective cross-sectional study was performed in a university hospital.

We included all consecutive non-CA adults ≥18 years who had undergone chest_PA and CT within 1 h from 2012 to 2017. Both studies were taken at the end of full inspiration according to the standard protocol. Chest_PA was taken with patient in standing position. Meanwhile CT, which was used to delineate the reference standard of P_max.LV (P_max.LV (CT_reference)), was performed in supine position.

Excluded were (a) thoracic abnormalities: > 2 cm-depth pleural effusion, > 1 cm-depth haemo-/pneumothorax, destroyed lung, lobectomy, atelectasis, hiatal hernia, > 5 mm-depth pericardial effusion, pericardial tumour/cyst, thoracic aorta dissection/aneurysm and widened mediastinum; (b) alteration in cardiopulmonary modifying medications between performing chest_PA and CT: anti-hypertensives, diuretics, inotropics, chronotropics, fluid loading, beta agonists and anticholinergics; and (c) any unmeasurable parameters on either tests [3].

Assigning enrolled cases randomly in a 3:2 ratio, we derived and validated the rules to determine P_max.LV with chest_PA.

Two feasibility analyses were performed with separate populations. Firstly, we checked the applicability of the rules to those initially excluded for structural abnormalities. Secondly, we investigated their feasibility in actual CA cases among the most recent 150 IHCA and 150 OHCA patients who had received CPR by checking the availability of previous chest_PA before CA and the measurability of the parameters to estimate P_max.LV.

Definition of anatomical structures on chest surface and CT: P_zero and P_max.LV (Fig. 1)

To locate P_max.LV, we had to firstly define zero point (P_zero), which was clinically and radiographically interchangeable Following the method of Hwang et al., we selected the midpoint of the xiphisternal joint, where both costal margins, sternal body and xiphoid process meet, as P_zero: (0, 0, 0) (Fig. 1.A and B) [3]. It is easily palpable for multi-conjunctional position and close to P_max.LV. From P_zero, the leftward, upward, and into-the-thorax directions were designated as positive on x, y and z axes, respectively.

As in previous studies, we identified the midpoint of the LV where it showed maximum diameter: (x_max.LV, y_max.LV, z_max.LV) [3–6]. Assuming that P_max.LV was located on the anterior chest surface (z = 0) just vertically above that midpoint, P_max.LV was defined as (x_max.LV, y_max.LV, 0) (Fig. 1.C). Therefore, to determine P_max.LV, which we assumed to be the theoretical optimum chest compression point, we had only to identify x_max.LV and y_max.LV.

Definition of anatomical structures on Chest_PA: cardiac diameter, right border and cardiac height (Fig. 2.A)

To measure parameters on chest_PA, we drew imaginary horizontal and vertical lines for calibration.

The vertical midline was drawn firstly. Thereafter, two parallel lines touching the right and left cardiac borders tangentially were drawn, the distance between which defined cardiac diameter (CD). The distance from the midline to the right line was designated as right cardiac border (RB).

Two horizontal lines were drawn. The upper touched the bottom of the carina which we assigned as the surrogate for cardiac top. The lower passed the uppermost point of the left hemi-diaphragm, which was the surrogate for cardiac bottom. The distance between these lines was defined as cardiac height (CH).

Mathematical derivation of the rule to estimate P_max.LV (Fig. 2.B–D; Explanation S1)

In deriving rules to determine P_max.LV, we made a mathematical assumption: cardiac structure would be identical in shape despite size

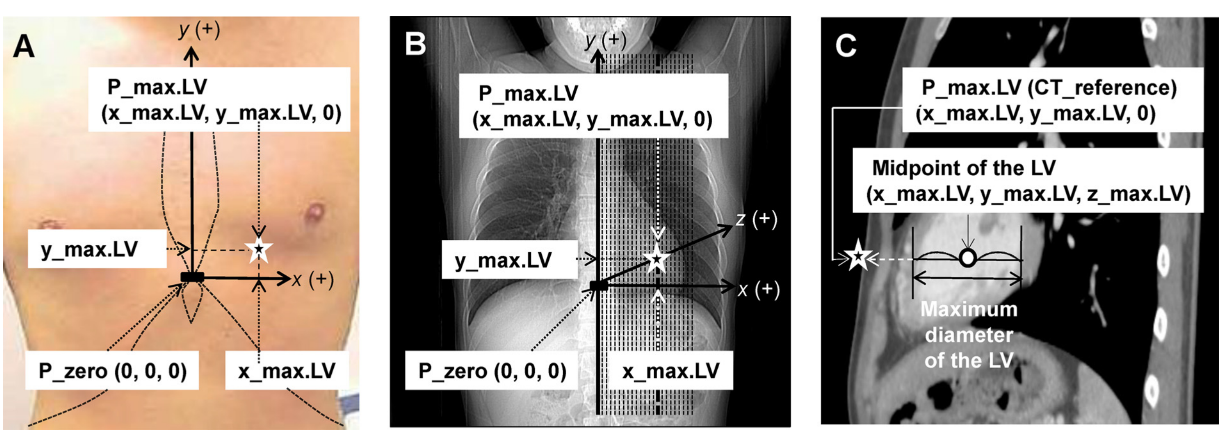

Fig. 1. Identification of the zero point and the theoretical optimum chest compression point (Adapted with permission from Elsevier (See Ref. [3]).
(A) Clinical and (B) Radiographic identification of the zero point (P_zero) The midpoint of the xiphisternal joint, where both the costal margins, sternal body and xiphoid process meet, has been selected as the P_zero with its own coordinate of (0, 0, 0). From P_zero, horizontal, vertical and into-the-thoracic vertical lines, which form right angle with one another, were drawn as x, y and z axes, respectively. Leftward, upward and into-the-thorax directions were designated as positive.
(C) Identification of the theoretical optimum chest compression point on computed tomography (CT) (P_max.LV (CT_reference)) Firstly, the midpoint of the left ventricle (LV), where the LV shows its maximum diameter, is identified by navigating through the sagittal sections of computed tomography (CT) (See Fig. 1.B). Its 3-dimensional coordinate of (x_max.LV, y_max.LV, z_max.LV) is determined using the intrinsic gauging function of PACS. Then, P_max.LV (CT_reference) is defined as the point where the vertical line originating from P_max.LV meets the anterior chest surface. The 3-dimensional coordinate of P_max.LV (CT_reference) becomes (x_max.LV, y_max.LV, 0).
(rectangle: P_zero; star: P_max.LV; circle: midpoint of the LV).