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The impact of various backboard configurations on compression stiffness in a manikin study of CPR

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Abstract— **When performing cardiopulmonary resuscitation (CPR) it is important that adequate back support is given to the patient in order to allow the medical practitioner to produce an appropriate technique during chest compression (CC). The current study investigates how backboard configuration (i.e., orientation and size) impact compression stiffness during CPR using a torso CPR training manikin. The effect of backboard size on CC performance during CPR was found to be significant with the 94.8% larger backboard producing an increase in compression stiffness of as much as 62.7% relative to the smaller backboard. The impact of backboard orientation was also found to be important with a longitudinal orientation producing an increase in compression stiffness of as much as 60.3% relative to a latitudinal orientation. Backboard configuration should be considered by clinicians when trying to achieve optimal CC performance during CPR in hospital settings.**

I. INTRODUCTION

Cardiopulmonary Resuscitation (CPR) is an emergency medical procedure for victims of cardiac and respiratory arrest. When performing CPR, it is important that adequate support is given to the back of the patient in order to allow the medical practitioner to produce an appropriate technique during chest compression (CC) [1-2]. The depth, duration and frequency of CC are important because they control the circulation of blood through the patient's body when the heart is not functioning [2-4].

Several studies have been performed by various researchers to investigate different hemodynamic and mechanical aspects of the application of CC during CPR [3-14]. Many of these studies have focused specifically on the influence of back support on CPR performance [4, 9-14]. However, to date there is still active debate in the literature as to the beneficial or detrimental influence of back support on the effectiveness of CPR. Work by Boe et al. (1999) [4], Andersen et al. (2007) [9], Nishisaki et al. (2009) [10] and Noordergraaf et al. (2009) [11], indicates that CPR chest compressions may be degraded by soft, non-rigid supporting surfaces and improved (i.e., by increasing the compression depth) by the use of a backboard. In contrast, other work by Tweed et al. (2001) [12] and Perkins et al. (2003 & 2006) [13-14] suggests that the presence of a backboard provides a comparable level of back support to a mattress and therefore does not significantly enhance the quality of chest compressions during CPR.

The aim of the current study is to investigate how backboard configuration (i.e., orientation and size) impact compression stiffness during CPR.

II. EXPERIMENTAL SETUP

A. *Apparatus and Measurement Approach*

The experimental apparatus, shown in Fig. 1, consists of a standard hospital bed connected to an adjustable frame, assembled from 4 x 4 cm Bosch Rexroth extruded aluminium sections. All tests were performed using a 3.9 kg Laerdal Little Anne™ Model 020020 torso CPR training manikin measuring 64 cm x 21 cm x 34 cm (height x width x depth) [15]. The manikin was used to simulate the dynamics of a human chest under CPR conditions and produced an audible confirmation (i.e., 'clicking-sound') when the correct CC depth for CPR is achieved.

A polyvinyl carbonate (PVC) "hand" (CC unit) attached to a pneumatic cylinder with linear guide units was used as the actuator to apply chest compressions to the manikin. The amplitude of CC was varied by adjusting the position of the actuator above the bed along the vertical axis using the aluminium framework. The pneumatic cylinder was controlled using a FESTO MPPE proportional pressure regulating valve during the down-stroke and by a manually adjustable pressure regulator maintained at a constant backpressure of 1 bar during retraction. This allowed the pneumatic cylinder to exert a maximum force of approximately 1100 N (at 6 bar air pressure). Overshoot of the cylinder on the compression stroke (i.e., down-stroke) is minimized by the damping effect of the constant pressure applied at the up-stroke port.

All control commands were executed using a Schneider TSX Momentum programmable logic controller (PLC). Two parameters were measured during each compression stroke: the cylinder displacement and the axial reaction force. The cylinder displacement was measured using an HBM linear variable displacement transducer (LVDT). The LVDT was mounted on the cylinder guide and calibrated before use. The measurements from the LVDT were used by the PLC to control the proportional valve which regulates the speed and depth of CC. The reaction force from each CC was measured using an HBM U2A 2 kN load cell, mounted between the cylinder guide and the custom PVC hand. The load cell was statically calibrated prior to being installed. Data from the LVDT and load cell were amplified using HBM "clip" amplifiers. The amplified data were then used by the PLC to control the cylinder. Measurements were recorded using a NI-USB-6218 data logger sampled at 250 Hz on all channels for 30 seconds.

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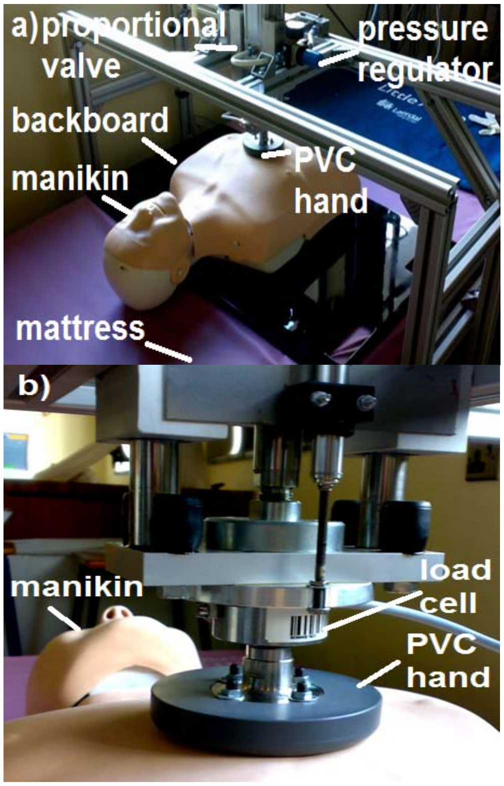

Fig.1. (a) Experimental setup showing the components of the CPR simulator: Manikin torso, PVC hand (CC unit), Backboard, Mattress, Proportional pressure valve, Pressure regulator and Load cell. (b) Close-up of actuator assembly: LVDT, Load cell and the PVC hand.

To obtain a reference for logging the force data, an electronic stethoscope was attached to the manikin and used to indicate when a "clicking" event has occurred. The stethoscope was developed and tested in a previous study on heart and lung sounds [16]. Data from the electronic stethoscope were also transmitted to the data logger which was synchronized with the PLC by a digital input trigger from the PLC to the data logger. The measured LVDT depth was used as the feedback signal for controlling the pressure valves.

Two different types of mattresses and backboards were tested, which have specifications as summarized in Table I. The mattresses are commonly used in clinical settings and have a 120kg patient mass rating. The backboards have different material compositions and dimensions, with BB1 94.8% larger than BB2 by volume.

B. *Procedure*

A series of ten tests were performed using the two different mattresses and backboards oriented either longitudinally or latitudinally. In each test the following steps were performed:

- The PVC hand was returned to the initial start position.
- The load cell was zeroed before starting CC.
- The PLC was used to apply periodic chest compressions to the manikin at a pre-selected rate for 10s.
- At each rate setting (slow: 42 cpm, medium: 60 cpm and fast: 96 cpm) the cylinder (i.e., combined mattress and sternal) displacement and the axial reaction force were recorded.

TABLE I

MATTRESS AND BACKBOARD SPECIFICATIONS

Abbreviations used in the table are Mat1: mattress 1; Mat2: mattress 2; BB1: backboard 1 and BB2: backboard 2. Mat1 is an anti-sore mattress composed of horizontally and vertically oriented foam castellations (i.e., grooves). Mat2 is an anti-sore mattress composed of vertically oriented foam castellations.

Description	Size (cm)	Density (g/cm^3)
Mat1	190.0 x 92.0 x 17.0	0.4038
Mat2	198.0 x 86.0 x 17.2	0.4097
BB1	86.0 x 50.0 x 1.2	0.800
BB2	56.0 x 43.0 x 1.1	1.410

III. DATA ANALYSIS

The displacement and force data were imported into a mathematical software package (MATLAB®, Natick, MA, USA) and processed offline. The compression stiffness (*k*) was computed from the measured axial reaction force (*F*) and cylinder displacement (*d*), using the following formula:

$$k = F/d \tag{1}$$

To gain insight into how backboard size impacts CC during CPR, a comparison was made between the back support stiffness for the different tests in which BB1 (large) and BB2 (small) were used with the same orientation and mattress. The differences in net compression depth and back support stiffness due to backboard size were calculated as follows:

$$\Delta k_{size} = k\big|_{BB1} - k\big|_{BB2} \tag{2}$$

In Eq. (2) positive values of Δk_{size} indicate an increase in back support stiffness due to the larger backboard (BB1), while negative values indicate an increase due to the smaller backboard (BB2).

The impact of backboard orientation on CC performance during CPR was evaluated by comparing the back support stiffness between the different tests in which the backboards were oriented in longitudinal and latitudinal directions, while using the same backboard size and mattress. The differences in net CC depth and back support stiffness due to orientation were computed as follows:

$$\Delta k_{orient} = k\big|_{long} - k\big|_{lat} \tag{3}$$

Here positive values of $\Delta k_{\mathrm{orient}}$ indicate an increase in back support stiffness due to longitudinal backboard orientation, while negative values indicate an increase due to latitudinal backboard orientation.

All statistical calculations were performed using MATLAB®. Data are presented as mean ± S.D. Student's t-testing was used to verify statistical significance, with p-values less than 0.05 considered significant.

IV. RESULTS

Fig. 2 shows a plot of the compression stiffness (N/cm) as a function of axial reaction force (N) for all 10 test cases at a target CC depth of 5.0 cm, at CC rates of: a) 42 cpm, b) 60 cpm and c) 96 cpm. '▷', and '◁' symbols indicate mean compression stiffness for the tests with Mat1 only and Mat2 only, respectively. The '●' symbols correspond to mean compression stiffness for tests using BB1, while '□' symbols correspond to tests using BB2. Mean and S.D. values are given in Table II.

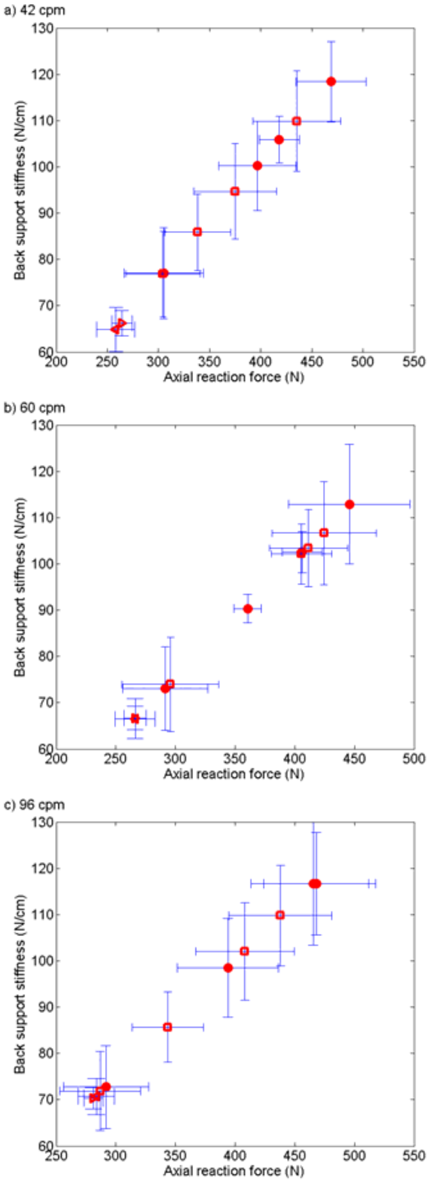

Fig.2. Compression stiffness (N/cm) as a function of axial reaction force (N) for all 10 test cases at a target CC depth of 5.0 cm, at CC rates of: a) 42 cpm, b) 60 cpm and c) 96 cpm.

Fig. 3a shows a plot of the difference in compression stiffness between the larger (BB1) and smaller (BB2) backboard as a function of the difference in axial reaction force between BB1 and BB2, for chest compressions at 96 cpm, with a target CC depth of 5.0 cm. The same mattress type and backboard orientation are used when computing the differences between BB1 and BB2. The '●' and '□' symbols indicate longitudinal and latitudinal backboard orientations respectively. Fig. 3b shows a plot of the difference in compression stiffness between longitudinal and latitudinal backboard orientations as a function of the difference in axial reaction force between longitudinal and latitudinal backboard orientations, at a CC rate of 96 cpm, with a target CC depth of 5.0 cm. The same mattress and backboard type are used when computing the differences between the two orientations. The '●' and '□' symbols indicate longitudinal and latitudinal backboard orientations respectively.

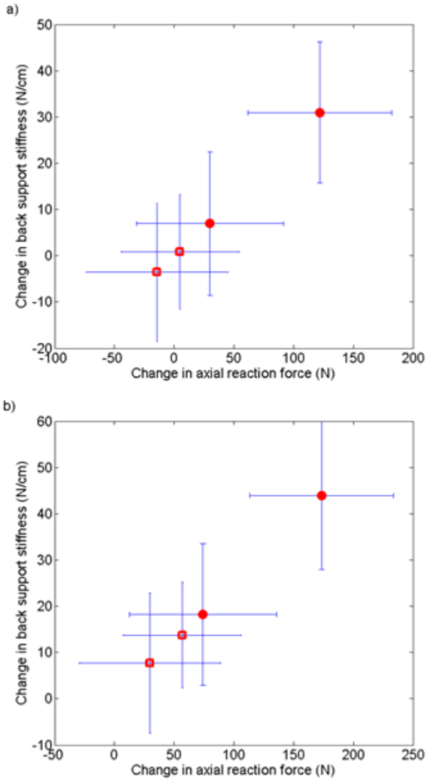

Fig.3. a) *Effect of backboard size*: Plot of the difference in compression stiffness between the larger (BB1) and smaller (BB2) backboard as a function of the difference in axial reaction force between BB1 and BB2, at a CC rate of 96 cpm, with a target CC depth of 5.0 cm. b) *Effect of backboard orientation*: Plot of the difference in compression stiffness between longitudinal and latitudinal backboard orientations as a function of the difference in axial reaction force between longitudinal and latitudinal backboard orientations, at a CC rate of 96 cpm, with a target CC depth of 5.0 cm.

TABLE II
CHEST COMPRESSION RESULTS†

Test	**Axial reaction force† (N)**			**Back support surface stiffness† N/cm)**		
	96 cpm	**60 cpm**	**42 cpm**	**96 cpm**	**60 cpm**	**42 cpm**
Mat1	281.3±8.1	266.1±9.1	264.2±10.0	70.3±2.3	66.7±2.5	66.2±2.7
Mat2	283.6±15.0	266.1±16.8	258.3±18.7	70.7±3.9	66.5±4.3	64.9±4.8
Mat1+BB1 long	465.4±52.3	406.2±16.8	418.2±19.5	116.6±13.2	102.6±4.4	105.9±5.1
Mat2+BB1 long	468.0±43.8	445.8±50.9	468.8±34.0	116.7±11.1	112.9±12.9	118.4±8.7
Mat1+BB1 lat	291.7±35.8	291.4±35.9	305.1±38.7	72.7±9.0	73.0±9.1	77.0±9.8
Mat2+BB1 lat	393.9±42.3	360.5±11.4	396.8±37.8	98.5±10.7	90.4±3.1	100.2±9.6
Mat1+BB2 long	343.5±30.0	405.6±25.3	338.3±32.3	85.7±7.6	102.2±6.5	85.9±8.2
Mat2+BB2 long	438.0±43.1	424.5±43.8	435.2±42.7	109.8±10.9	106.7±11.1	109.9±10.9
Mat1+BB2 lat	286.8±34.0	295.8±40.5	304.4±36.3	71.9±8.6	74.0±10.2	76.9±9.2
Mat2+BB2 lat	408.2±41.5	411.5±32.6	375.0±40.7	102.1±10.5	103.4±8.3	94.7±10.3

†T-tests comparing backboard and non-backboard tests yielded p-values<0.005
Abbreviations used in the table are long: longitudinal and lat: latitudinal

V. DISCUSSION

The results shown in Fig. 2 a-c suggest that the presence of a backboard (regardless of its configuration) increases the back support stiffness and axial reaction force relative to mattress-only chest compression. The increase in compression stiffness and axial reaction force due to the presence of a backboard was as much as 53.5 N/cm and 204.6 N, respectively. The measured axial reaction force was in all cases comparable to the force typically required to achieve CC in human adults (≈300-350N). This builds confidence that the results reported here are reasonable. Furthermore, Fig. 2 a-c clearly show that the axial reaction force is directly proportional to the back support stiffness which is consistent with expectation. Fig. 3 a-b show the effect of backboard size and orientation on CC performance for the most clinically relevant data (i.e., 96cpm).

The results for backboard size indicate that the 94.8% larger backboard (BB1) in general produced higher axial reaction force and compression stiffness than the smaller backboard (BB2), since in three of the four cases the difference in compression stiffness and axial reaction force between BB1 and BB2 is positive. In the fourth case the decrease in reaction force and compression stiffness is very small (3.6 N/cm and 14.7 N, respectively) and within experimental error, which may suggest that the trend observed is significant. The magnitude of the difference in compression stiffness due to backboard size can be large, as much as 43.9 N/cm for a longitudinal backboard orientation using Mat1. When compared to the mattress-only compression stiffness (≈70–71 N/cm), this represents a 62.7% increase in back support stiffness due to the presence of the backboard. The increase in compression stiffness with backboard size makes sense since stiffness is an extensive property of a material and therefore it should vary with backboard size and mass.

The results for backboard orientation show that a longitudinal orientation in all cases produced higher axial reaction force and compression stiffness than a latitudinal orientation. The magnitude of the difference in compression stiffness due to longitudinal backboard orientation verses latitudinal orientation varied between 7.8–43.9 N/cm, while the difference in axial reaction force ranged from 29.8 –173.7 N . This represents an increase in the compression stiffness and axial reaction force of as much as 60.3% and 59.6% respectively. The trends observed for the effect of backboard orientation may be explained by the fact that the manikin torso is 55.0 cm long, which means that when each backboard is orientated in a latitudinal direction it does not fully support the manikin torso and as a result produces poorer CC performance relative to the longitudinal orientation.

VI. CONCLUSION

This study demonstrates that backboard configuration can have a significant impact on the compression force and stiffness during CPR. Comparison of the CC performance between mattress-only and backboard supported CPR showed that the presence of a backboard regardless of size or orientation increases the compression stiffness and axial reaction force produced during CPR. The effect of backboard size on CC performance was found to be significant with the 94.8% larger backboard producing an increase in compression stiffness of as much as 62.7 % relative to the smaller backboard. The impact of backboard orientation was also found to be important, with a longitudinal orientation producing an increase in compression stiffness of as much as 60.3% relative to a latitudinal orientation. Overall, these findings suggest that backboard size and orientation should be considered by clinicians when administering CPR in a hospital setting. Further work is needed to determine the optimal backboard configuration to maximize CC performance during CPR.

VII. FUTURE WORK

Future work will explore the correlation between the internal CC and the mattress compression under the conditions discussed in this paper. The effect of mattress pre-compression by the weight of a patient will also be considered.

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