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Reinventing Aerosol Containment Unit for Use in Medical Operating Theatre

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Abstract. The aerosol containment box or intubation box is medical tool invented to help protect healthcare workers from airborne aerosols while performing procedures such as intubation that are close to the mouth of the patient. The current design of the aerosol containment box is used heavily during the COVID-19 pandemic due to the virus being present in airborne aerosol particles from a patient's breath. However, the current design has been reported to be flawed in its design aspects. Adding ergonomic considerations into the design is expected to provide improved mobility and better usage of medical instruments. The research conducted analyzed how effective the current design in containing the spread of aerosols from the patient. To execute the research, the current design is modelled in a 3D render using SOLIDWORKS 2020 using dimensions to scale. The 3D model is imported into ANSYS 18.2 to conduct an airflow analysis when a patient cough or breathes to analyses the spread of the aerosols from the patient. The patient coughing was simulated using a nozzle with the boundary space of the model based on the size of the intubation box. The key outcome of the project that the present design is not verry effective in containing aerosol spread as there is still airflow of the particles leaving the intubation box into the environment. The improved design of the intubation box prevents flow of the aerosols into the environment by using suction and seals to close of outlets. The data gained from the study of the aerosol spread proves that there is a higher pressure concentration of the aerosols particles on the walls of the outlets in the existing design in the market as compared to the improved design suggested. This data can help better justify the dimensions and criteria needed to further enhance the current design of the aerosol containment box.

1 Introduction

Aerosols are defined as a colloidal suspension of particles dispersed in air or gas. These airborne particles are commonly harmless. However, in the case of an infection, the breath of the infected person can be harmful since the aerosols released may contain organisms or be a carrier of infections [1]. Some of these infections like COVID-19 or better known as the Coronavirus, for example can be airborne for 3 hours and on steel or surfaces for up to 72 hours [2]. Medical workers (doctors, nurses, etc.) are constantly in danger of contamination of infection from airborne spread infections. This risk is highly elevated in the operation theatre where they are nearer to the patients and often carrying out medical operations without prior knowledge if an airborne infection is present from the patient.

During the 2020 COVID-19 pandemic which declared on March 11 by the World Health Organization (WHO), the shortness in global personal protective equipment experienced a major shortage due to the increase in hospitalized patients which in turn, increases demand. Millions of people were infected, and hundreds of thousands needed medical attention with the majority having breathing difficulties. Ventilators are short of supply and so are Personal Protective Equipment (PPE) [3]. An aerosol containment unit aids in procedures such as endotracheal intubation to contain dangerous droplets that may be released from the patient during procedures. The present design was created by a Taiwanese doctor, Dr. Hsien Yung Lai. The design consists of a box that is transparent with arm holes for the doctor to operate through. The design can be seen in Figure 1 [4].

Fig. 1. Current aerosol box in use.

The design created is noted to have worked after basic testing using a human volunteer to cough while his head is inside the box and is now widely used in many operating theatres around the world [6]. However, some design flaws were discovered when operating this design of aerosol containment box.

The studies conducted on the aerosol spread using the box does not take into account the effect on the assistants during the medical procedures, which was the intubation of a patient with breathing difficulties [4]. The movement of the doctor's hands and the fixed size of the box has limitations which can be improved to provide mobility and ease of use to be even portable in case of need to be used outside the operating theatre.

The design can also be improved to allow better freedom of movement for the health workers which is one of the highlighted problems post usage of the design [7]. In this research and innovation process, the existing box design in the market is used to obtain data on the aerosol containment. The material used and the design type must be applicable to operating theatre standards because not all materials are safe for long term use in that environment [5].

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The design is evaluated based on actual containment levels of aerosols spread based on the pressure on the outlet resulting from the particles. This is done by preliminary research for the model data and SOLIDWORKS to create a 3D model for dimensions to scale and ANSYS. This study is new in engineering aspects so after the initial tests are done, the data can be used to improve the present design and create a design that is more effective.

Begley et al. (2020) concluded that the current design can be improved and suggested an improved design. His suggestion was to increase the width of the box and add a hole on the top to allow tools for intubation to be inserted through. However, an experimental study on the design reports the time taken to conduct an intubation process is the same as with the previous design. He reports there is still a difficulty in the doctor maneuvering within the aerosol box [11]. The experiment did not however include factors such as the aerosol spread with the new dimensions or mobility of the assistant to the doctor. This strongly suggests that the design has flaws which have yet to be detected by current research. Engineering data obtained from proper research methods such as ergonomic studies and computer assisted analyses can possibly increase the credibility of the data and suggest improvements to be made to the current design.

To help narrow down the scope of study, the aerosol box is so far only used on patients that are unconscious including those that are medically sedated. The Massachusetts Medical Society (2020) conducted a study using a mannequin, a balloon filled with fluorescent dye and a standard operating theatre environment. The experiment is done by placing the balloon with dye inside the thoracic area of the mannequin and filling it with oxygen until it explodes, to simulate a cough or a gagging reflex. The dye was found on floor surfaces 1m from the head of the bed and on a monitor 2m away [6]. To conclude, the spread was extensive for 2m away. The test is then done again with an aerosol box and the spread is contained. This study however is not as accurate as the dye is not an accurate representation of the aerosol particles. The dye is heavier and denser in form. The way the aerosol moves in the air is also not recorded. Also, using a balloon bursting to simulate the coughing of a person is not accurate in terms of velocity and direction. The mechanics of a cough is unclear here.

Amid the COVID-19 pandemic, the use of the aerosol containment box has become critical due to the virus being airborne within aerosol particles released in the breath of an infected person. The aerosol containment box was created to protect doctors, surgeon, and health care workers from being exposed to the airborne particles when working near the mouth of the patient in an operating theatre. However, the aerosol box is primitive in design and has been reported to not being a complete fail-safe guard against the airborne aerosol particles. This project is aimed to study the flaws of the present design and improve it to be more efficient for use of doctors and their assistants. The key objectives of this study are to evaluate the current aerosol containment box in use in terms of its effectiveness in preventing a spread of aerosols from the patient to their surroundings and design the aerosol containment box to increase its effectiveness in containing aerosol spread from a patient.

2 Methodology

2.1 Existing Aerosol Intubation Box Design

The aerosol box was a sufficient barrier between the patient and the doctors to provide protection against airborne aerosols [8]. The box schematics are dimensioned to fit the size of a standard operating table. Although the design was made in Taiwan, in the peak infection rate of the COVID-19 pandemic, the design was used globally [2]. The dimensions in Fig. 2 is original design that was made public information to help users around the world to gain access to it for free. The dimensions are used to make a SOLDIWORKS part file. This 3D model can be imported for use in other software. The details of the design are specified in Table 1.

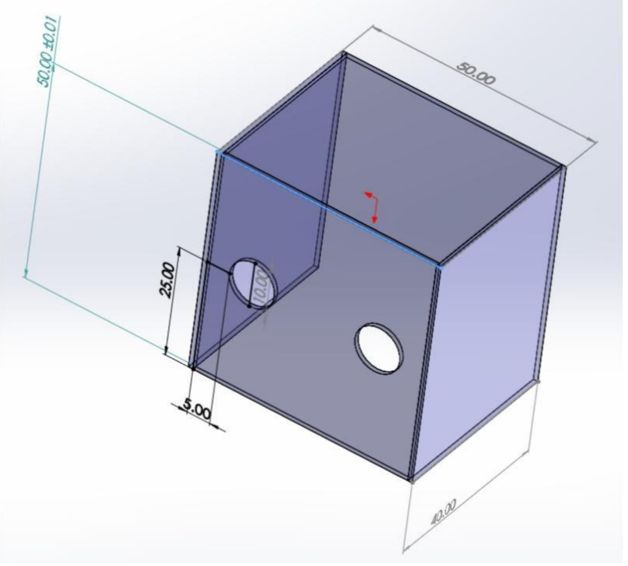


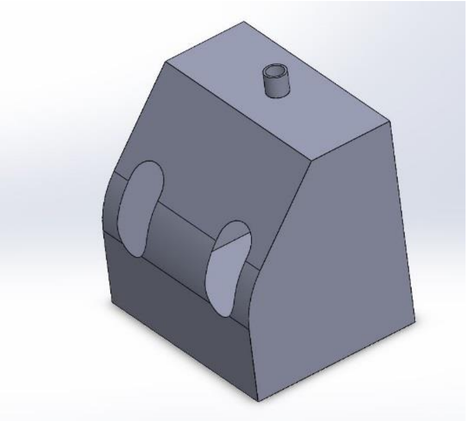
Fig. 2. Intubation Box Design Dimensions (cm)

Table 1. Dimension and Material Used in SOLIDWORKS Model

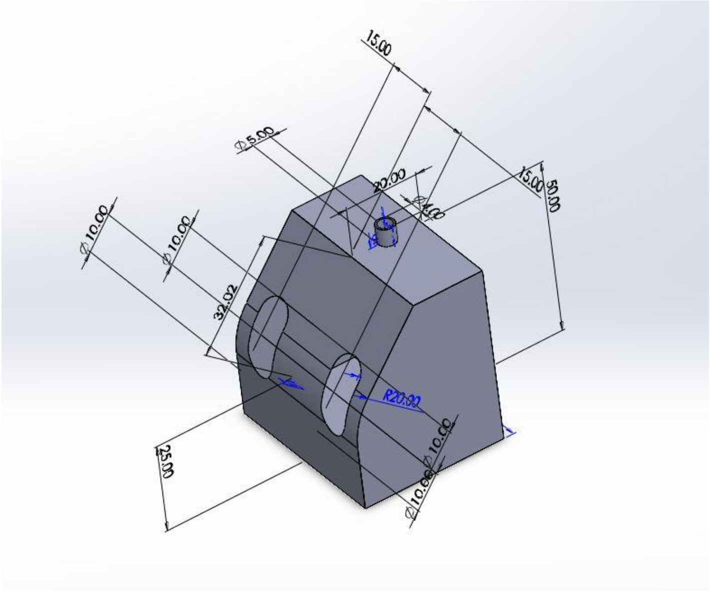
Item	Description
Diameter of Armhole (m)	0.1
Height (m)	0.5
Width (m)	0.5
Length (m)	0.4
Shell Thickness (cm)	0.01
Material	Acrylic (Medium High-Impact)
Density (g/cm^3)	1.20 grams per cubic centimeter
Mass (g)	100.09
Volume (cm^3)	83.41
Surface Area (cm^2)	16684.67

2.2 Improved Aerosol Intubation Box Design

The original box dimensions are used to setup an improved design to allow better movement of the user's arms. To prevent further aerosols from exiting the intubation box into the operating room atmosphere, a vacuum feature is added to the top of the box as seen in Fig. 3. The nozzle added to the top of the box can be connected to a vacuum readily available in operating rooms. The standard hospital operating room has a vacuum that can generate a maximum negative pressure of 260mmHg. The holes and opening on the intubation box are also covered with silicone flaps to prevent lingering aerosols from escaping into the atmosphere. The model of the intubation box with a patient inside is seen in Fig. 4 however only the box and the boundary area inside the box is used in the simulation due to student software limitations.



(a)



(b)

Fig. 3. (a) Improved Boxed Design, (b) Dimensions of Improved Design

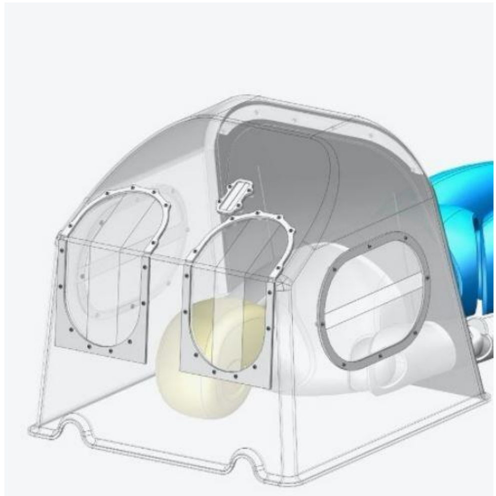


Fig. 4. 3-D Model of Improved Design

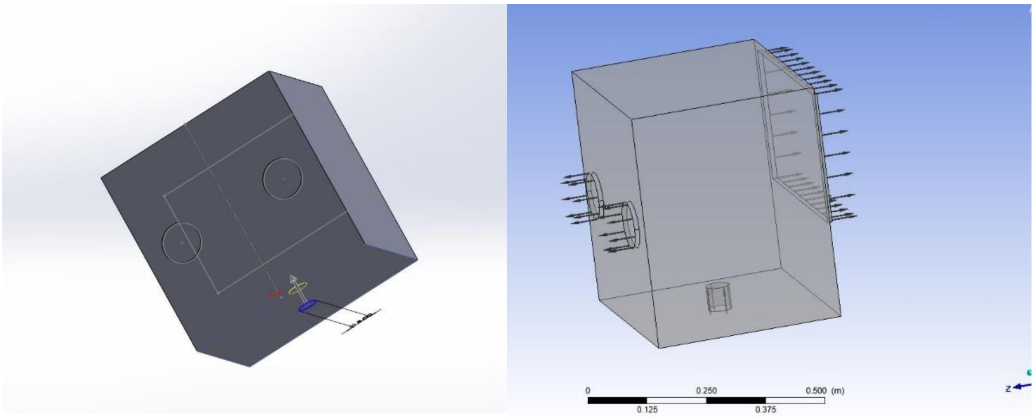
2.3 Computational Fluid Dynamics

ANSYS 2020 R2, Student Version (CFX) is used to carry out Computational Fluid Dynamics modelling of the aerosol dispersion. The model simulates a person coughing within the intubation box with different cough velocities. Based on a previous study, the vertical cough velocity is assumed at two states, mild cough, and strong cough. In the case of the strong cough, the highest velocity is observed at peak expiratory flow. The mild cough velocity is predicted at 49.96 m/s and the strong cough at 117 m/s [9]. The simulation uses a standard Navier-Stokes equation, k-epsilon which includes conservation of mass, momentum, and energy characteristics of the fluid. The fluid components include the size of the particle which is obtained from previous study. Ranging from 1 to 100 microns, a mean particle size of 100 microns is chosen for the study. The fluid domain within the intubation box is set to be the ambient temperature of a hospital operating room , set at 20^{o} C, which is the mean allowable temperature of the operating room according to guidelines [10].

Table 2. CFX Setup Numerical Data

Velocity of Mild Cough (m/s)	49.96
Velocity of Strong Cough (m/s)	117
Governing Equation	k-epsilon
Temperature of Fluid (^{o}C)	20
Particle Size	100 Microns

The 3-D model of the existing intubation box is imported in ANSYS (CFX) and the boundary conditions are set as seen in Fig. 5. Two simulations are set up to allow for simulation of a mild cough and a strong cough. A cylindrical extruded cut (r=5cm, h=5cm) is added to the bottom of the to act as the mouth opening of a patient within the intubation box. This surface will act as an inlet for the model. The relative pressure for this model is 0 Pa as there is no pump or vacuum in this design.



(a) (b)

Fig. 5. (a) Location of nozzle inlet on bottom of box, (b) Inlet and Outlet Boundary Locations

The 3-D model of the improved design uses the same numerical data as the existing design with the addition of -260 mmHg at the outlet to simulate the vacuum suction. The boundaries are changed to the surfaces in Fig.6. the outlets at the holes and the opening are removed due to the assumption that there are silicone sheets covering the exits.

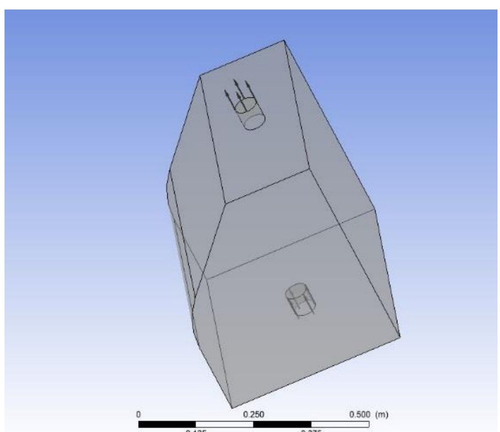


Fig. 6. Inlet and Outlet Boundary Locations

3 Results and Discussions

3.1 Computational Results and Discussion

Solving the simulation model provides results to compare the models based on the pressure on the walls of the domain and the streamlines they produce before leaving the fluid domain. In this case, the streamlines show the particle movement before it exits the intubation box. In the exiting design, the particles leave the box through the holes and the opening on the opposite side of the user, however in the improved design, the vacuum causes suction that removes the particles from the intubation box. The efficiency of the designs can be observed based on the streamlines in Fig. 7.

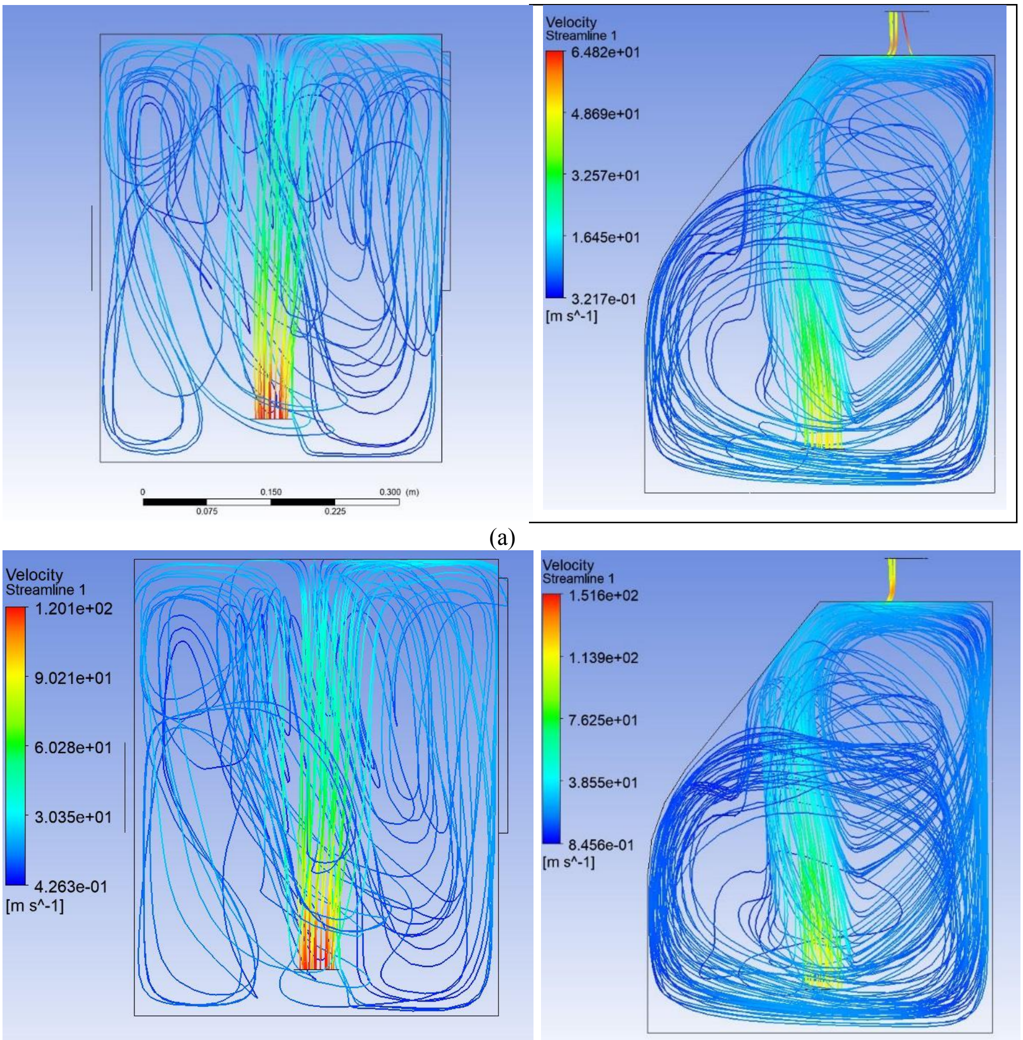


Fig. 7. (a) Left, Existing design mild cough velocity. Right, Improved design mild cough velocity, (b) Left, Existing design, strong cough velocity. Right, Improved design, strong cough velocity.

It is observed that the streamlines are more uniform in the improved design in both cases. The vacuum suction in the top of the box helps generate a negative pressure outlet. This causes a fluid flow that affects the particles to exit through the outlet. In the existing design, the particles not only flow around the box in a non-steady streamline, they also show loops which suggest the particles are lingering aerosols in the intubation box. The pressure forces on the wall also show a significant change when comparing the improved design and the existing design as seen in Fig. 8. The pressure forces on the walls in the existing design in the Z-component which is the direction of the holes and the opening for thew patient is seen to be lesser in the improved design compared to the existing design.

```
+-----------------------------------------------------------
|                  Pressure Force On Walls
+-----------------------------------------------------------
                                X-Comp.       Y-Comp.

Domain Group: Default Domain

Default Domain Default        -8.9156E-02    6.6443E+00   3
                              -----------   -----------   -
Domain Group Totals :         -8.9156E-02    6.6443E+00   3
```

```
+-----------------------------------------------------------
|                  Pressure Force On Walls
+-----------------------------------------------------------
                                X-Comp.       Y-Comp.

Domain Group: Default Domain

Default Domain Default         3.0537E-03    4.2662E+00  -1.
                              -----------   -----------  --
Domain Group Totals :          3.0537E-03    4.2662E+00  -1.
```

(a)

```
+-----------------------------------------------------------
|                  Pressure Force On Walls
+-----------------------------------------------------------
                                X-Comp.       Y-Comp.

Domain Group: Default Domain

Default Domain Default        -5.7085E-01    3.6287E+01   2.
                              -----------   -----------   --
Domain Group Totals :         -5.7085E-01    3.6287E+01   2.
```

```
+-----------------------------------------------------------
|                  Pressure Force On Walls
+-----------------------------------------------------------
                                X-Comp.       Y-Comp.

Domain Group: Default Domain

Default Domain Default         1.0513E-02    2.3322E+01  -8
                              -----------   -----------   -
Domain Group Totals :          1.0513E-02    2.3322E+01  -8
```

(b)

Fig. 8. (a) Mild cough case; Left, Existing design. Right, Improved design (b) Strong cough case; Left, Existing design. Right, Improved Design

With the implementation of the vacuum and closing the outlets in the initial design with silicone sheets, the aerosol release into the operating room is considered minimum. The case of the silicone covered outlets are assumed as walls because in the event that aerosols flow towards those outlets, the particles that escape are considered negligible since the negative pressure of the vacuum forces the majority of particles to flow towards the top of the box.

4 Conclusion

The improved design is more effective in containing aerosol from spreading to the operating room atmosphere compared to the existing design. While the improved design will not negate the use of personal protective equipment (PPE) of healthcare worker during intubation, it can further reduce the possibility of viral transmissions of the airborne virus. This is especially important in the scenario where PPE usage and supply are limited due to overwhelming infected patient numbers. The improved design can also be implemented into other uses where oxygen can be supplied into the nozzle meant for the vacuum and the patient can be transported on a bed with the intubation box on. Expanding on the uses of the intubation box can range from transporting patients in a hospital to also allowing safer isolation of patients in a ward. To date, the effects of using intubation boxes to reduce aerosol spreads and contaminations have not been widely tested. This study should open a door for a wider range of features and test studies to be conducted to allow the progress of healthcare technology in the future.

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References

1. D. K. Milton, M. P. Fabian, B. J. Cowling, M. L. Grantham, and J. J. McDevitt, *PLoS Pathog*., **9**, 3 (2013)
2. J.-Y. Tseng and H.-Y. Lai, *J. Chinese Med. Assoc*., **1** (2020)
3. S. Koven, *N. Engl. J. Med*., **1–2** (2020)
4. R. Kearsley, *Anaesthesia*, **April** (2020)
5. S. Dharan and D. Pittet, *J. Hosp. Infect*., **51**, 2 (2002)
6. R. Canelli, C. W. Connor, M. Gonzalez, A. Nozari, and R. Ortega, *N. Engl. J. Med*., **Apr.** (2020)
7. Annonymous, https://www.statnews.com/2020/05/05/intubation-boxes-extra-layer-safety-or-false-sense-security/ (accessed May 20, 2020)
8. G. Zayas, *BMC Pulm. Med*., **12** (2012)
9. B. Hoffman Ruddy, D. Nadun Kuruppumullage, G. Carnaby, M. Crary, J. Lehman, and O. J. Ilegbusi, *Laryngoscope Investig. Otolaryngol*., **2**, 1 (2017)
10. Y. E. S. No, “Name of Facility : Address : If comply tick (√) Yes , if not tick (√) No . Please add comment for any explanation .,” **1–11** (2016)
11. J. Safurah, J., kamaliah, M.H., Khairiyah, A.M., Nour, H.O., and Healy, *Malaysia Heal. Syst. Rev*., **3**, 1 (2013)