Design of an Automated Over-bed Hospital Meal Cart for Public Hospitals

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Abstract - Hospital meal carts are used to deliver meals, drugs and some other materials to patients in the hospital environment. These carts which are moved manually by operators, the health workers, mostly do not comply with ergonomics guidelines and physical requirements of the equipment users in terms of anthropometry data of the region thus increasing the risk of musculoskeletal disorder among the meal cart users. Based on the preliminary study, most operators expressed the feeling of fatigue and postural discomfort in the shoulders, arms, back and thighs as a result of moving the hospital meal cart around the hospital environment. Also, patients who are limited in terms of sitting and standing needs this for their comfort and assistant. In order to ease this discomfort, an automated over-bed hospital table was designed using the adult working class anthropometry data of Nigeria. The cart has an adjustment feature of forth and back movement as well as height adjustment mechanism to suite the use of the patient. The responses obtained from ergonomic evaluation of the re-designed hospital meal carts were analyzed using SPSS to obtain the non-parametric Chi-Square test as well as the median and interquartile range. The test however showed significant difference when p < 0.050, hence the redesign is justified. The table can be operated by the patient with little or no assistance hence will reduce fatigue and risk of musculoskeletal disorder among the meal cart users.

Keywords - Anthropometric data, Discomfort, Ergonomics, Hospital and Meal cart

1 INTRODUCTION

The use of carts in the hospital environments is a common feature because moving things e.g. meal, prescriptions, light equipment are inevitable. Hospital meal carts are used to deliver hot meals, breakfast, lunch and dinner, on trays to the patients. These carts are moved manually by operators which are both males and females. These people perform other functions aside moving these meal carts and they continue to work in standing posture throughout their work shift. Schibyte et al., (2001) and Das et al., (2002) reported that carts, hand trucks and wheel barrows provided a great advantage in transportation of materials due to the presence of wheels. They established that the use of manual vehicle is less stressful and more efficient than their non-use material handlings. However, automating these manual vehicles will provide more efficiency.

Ayodeji et al., (2015) posited that pulling forces are involved in moving these hospital meal carts as well as bending and lifting operations during the process of handling these meal carts. In discharging these duties, fatigue tends to set in on the workers before the end of the shift period. Jung et al., (2005) revealed that recent studies show that these carts have caused suffering and injuries to workers and has increased the risk of musculoskeletal problems. Figure 1 shows some examples of the hospital meal carts. People who are prone to musculoskeletal disorder from the use of hospital meal carts are physicians, nurses, patients and their families as they form part of the health care team as rightly observed in some hospitals (Wetterneck et al., 2012). Lin et al., (2006) attributed musculoskeletal and low back disorders to over exertion of the body when the operator works to meet the demand of Manual Material Handling (MMH) tasks. Thus, the use of ergonomic principle in the design and evaluation of human work has been adopted in the workplace to minimize the occurrence of work-related musculoskeletal injuries.

Ayodeji et al., (2015) identified the ergonomics and design problems of the Nigerian hospital meal carts by conducting an evaluation through questionnaires administration in which it was established that pains, soreness and discomfort are being experienced by users at their shoulders, forearms, wrists and legs. In view of this, this research finding has led to the need for improvement or redesigning of Nigerian hospital meal carts as corroborated by the findings of (Omotade, 1989; Carayon et al., 2013; Gurses et al., 2012; Institute of Medicine, 2012; Leape et al., 2002; Pronovost and Goeschel, 2011; Pronovost and Weisfeldt, 2012).

Therefore, this article presents the design of an automated hospital over bed meal carts with features providing the ease at which the discomfort experienced by initial meal carts have been eliminated. The design aims at attaching the meal cart directly to the bed for the patient to reduce the need for assistance in order to operate and adjust it to convenient position while sitting, hence reducing the fatigue experienced by health workers at the end of the day’s work using the anthropometric parameter of adult working class in Nigeria with reference to (Igboanugo et al., 2002). The over-bed table/meal cart is designed to use locally sourced material like plywood, 1” pipes, bolt and nuts, bearings and just to mention a few for ease of maintenance and light-weighting.

Fig. 1: Some hospital meal carts: (a) Cupboard Type Hospital Meal Cart; (b) over bed table meal (Ayodeji et al., 2015)
2 THE REDESIGNED AUTOMATED MEAL CART

Generally, over-bed table / meal cart are constructed with hollow pipes of an inch diameter steel pipe. While the table head is constructed with plywood for the sake of light-weighting of the cart.

The basic features in the redesigned over-bed table / meal cart include the following:

i. Automation: the over-bed table is designed and constructed with the inclusion of direct current (D.C.) electric motors that will control the basic movements of the table when necessary. This will help the patient to control the table with little or no assistance from anybody.

ii. Height Adjustment: the table is designed and constructed with adjustable height in order for it to be ergonomically fit for any user. Therefore the height can be adjusted to the user’s best position.

iii. Forth and Back Movement: the table is designed and constructed with capacity to move forth and back on the bed. This will enable the user to place the table at a convenient position during use.

The over-bed table / meal cart is designed to use locally sourced material like plywood, 1” pipes, bolt and nuts, bearings and just to mention a few for ease of maintenance and light-weighting.

2.1 DESIGN FOR ERGONOMICS COMPLIANCE USING ANTHROPOMETRIC DATA

i. Minimum Height of Table: The minimum height of the over-bed table from the top of the bed frame is equivalent to the elbow rest height while sitting (Ayodeji et al., 2015).

Elbow rest height while sitting of 5th percentile Male to 95th percentile Female is determined taking the mean of the below data using Equation 1 (Stroud and Booth, 2007).

\[
\text{Mean Value} = \sum \frac{f \cdot x}{f} \tag{1}
\]

where \( f \) = frequency
\( x \) = value / score

5th percentage Male = 16.0 cm
50th percentage Male = 21.0 cm
95th percentage Male = 31.4 cm
5th percentage Female = 16.0 cm
50th percentage Female = 21.0 cm
95th percentage Female = 29.1 cm

\( \therefore \) Therefore, Minimum height of table above the bed frame = 22.42 cm

ii. Maximum Height of Table: The maximum height of the over-bed table / meal cart above the bed frame is equivalent to the shoulder height while sitting:

Shoulder height while sitting of 5th percentile Male to 95th percentile Female is determined taking the mean of below data using Equation 1.

5th percentage Male = 46.6 cm
50th percentage Male = 56.0 cm
95th percentage Male = 66.0 cm
5th percentage Female = 44.0 cm
50th percentage Female = 53.0 cm
95th percentage Female = 62.0 cm

\( \therefore \) Therefore, maximum height of the table above the bed frame = 54.6 cm

2.2 STRUCTURAL DESIGN

The parts that are more susceptible to failure are the stands (column) that bear the table top. The force that the table will be subjected to mostly is axially directed pushing forces. Since the column is subjected to compressive load and the load gradually increases, it will get to a point where the column will be subjected to ultimate load, beyond this, the column will fail by bending i.e. buckling. Using Euler’s Buckling Load Equation 2 (Khurmi, 2012), buckling load for column is determined.

\[
W_{cr} = \frac{\pi^2 E I}{L^2} \tag{2}
\]

where

\( W_{cr} \) = Buckling Load for column
\( E \) = Yong’s Modulus for the Material
\( L \) = length of material under buckling

\( I \) = Moment of Inertia = \( \frac{nd^4}{64} \) \tag{3}

Each of the two stands has a height of 546 mm i.e. the maximum height of the table and diameter of 25.4mm.

\( \therefore \) \( W_{cr} = \frac{\pi^2 \times 2 \times 10^5 \times 2 \times 10^4}{25.4^2} = 530 \text{ KN} \)

Therefore the maximum load the table can carry before it begins to fail is 530 KN.

2.3 DESIGN FOR CHAIN SELECTION

The Length of Chain (L) required is determined using Equation 4 (Khurmi and Gupta, 2005; Bansal, 2005).

\[
L = P \times K \tag{4}
\]

Where

\( L \) = Length of chain
\( P \) = Pitch of chain
\( K \) = number of links of chain

The number of links of Chain (K) is determined using Equation 5 (Khurmi and Gupta, 2005).

\[
K = \frac{\left( \frac{t_1 + t_2}{2} \right) + \frac{2X}{P} + \left( \frac{t_2 - t_1}{2} \right)^2}{\frac{P}{2}} \tag{5}
\]

Where

\( t_1 \) = Number of teeth on the smaller sprocket
\( t_2 \) = Number of teeth on the larger sprocket
\( X \) = Centre distance
\( P \) = Pitch of chain

Rated power of the motor is 0.18 KW with speed of 60 r.p.m

The Velocity ratio of chain drive is as given in Equation 6 (Bansal, 2005)

\[
V.R. = \frac{n_1}{n_2} \tag{6}
\]

Where

\( n_1 \) = speed of rotation of the smaller sprocket in r.p.m.
\( n_2 \) = speed of rotation of larger sprocket in r.p.m.

\( T_1 \) = number of teeth on the smaller sprocket
\( T_2 \) = number of teeth on the larger sprocket

\( \therefore \) \( n_1 = 60 \text{ r.p.m.} \)

\( n_2 = 60 \text{ r.p.m.} \) (since the legs of the table must be lifted at the same time)

The Velocity Ratio, V.R. is determined as

\[
V.R. = \frac{60}{\frac{60}{31}} = 1 \tag{7}
\]

Number of teeth \( T_1 \) for smaller sprocket for a velocity ratio of \( 1 = 31 \)

\( \therefore \) number of teeth \( T_2 \) for larger sprocket = 31

The design power is as given in Equation 7 (Bansal, 2005).

Design power = Rated power \times Service factor (K.)
The service factor (K_s) is the product of factors K_1, K_2, K_3. The values of these factors are taken as follows (Khurmi and Gupta, 2005):

- Load Factor (K_1) for variable load with mild shock = 1.25.
- Lubrication Factor (K_2) for periodic lubrication = 1.5
- Rating Factor (K_3) for 8 hours per day = 1.0

.: Service factor K_s = K_1 x K_2 x K_3 = 1.25 x 1.5 x 1.0 = 1.875

From Table 1, for a pinion speed of 100 r.p.m, the power transmitted for chain number 8 is 0.64KW. Therefore a chain number 8 with one strand can be used to transmit the required power. Also from standard table on characteristics of roller chain according to ISO: 2403 — 1991, other parameters needed for the design are computed.

\[
P = \text{Pitch in mm} = 12.70 \text{ mm} \\
d = \text{Roller diameter, } d = 8.51 \text{ mm} \\
W = \text{Width of roller, } W = 7.75 \text{ mm} \\
B = \text{Breaking Load, } B = 17.8 \text{ KN} \\

\text{The pitch circle diameter of the pinion (d_1) is given by Equation 8 (Bansal, 2005).}
\]

\[
d_1 = P \csc \left( \frac{180}{T_1} \right) \\
\]

Where: 
- P = Pitch of chain
- T_1 = number of teeth on the pinion

\[
d_1 = 12.70 \csc \left( \frac{180}{31} \right) \text{ mm} = 125.46 \text{ mm} = 0.123 \text{ m} \\
\]

Since T_1 = T_2:

.: Pitch circle diameter of the larger sprocket d_2 = 0.123m

\[
V_1 = \frac{\pi \times d_1 \times N_1}{60} = 0.39 \text{ m/s} \\
W = \frac{\text{rated power}}{\text{pitch line velocity}} \\
\]

\[
W = \frac{0.18}{0.39} = 0.462 \text{ KN} = 462 \text{ N} \\
\]

Factor of safety = \frac{W_B}{W} (Khurmi and Gupta, 2005).

Where W_B = Breaking Load; W = Load on the chain

\[
\text{Factor of safety} = \frac{17.8 \times 10^3}{462} = 38 \\
\]

The minimum centre distance between the smaller and larger sprockets should be 30 to 50 times the pitch (Khurmi and Gupta, 2005).

.: centre distance between the sprockets = 40P

Where P is the pitch in mm

.: centre distance = 40 \times 12.70 = 508 \text{ mm}

In order to accommodate initial sag in the chain, the value of centre distance must be reduced by 2 to 5mm (Khurmi and Gupta, 2005).

.: correct centre of distance; x = 508 - 4 = 504mm

Using equation (5):

\[
K = 110; \\
L = K \times P = 110 \times 12.70 = 1.397m \\
\]

### 2.4 Working Mechanism of the Re-designed Automated Hospital Over-Bed Meal Cart

#### 1. Adjustment of Table Height

Adjusting the height of the table make use of bolt and nut mechanism. The legs of the table are constructed like hydraulic cylinder in other to give room for adjustment. A d.c. motor that can rotate in clockwise and anticlockwise direction is attached to the end of one of the legs as shown in Figure 2. A chain can also be used to connect the two legs together by the use of sprockets in order to transfer the motion from motor to both legs at the same time for both to move together as shown in Figure 3. Control switches are provided to activate the electric motors either to move in clockwise or anticlockwise direction. If the motor move in clockwise direction the bolt tightens in the nut thereby reducing the height and if in anticlockwise direction, it loses and the height increases.

#### 2. Forward and Backward Movement of the Table

To move the table forward and backward also involves the use of bolt and nut as the working mechanism. A stud (long bolt) with large pitch of thread (to enhance speed) is used as shown in Figure 4. The nut is attached in between the legs of the table as shown in Figure 5. An electric motor that can rotate in both clockwise and anticlockwise direction is attached to one end of the stud as shown in Figure 6. As the motor rotates in clockwise direction, the table slides forward with the aid of the nut attached to the stud and with the help of the sliding slot and bearing provided by the side of the bed frame and table legs respectively. Also the motor rotates anticlockwise, the table slides backward.

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**Table 1. Power rating (in KW) of simple roller chain**

| Speed of Smaller Sprocket or Pinion | Power (KW) |
|------------------------------------|------------|
| 6B                                 | 0.25       |
| 8B                                 | 0.64       |
| 10B                                | 1.18       |
| 12B                                | 1.52       |
| 16B                                | 2.01       |

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**Fig. 2: Height adjustment mechanism with D.C. electric motor**

**Fig. 3: Height adjustment mechanism for both legs using chain drive for power transmission**
Fig. 4: Stud used for the forward and backward movement

Fig. 5: Forth and back movement mechanism using bolt and nut system

Fig. 6: Forward and backward movement mechanism using bolt and nut system and a D.C. electric motor

Table 2: Cost estimate for fabrication of the improved hospital over-bed meal table

| S/N | Material                     | Quantity | Cost (₦) | Material                      | Quantity | Cost (₦) |
|-----|------------------------------|----------|----------|------------------------------|----------|----------|
| 1   | 30 mm Galvanized Pipe        | 4 Feet   | 800      | 1.5 inch Pipe (Black)        | 2 Length | 2,300    |
| 2   | 1 inch Galvanized Pipe       | 4 Feet   | 500      | 1.5 mm Plate                 |          |          |
| 3   | 1.5 inch Pipe (Black)        | 1/2 Length | 600      | Wheel                        | 4        | 4,800    |
| 4   | 1.5 inch Angle               | 2 Length | 2400     | Brake System                 | 2        | 1600     |
| 5   | Chain                        | 1        | 450      | Synthetic Rubber            | 2        | 400      |
| 6   | Sprocket                     | 2        | 400      | Electrode                    | 1 pack   | 2,500    |
| 7   | Bearing                      | 4        | 600      | Cutting Disc                 | 1        | 500      |
| 8   | Stud                         | 1        | 2500     | Grinding Disc                | 1        | 350      |
| 9   | Bolt and Nut                 | 2 Dozens | 700      | Miscellaneous                |          | 2,000    |
| 10  | Electrode                    | 1 pack   | 2,500    | Labour                       |          | 10,000   |
| 11  | Cutting Disc                 | 1        | 500      |                              |          |          |
| 12  | Grinding Disc                | 1        | 350      |                              |          |          |
| 13  | D.C. Motor                   | 2        | 8,000    |                              |          |          |
| 14  | Miscellaneous                |          | 3,500    |                              |          |          |
| 15  | Labour                       |          | 20,000   |                              |          |          |
|     | TOTAL                        |          | 43,800   |                              |          | 28,450   |

Fig. 7: Automated hospital over bed meal table

Fig. 8: Improved two layer hospital meal cart
2.5 BILLING OF ENGINEERING MATERIALS AND EVALUATION

The cost estimate (BIME) for the fabrication of the improved hospital meal cart is presented in Table 2.

Table 3. Operator scores obtained for operational survey of the re-designed meal carts and Chi-Square test for responses to the factors

| S/N | Design and Other Factors                  | Median | Interquartile Range | Chi-Sqr. Test: p-value |
|-----|------------------------------------------|--------|---------------------|-----------------------|
| 1   | Getting the four wheel Cart into Motion  | 0.000  | 0.000               | 0.777                 |
| 2   | Turning the four wheel Cart              | 0.000  | 0.000               | 0.157                 |
| 3   | Seeing over the four wheel Cart          | 0.000  | 0.000               | 0.090                 |
| 4   | Placing and Removing Trays               | 0.000  | 0.000               | 0.572                 |
| 5   | Opening and Closing Doors                | 0.000  | 0.000               | 0.258                 |
| 6   | Handle Height (Pushing)                  | 2.000  | 2.000               | 0.106                 |
| 7   | Handle height (Pulling)                  | 2.000  | 2.000               | 0.062                 |
| 8   | Force use to stop Cart                   | 3.000  | 3.000               | 0.777                 |
| 9   | Need for Emergency Brake                 | 2.000  | 2.000               | 0.396                 |
| 10  | Need for Parking Brake                   | 2.000  | 2.000               | 0.777                 |
| 11  | Overall Work Load                        | 3.000  | 3.000               | 0.052                 |

The re-designed automated over-bed meal table and improved two layer hospital meal cart are shown in Figures 7 and Figure 8 respectively.

2.6 EVALUATION OF THE IMPROVED HOSPITAL OVER BED MEAL TABLE

The performance evaluation of the developed carts was carried out by experienced users of the conventional carts that were initially evaluated. The operators were giving questionnaire (same type of questionnaire used by Ayodeji et al., (2015) for evaluating Nigerian hospital meal carts) to fill at the end of the day’s shift after making use of the improved meal carts for a period of seven days. The responses obtained from ergonomic evaluation of the re-designed hospital meal carts were analyzed using SPSS to obtain the non-parametric Chi-Square test as well as the median and interquartile range. The result of the operational survey which is the effect of design factors on the use of the re-designed hospital meal carts is presented in Table 3

The result of the biomechanical survey which is the response on discomfort felt by the users on the different body region while using the re-designed hospital meal carts is presented in Table 4 and Table 5. Evaluation of the re-designed hospital meal carts were carried out and the results of the operational and biomechanical survey were presented in Table 3 to Table 7. The performance evaluation was carried out with referential comparison between available hospital meal carts in Nigeria and the redesigned hospital meal carts presented in this paper.

The median scores for handle height placement while pushing and handle height placement while pulling the cart was 2.000 (Table 3) revealing that they are low, however the percentage of responses with moderate (44%) is higher than the percentage of low (36%) (Table 5), and the chi-square test also shows no significant difference since p>0.050 in the responses of the users. Figure 9 shows the chart comparing the handle height place while pushing of the existing cart and the re-designed cart; the charts shows 0% of users complained of handle height placement been too low, 8% and 36% of the users said the handle height is low for existing meal cart and re-designed meal cart respectively, 22% and 44% of the users accept that the handle height is moderate for the existing and re-designed meal cart respectively, 58% and 20% of the users responded that the handle height placement is high for the existing and the re-designed meal cart respectively while 12% of the users responded that the handle height placement for the existing meal cart is too high.

Also the biomechanical survey (Table 6 - 7) reflects the effect of the design factors that were improved upon in the modified meal cart on the different region of the user’s body. Left upper back, right upper back, left upper arm, and right shoulder had a median score of 1.000 (Table 5) revealing feeling of slight pain or soreness as oppose feeling of pain or soreness in the conventional meal carts.

Figure 10 shows the comparison chart of the feeling of discomfort on the upper back between the existing meal cart and re-designed meal cart; 38% and 42% of the users have no feeling of discomfort on the left and right upper back respectively in the re-designed meal cart against 20% in both right and left upper back in the existing meal cart. 26% of users responded to slight pain or soreness on both left and right upper back in the re-designed against 28% and 26% respectively in the existing meal cart. 14% and 12% of the users responded to the discomfort feeling of pain or soreness on the left and right upper back respectively against 36% feeling of pain or soreness on the left and right upper back in the existing meal cart. 20% and 18% of the users responded to the feeling of strong pain and soreness on both left and right upper back respectively in the re-designed meal cart against 12% of users on both left and right.
upper back in the existing meal carts. 2% of users responded to the feeling of extreme pain or soreness on both left and right upper back respectively in the re-designed meal cart against 4% and 6% of feeling of extreme pain or soreness on the left and right upper back respectively in the existing meal cart. Figure 11 shows the chart of comparison of feelings of discomfort on the shoulder between the existing meal cart and the re-designed meal cart. 44% and 38% of the users responded to no feeling of pain or soreness on the left and right shoulder respectively in the re-designed meal cart against 24% and 18% on the left and right shoulder respectively in the existing meal cart. 54% and 36% of the users responded to the feeling of slight pain or soreness on the left and right shoulder respectively in the re-designed meal cart while 56% and 32% of the users responded to slight feeling of pain or soreness on the left and right shoulder respectively in the existing meal cart. 2% and 26% responded to feeling of pain and soreness on the left and right shoulder respectively in the re-designed meal cart against 16% and 36% on the left and right shoulder in the existing meal cart. 0% of the users responded to feeling of strong pain or soreness on both left and right shoulder in the re-designed meal cart against 4% on both left and right shoulder in the existing meal cart. Also 0% responded to feeling of extreme pain or soreness on both left and right shoulder against 0% and 10% on the left and right shoulder respectively in the existing meal cart.

Table 4. Discomfort scale scores for the body region of the improved hospital meal cart and Chi-Square test for response to the body region

| S/N | Body Region | Left | Median | Interquartile Range | Chi-Sqr. Test: p-value | Right | Median | Interquartile Range | Chi-Sqr. Test: p-value |
|-----|-------------|------|--------|---------------------|-----------------------|--------|--------|---------------------|-----------------------|
| 1   | Neck        | 1.000| 1.000  | 0.025               | 1.000                 | 1.000  | 1.000  | 0.016               | 1.000                 |
| 2   | Upper back  | 1.000| 1.000  | 0.061               | 1.000                 | 1.000  | 1.000  | 0.116               | 1.000                 |
| 3   | Shoulder    | 1.000| 1.000  | 0.396               | 1.000                 | 1.000  | 1.000  | 0.396               | 1.000                 |
| 4   | Upper Arm   | 1.000| 1.000  | 0.062               | 1.000                 | 1.000  | 1.000  | 0.106               | 1.000                 |
| 5   | Mid-to-lower back | 0.000| 0.000  | 0.777               | 0.500                 | 0.500  | 1.000  |                   |                       |
| 6   | Elbow       | 1.000| 1.000  | 0.072               | 1.000                 | 1.000  | 1.000  | 0.052               |                       |
| 7   | Fore-Arm    | 1.000| 1.000  | 0.052               | 1.000                 | 1.000  | 1.000  | 0.078               |                       |
| 8   | Buttock     | 1.000| 1.000  | 0.258               | -                     | -      | -      |                    |                       |
| 9   | Wrist       | 1.000| 1.000  | 0.021               | 1.000                 | 1.000  | 1.000  | 0.011               |                       |
| 10  | Hand        | 0.000| 0.000  | 0.258               | 0.000                 | 0.000  | 0.258  |                    |                       |
| 11  | Fingers     | 1.000| 1.000  | 0.157               | 1.000                 | 1.000  | 1.000  | 0.258               |                       |
| 12  | Thigh       | 1.000| 1.000  | 0.012               | 1.000                 | 1.000  | 1.000  | 0.015               |                       |
| 13  | Knee        | 1.000| 1.000  | 0.258               | 1.000                 | 1.000  | 1.000  | 0.157               |                       |
| 14  | Lower Leg   | 1.000| 1.000  | 0.016               | 1.000                 | 1.000  | 1.000  | 0.021               |                       |
| 15  | Ankle or Foot | 0.000| 0.000  | 0.396               | 0.000                 | 0.000  | 0.572  |                    |                       |

Note: There is significant difference when p<0.050

Table 5. Frequency and percentage frequency of scores obtained for operational survey of improved hospital meal carts.

| S/N | Design and Other Factors         | F %F | %F | %F | %F | %F | %F | %F |
|-----|----------------------------------|------|----|----|----|----|----|----|
| 1   | Getting the four wheel Cart into Motion | 26   | 52 | 24 | 48 | 0  | 0  | 0  |
| 2   | Turning the four wheel Cart      | 30   | 60 | 20 | 40 | 0  | 0  | 0  |
| 3   | Seeing over the four wheel Cart  | 31   | 62 | 19 | 38 | 0  | 0  | 0  |
| 4   | Placing and Removing Trays       | 27   | 54 | 23 | 46 | 0  | 0  | 0  |
| 5   | Opening and Closing Doors        | 29   | 58 | 21 | 52 | 0  | 0  | 0  |
| 6   | Handle Height (Pushing)          | 0    | 0  | 18 | 36 | 22 | 44 | 10 | 20 |
| 7   | Handle height (Pulling)          | 0    | 0  | 19 | 38 | 22 | 44 | 9  | 18 |
| 8   | Force use to stop Cart           | 0    | 0  | 0  | 0  | 26 | 52 | 24 | 48 |
| 9   | Need for Emergency Brake         | 22   | 44 | 28 | 56 | 0  | 0  | 0  |
| 10  | Need for Parking Brake           | 24   | 48 | 26 | 52 | 0  | 0  | 0  |
| 11  | Overall Work Load                | 0    | 0  | 0  | 10 | 20 | 24 | 48 | 16 | 32 |

Note: F is Frequency
The force required to stop the cart while in motion had a median score of 3.000 (Table 3) reflecting moderate on the questionnaire and the p-value (0.777) showed that there is no significant difference in the responses of the operators while the percentage of moderate as response from the operator (52%) is higher than that of high (48%) (Table 5). Also, the result from the biomechanical survey (Table 6) revealed that the left mid-to-lower back and right upper arm had median score of 0.000 and 0.500 respectively revealing the feeling of no pain or soreness in the mid-to-lower back and a range between feeling of no pain or soreness and slight pain or soreness in the right upper arm region. The chi-square test also reveals that responses (Table 6) of the users show no significant difference. Figure 12 shows the chart of comparison of feeling of discomfort on the mid to lower back between the conventional meal cart and re-designed meal cart; 52% and 44% of users responded to no feeling of pain or soreness on the left and right mid to lower back respectively in the re-designed meal cart against 24% and 22% on the left and right mid to lower back respectively in the existing meal cart. 48% and 56% responded to feeling slight pain or soreness on the left and right mid to lower back respectively in the re-designed meal cart while 28% and 54% responded to feeling of slight pain or soreness on the left and right mid to lower back respectively in the existing meal cart. 0% of the users responded to feeling of pain or soreness on the left and right mid to lower back in the re-designed meal cart against 30% and 18% on the left and right mid to lower back respectively in the existing meal cart. Also 0% of the users responded to feeling of strong pain or soreness on the left and right mid to lower back in the re-designed meal cart against 16% and 4% on the left and right mid to lower back respectively in the existing meal cart. Also 0% of users responded to feeling of extreme pain or soreness on both left and right mid to lower back in the re-designed meal cart against 2% in both left and right mid to lower back in the existing meal cart.

Table 6. Frequency and Percentage Frequency of Discomfort Scale Score of Users on the Improved Hospital Meal Carts

| S/ N | Body Region | Left |  | Right |  |
|------|-------------|-----|---|-------|---|
|      |             | F% | F% | F% | F% | F% | F% | F% | F% | F% | F% | F% | F% | F% |
| 1    | Neck        | 11  | 22 | 21  | 42  | 12  | 24  | 6   | 12  | 0   | 9   | 18  | 21  | 42  | 14  | 28  | 6   | 12  | 0   |
| 2    | Upper back  | 19  | 38 | 13  | 26  | 7   | 14  | 10  | 20  | 1   | 2   | 21  | 42  | 13  | 26  | 6   | 12  | 1   |
| 3    | Shoulder    | 22  | 44 | 27  | 54  | 1   | 2   | 0   | 0   | 0   | 19  | 38  | 18  | 36  | 13  | 26  | 0   | 0   |
| 4    | Upper arm   | 9   | 18 | 19  | 38  | 22  | 44  | 0   | 0   | 0   | 25  | 50  | 25  | 50  | 0   | 0   | 0   | 0   |
| 5    | Mid-to-lower back | 26  | 52 | 24  | 48  | 0   | 0   | 0   | 0   | 0   | 22  | 44  | 28  | 56  | 0   | 0   | 0   | 0   |
| 6    | Elbow       | 15  | 30 | 14  | 28  | 7   | 14  | 10  | 20  | 4   | 8   | 15  | 30  | 14  | 28  | 6   | 12  | 11  |
| 7    | Fore-arm    | 14  | 28 | 15  | 30  | 8   | 16  | 10  | 20  | 3   | 6   | 13  | 25  | 15  | 30  | 9   | 18  | 10  |
| 8    | Buttocks    | 21  | 42 | 29  | 58  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 9    | Wrist       | 13  | 26 | 21  | 42  | 10  | 20  | 6   | 12  | 0   | 0   | 12  | 24  | 22  | 44  | 10  | 20  | 6   |
| 10   | Hand        | 29  | 58 | 21  | 42  | 0   | 0   | 0   | 0   | 0   | 21  | 42  | 29  | 58  | 0   | 0   | 0   | 0   |
| 11   | Fingers     | 20  | 40 | 30  | 60  | 0   | 0   | 0   | 0   | 0   | 29  | 58  | 21  | 42  | 0   | 0   | 0   | 0   |
| 12   | Thigh       | 14  | 28 | 21  | 42  | 10  | 20  | 5   | 10  | 0   | 0   | 13  | 25  | 21  | 42  | 11  | 22  | 5   |
| 13   | Knee        | 21  | 42 | 28  | 59  | 0   | 0   | 0   | 0   | 0   | 20  | 40  | 30  | 60  | 0   | 0   | 0   | 0   |
| 14   | Lower leg   | 16  | 28 | 21  | 42  | 9   | 18  | 6   | 12  | 0   | 0   | 13  | 25  | 21  | 42  | 10  | 20  | 6   |
| 15   | Ankle or foot | 28  | 56 | 22  | 44  | 0   | 0   | 0   | 0   | 0   | 27  | 54  | 23  | 46  | 0   | 0   | 0   | 0   |
Table 7. Frequency and Percentage Frequency of Discomfort Scale Score of Users on the Existing Hospital Meal Carts

| S/N | Body Region   | Left Side | No Feeling of Pain or Soresness | Slight Pain or Soresness | Pain or Soresness | Strong Pain or Soresness | Extreme Pain or Soresness | No Feeling of Pain or Soresness | Slight Pain or Soresness | Pain or Soresness | Strong Pain or Soresness | Extreme Pain or Soresness |
|-----|--------------|-----------|-------------------------------|--------------------------|-----------------|-------------------------|--------------------------|-----------------------------|--------------------------|-----------------|------------------------|------------------------|
| 1   | Neck         | F 13 %   | F 26 %                       | F 21 %                   | F 42 %          | F 10 %                  | F 20 %                   | F 0 %                        | F 12 %                   | F 0 %           | F 0 %                  | F 0 %                  |
| 2   | Upper Back   | F 20 %   | F 20 %                       | F 14 %                   | F 28 %          | F 18 %                  | F 36 %                   | F 6 %                        | F 12 %                   | F 2 %           | F 0 %                  | F 0 %                  |
| 3   | Shoulder     | F 12 %   | F 24 %                       | F 28 %                   | F 56 %          | F 8 %                   | F 16 %                   | F 2 %                        | F 4 %                     | F 0 %           | F 0 %                  | F 0 %                  |
| 4   | Upper Arm    | F 6 %    | F 12 %                       | F 14 %                   | F 28 %          | F 56 %                  | F 4 %                    | F 2 %                        | F 3 %                     | F 1 %           | F 0 %                  | F 0 %                  |
| 5   | Lower Back   | F 24 %   | F 24 %                       | F 28 %                   | F 15 %          | F 30 %                  | F 8 %                    | F 6 %                        | F 2 %                     | F 4 %           | F 0 %                  | F 0 %                  |
| 6   | Elbow        | F 15 %   | F 30 %                       | F 14 %                   | F 28 %          | F 7 %                   | F 10 %                   | F 4 %                        | F 8 %                     | F 18 %          | F 10 %                 | F 24 %                 |
| 7   | Forearm      | F 24 %   | F 24 %                       | F 28 %                   | F 14 %          | F 28 %                  | F 16 %                   | F 2 %                        | F 4 %                     | F 18 %          | F 12 %                 | F 24 %                 |
| 8   | Buttck       | F 24 %   | F 24 %                       | F 28 %                   | F 15 %          | F 30 %                  | F 8 %                    | F 6 %                        | F 2 %                     | F 4 %           | F 0 %                  | F 0 %                  |
| 9   | Wrist        | F 16 %   | F 32 %                       | F 64 %                   | F 2 %           | F 4 %                   | F 0 %                    | F 0 %                        | F 0 %                     | F 0 %           | F 0 %                  | F 0 %                  |
| 10  | Hand         | F 26 %   | F 52 %                       | F 24 %                   | F 48 %          | F 4 %                   | F 0 %                    | F 0 %                        | F 0 %                     | F 0 %           | F 0 %                  | F 0 %                  |
| 11  | Fingers      | F 20 %   | F 40 %                       | F 30 %                   | F 60 %          | F 0 %                   | F 0 %                    | F 0 %                        | F 0 %                     | F 0 %           | F 0 %                  | F 0 %                  |
| 12  | Thigh        | F 24 %   | F 48 %                       | F 22 %                   | F 44 %          | F 4 %                   | F 8 %                    | F 0 %                        | F 0 %                     | F 0 %           | F 0 %                  | F 0 %                  |
| 13  | Knee         | F 23 %   | F 42 %                       | F 29 %                   | F 58 %          | F 0 %                   | F 0 %                    | F 0 %                        | F 0 %                     | F 0 %           | F 0 %                  | F 0 %                  |
| 14  | Lower Leg    | F 20 %   | F 40 %                       | F 18 %                   | F 36 %          | F 10 %                  | F 20 %                   | F 2 %                        | F 4 %                     | F 0 %           | F 0 %                  | F 0 %                  |
| 15  | Ankle or Foot| F 26 %   | F 52 %                       | F 24 %                   | F 48 %          | F 0 %                   | F 0 %                    | F 0 %                        | F 0 %                     | F 0 %           | F 0 %                  | F 0 %                  |

3 Conclusion

Based on the results from the ergonomic evaluation, improved hospital meal carts were re-designed and fabricated using Nigerian adult working class anthropometric data in the design parameters. The improved hospital meal carts are; two layer hospital meal cart and automated over-bed table / meal cart. The two layer hospital meal cart focuses on reducing the problem of handle height position as well as the force required stopping the cart while in motion and the automated over-bed table focuses on providing hospital meal cart that can be operated by the patient with little or no assistance from anyone. Evaluation of the fabricated meal carts were carried out by the health workers that uses the conventional hospital meal cart that were visited for the ergonomic evaluation of the conventional hospital meal cart using same questionnaire used for evaluation of existing meal carts.

The result of the evaluation of the improved meal carts shows that only 20% of the operators described the handle height as high, 52% of the described the force use to stop the cart as moderate while only 32% described the overall work load as very hard. These improvements over the existing meal carts in the areas of handle height placement, ease of stopping the meal cart especially if in motion and the incorporation of brake system for emergency stop and to facilitate the ease of stopping the meal cart and the overall workload reduction through the use of automated over-bed table by patient which required little or no support for the patient to use, all of these contributed to the improved hospital meal carts reducing the risk of musculoskeletal problems among health workers and patients.

The re-designed automated hospital table / meal cart can be attached to any existing hospital bed in the adult wards. The re-designed meal cart is recommended to hospitals in Nigeria for the use of their various wards especially in the adult wards. It is also recommended for manufacturers of hospital equipment in Nigeria because the materials needed are readily available locally and the cart can be produced and maintained at a cheaper price compared with the imported ones.

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