A conceptual method for developing a Torso Assisted Orthopedic Support Brace (TAOSB) device for people with spinal deformities

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Abstract. This paper proposes a concept for design, analysis and development of Torso Assisted Orthopedic Support Brace (TAOSB) device for the unique rehabilitation needs of Camptocormia patients. TAOSB device will facilitate an upright posture and also give assistance to bend and perform the daily activities such as using toilet, cooking, gardening, etc., Posture Instability (Stooped Posture) as being the preeminent reason for the Fear of Falling (FOF), this TAOSB will aid to reduce the FOF. Considering the moral values of the patients the device needs to be developed to meet the aesthetic needs and comforts which can be achieved through body fitted individual customization by using Additive Manufacturing Technology. This paper concludes with the need for relevant force and moment calculations based on the individual height and weight needs to be considered for developing the TAOSB device with adequate strength and safety aspects as a concern.

Keywords. Parkinson’s Disease (PD), Camptocormia, Back braces, Posture instability, Spinal deformities, Emed platform, TAOSB device.

1. Introduction

Parkinson’s Disease (PD) remnant incurable and progressive disease with severe postural deformities like Camptocormia, Antecollis, Pisa syndrome and Scoliosis which are labelled by Dr. James Parkinson [1]. These abnormalities affect the motor functions of PD patients and possibly compacts the quality of life. The pathophysiology behind the impairments are unidentified and managing these remains difficult [2].

The word Camptocormia is comprised of two Greek words “Kamptos” (to bend) and “Kormos” (trunk) invented by the French neurologist Souques in the year 1915 [3] and was described for a PD patient with bent spine in 1999[4]. Camptocormia or Bent Spine syndrome is the disorder, impaired with forced abnormal posture of trunk and flexion in the thoracolumbar spine of ≥ 450 [5] often accompanying with PD patients which shows up during standing or walking and abates in the recumbent position [6] as shown in figure 1. During the advancement of PD, the involuntary posture abnormality leads to back pain, gait problems and posture instability etc. [5]. Treatments of pharmacological efforts are often unsatisfactory for these impairments [6].

Treatments for this condition focused mainly on preventing the curve progression (Braces) to evade primary difficulties from worsening curvature of spine involves back pain, respiratory problems and
complications with patient care [7]. Among all the deformities discussed earlier, Camptocormia is remained as the research of interest for this paper and discussed furthermore.

PD abnormalities can be recognized throughout the body namely flexion to the anterior, lateral or an-terolateral parts of the trunk, neck flexion, flexion of the extremities, and abnormal postures of the hands, fingers and toes such as thalamic hand or hammer toe [1].

This research is restricted to forward flexion (Figure 1) which leads to Fear of Falling (FOF), intern grounds to fatal and non-fatal injuries or even death [8].

![Figure 1. (A) Extreme forward flexion of the thoracolumbar spine. (B) Resolved in the Supine position (C) In the recumbent position, no traces of fracture seen on the plane X-Ray [5].](image)

1.1. Demographics – falls with PD
Falls precedes to fatal and non-fatal injuries causing illness and deaths among older adults [9] and the risk is twice in the case of people with PD than other neurological diseases [10]. The collected data and analysis report from behavioural risk factor surveillance system survey and centres for disease control and prevention respectively in the year 2014, stated approximately 28.7 % of older adults’ experience at least one falls during the past 12 months, resulting with an estimation of 29.0 million falls and 7.0 million injuries in the United States [8]. The statistics also reported about 2.8 million with fall related injuries in the emergency departments for diagnosing and approximately 800,000 of them were hospitalized subsequently [8]. Dejectedly approximately 27000 older adults died because of the preceding falls during the same period [8].

Relating among men and women, the latter is more expected to report falling than men. As age being one of the foremost factor, falls increases with increase in age. Percentage of falls reported, according to the age groups 65 to 75 years, 75 to 84 years, 85 years above are 26.7 %, 29.8 %, and 36.5 % respectively [11].

Direct falls heads to injuries, Fear of Falling (FOF), weakened activity level, poor life quality and increased stress for caregivers [12]. The frequency of PD is likely to double from 2005 to 2030 in the developing countries which will extremely have an impact on the health care industries in the upcoming decades [13].

2. Treatments – clinical and non-clinical

2.1. Clinical methods
Regrettably, diagnosis terms or exact meanings are unavailable for camptocormia so doctors look for the 450 bent of thoracolumbar flexion which shows up during standing or walking and abates in the supine position [2]. The root cause behind the thoracolumbar flexion is yet to be ascertained, due to this availability of treatments are fewer for this disorder [2]. The trials with drugs haven’t worked so far as this disorder didn’t respond to levodopa, a drug used for PD, even levodopa drug has not responded well
with people with PD symptoms as well [2]. Understanding the difficulties of Camptocormia patients and from the demographics discussed, some Orthopedic device has been developed to enhance the quality of life.

2.2. Non-clinical methods – patents/market available products

Sèze et al., used a Thoraco-Pelvic Anterior Distraction (TPAD) device (Figure 2(A)) in a study to treat the people with camptocormia. This device used a chest plate to push torso to make it to upright position, whereas the hip belt and chest belt ensures the device stick to the body, resulting in increasing lumbar lordosis, thoracic kyphosis, and sagittal balance [14]. Though, the device lacks in improving the degrees of freedom which was restricting them from bending and carrying out daily activities like using toilet, cooking, gardening etc.

Brown, 1921 patented a mechanical Brace or Support (Figure 2(B)) for retaining erect posture of the operators who performs picking cotton and doing other duties being in the stooped posture which interns come up with back pain, weaken the spinal cord as they do it for longer periods. The device consists of right bars to hold it to the body and a helical spring was used to bring the torso to an upright equilibrium position.

Victor Toso, 1989 patented an upper torso garment (Figure 2(C)) for people to sit comfortably for longer period of time on the ground or on a bench with backless support being the torso straight. It was achieved through the force of pair of straps in the wearer’s knees, which will pull the torso so as to make it straight on extending legs longitudinally. The straps were coupled with buckles so as to use the same device for different individuals [15].

Mitchell et al., 2002 patented an Upper Body Support (Figure 2(D)) intended to use for the people under the circumstances requiring bending at waist to complete a task or work. The device consists of a dorsal member which is interconnected with the lower portion of the body and a resilient element connected to the latter which will born the weight of the body at least partly there through [17].

Mohammad Abdoli, 2009 patented a lift assist device (Figure 2(E)) and method for assisting the people to perform a motion such as lifting a weight. It consists of a first anchor, second anchor attached to the upper and lower body respectively, an elastic member connected to the upper and lower anchor stores energy and provides energy while performing the required task [18].

Daniel et al., 2011 patented a Torso Assist Orthosis device (Figure 2(F)) with a hinge making the upper portion, lower portion to be in connection and for torso assistance a spring (helical) device was used for storing and releasing energy. The device may be included as a preload adjustment [19] and the modified design of Torso assisted orthotic device (Figure 2(G)) was patented in the year 2013 [20].

Gregory et al., 2013 patented an Active Spinal Support System (Figure 2(H)) having an adapter for engaging the upper body, torso, head and a lower body adapter engaging the hips/pelvis. The upper body and lower body adapter are connected by an articulated structural column. The structural column containing tendons engaged to mechanical control element. The tendons are fixed at one end and each engaged to mechanical control element at the other end such that the tension/payout in each tendon is independent variable under direction of a controller receiving sensor feedback in order to support the loaded upper body of the wearer and position it relative to the lower body when desirable according to the controller [21].

Park et al., 2018 patented a lumbar device for PD patient’s waist orthosis. Considering the future growth of patients in terms of height and weight, Correction of posture is possible by adding customized weight in the provided rectangular box as shown in figure 2(I) according to the degree of leaning forward [22], but this device lack in facilitating or assisting the user to return to the equilibrium position.
Figure 2. Non-clinical methods- patents (A) Thoraco-pelvic anterior distraction (TPAD) device [14], (B) Brace or support for stoop labour [16], (C) Upper torso garment with integral back support [15], (D) Upper body support [17], (E) Lift assist device [18], (F) Torso assist orthosis [19], (G) Torso assist orthotic device [20], (H) Active spinal support system [21], (I) Lumbar device for Parkinson's patients [22].

2.3. Market available products
A detailed exploration of Internet database has aided in approaching with very limited products intended to overcome the posture instability as listed in the below table 1. Realized is that, not many products have been developed or tested in real time particularly for evading the difficulties of PD patients with Camptocormia. Literature survey revealed that all the research regarding the camptocormia is at the patent level.

Some of the braces that are available in the market related to posture correction highlighted in table 1 are for old agers, office workers etc., these are suitable for people who are intended to work for prolong durations which precedes to back pain, arthritis, herniated disc etc. These braces will remind the body
about standing, sitting and sleeping postures correctly and have been considered here as they partially do the function as per the papers research of interest.

2.4. Outcome of literature review:
Literature survey has facilitated in knowing the current treatments and aids developed for assisting PD patients with camptocormia. Among all other symptoms of PD, Posture instability/Stooped Posture leads to devastating falls which affect the quality of life of PD patients [25-26]. The patents (1921 to 2018), related braces available in the market proposes a lot of devices and methods for assisting PD patients, Camptocormia patients or for other spinal deformities.

Detailing about the research done at patent level, projected a number of concepts but not much of functional products are available. Looking at the comfort, customization of individuals and moral values of the patients, the proposed device are in the patent levels (1921 to 2018). On the other hand, the market available products related to the research of interest listed in the table 1. These products provide the comfort and are light weight but there lacks in terms of assistance required for torso.

Table 1. Market available products for posture corrections of people with spinal deformities.

| Product name | Description |
|--------------|-------------|
| **Calibrace** | Brace used to improve the posture of people living with PD, Osteoporosis, Scoliosis or other cases that impact spine. No assistance provided for returning the torso from bent posture to equilibrium position. |
|              | It functions manually, improves posture by lifting up the shoulder and back to retain an equilibrium posture. Not customized |
|              | Only brace in available in market for PD patients [23]. Standard sizes only available |
| **Posture corrector Clavicle support brace -Comfy Med [24]** | In this design, for additional relaxed fit, straps and wraps were eliminated around the stomach. Rides up a little bit on wearing |
|              | Relief to the stomach Not customized |
|              | Standard sizes only available |
3. Mechanical design requirements of TAOSB device:

In order of improving the assistance and to attain the effectiveness in the product utilization, required is to understand the specific functionality of the device. This section provides a detailed outline in terms of the design requirements. Significant design calculations need to be accomplished for adequate strength requirements and the capability of the design to make the torso upright are studied. This includes the forces and moments produced by upper body weight, and additional weight picked by the patient also to be considered.

Figure 3(A) illustrates a side view of one embodiment of an TAOSB device with a patient in an upright position, figure 3(B), side view of the TAOSB device showing an inclined position of the patient for finding the spring rate required to give adequate counter balance torque for the specific patient and figure 3(C) shows a patient in a seated position.

According to the conceptual design, TAOSB device is to support the torso by using a chest provision with custom adjustments and is connected to the hip with a link as shown in figure 3(A). It is also required to transmit the related forces through the rigid spring to the legs with thigh cuffs. These components are made precisely for a high custom fit to suit the individual. Suppose, when an individual wish to bend over, all that’s essential is to lean forward and relax. Customized (or adjusted) springs will ensure to match the weight of the torso, \( W_T \) in order to counterbalance the effect of gravity generated because of torso weight. Once the individual task is completed in a bent position, the individual can resume to upright position with a very nominal muscle effort.

Figure 3. Free body diagram of TAOSB device in upright, inclined and seated position.
TAOSB assistance can be altered in relevance to the individual muscular capabilities. In case of
patients, who can support the weight of the torso to some extent may require lesser assistance.
Alternatively, patient with minimal muscular strength may require full assistance in making the torso
upright. Therefore, customization is highly demandable which can be achievable through the load
requirements of each individual patient.

Customization of the spring initiates is shown in figure 3(B), by appropriate measurement of torso
weight, $W_T$ and distance from the chest provision (A) to the centre of the patient hip joint (O). In order
to accomplish this, individual pelvis may be fixed to an object (a parallel bar may be used) in a standing
posture. Now to measure the length of torso, $L$, a strap is placed on the individual chest (A) and
measurement can be recorded from it to the center of hip joint (O).

A precise tension weight scale can be connected to the back strap of the individual and then ask the
patient to bend to an angle, $\alpha_1$, of 40 to 50 degrees and through the scale, a lifting force is applied at angle
desirable perpendicular to the torso, suppose in case of application of lifting force other than
perpendicular, then the angle between the lifting force and perpendicular is to designated as $\alpha_2$ [20].
Assuming $\alpha_2$ as zero, the three parameters required for sizing the spring can be measured: Length of the
torso, $L$, bent angle, $\alpha_1$ and lift force, $P$.

For achieving the optimum result of lift force, $P$, multiple attempts of lifts can be done to ensure
accurate force required for attaining equilibrium. When the equilibrium position is reached, lift force, $P$
shown on scale and lean angle is measured with a goniometer or arthrometer are recorded [20].
The torque, $T$, required for lifting the individual torso weight can be expressed from the free body
diagram as shown in figure 3(B). We know that,

\[ T = \text{Force} \times \text{Perpendicular distance} \]  

Therefore,

\[ T = [ P \times \cos \alpha_2 ] \times L \]  

Assuming $\alpha_2 = 0$ [20], the above equation (2) simplifies to,

\[ T = P \times L \]  

The spring rate, $R$ can be expressed as the ratio of torque, $T$ to the degree of lean angle, $\alpha_1$. Therefore,

\[ R = \frac{T}{\alpha_1} \]  

As shown in figure 3 (B), Torso weight, $W_T$ is due to force of gravity on leaning torso and the force
which is to be opposed by the spring is,

\[ W_T \times \sin \alpha_1 \]  

For camptocormia condition, the maximum operating range is approximately 45 degrees or less and
preload adjustments of 10 % constant spring rate can offer attainable counterbalance, but the ideal
combination of spring rate and preload solemnly depends on the physiology and capability of the patient
[20]. In order to assure a relaxed upright seated position as shown in figure 3(C), the spring or device
will have to facilitate a suitable mechanism for engaging and disengaging the spring. As seen through
the above section these were the involved design mechanisms that were adopted, but for the difficulty
in manufacturability of the TAOSB device these critical measuring facts are eliminated.

Along with the mechanical design requirements the device is to undergo further design requirements
in terms of;

- **Functional requirements.** This device can be worn as needed for the whole day when the
  patient is not sleeping or lying down and it should also facilitate relaxed standing sitting and
  slight twisting. The device should also apply necessary lift force at the mid-section of the spine
to make upright so as to worn throughout the day comfortably [27].
- **Safety.** In case of emergency the device must have a capability to be removed with ease, and to prevent skin irritation such as bed sores, breathable material can be used. Upon using the device, the patient shouldn’t depend completely on it, so that muscle strength is retained [27].

- **Accuracy and reliability.** The anthropometric data is unique for every individual, therefore the device must apply customized forces in respective locations and amounts when the patient in standing or sitting position [27].

- **Life in service.** As the device would be used for seven days a week, 10 hours day therefore it should last for at least 20 years [27].

- **Operating environment.** During the selection of brace material, operating environmental constraints needs to be determined [27].

- **Ergonomics.** The device should ideally facilitate motion of the patient without any restrictions and allow for the both extension upward (to reach high cabinet), to bend (for gardening) and should facilitate minor twisting [27].

- **Size.** The device should be small in order to reduce the weight and should fit through the unique body shapes of the patient, AM technology will be fruitful in this case.

- **Materials.** The usage of the device would be throughout the day and especially in kitchen environment, therefore flammable materials are not recommended. Device should be washable, resist against rusting over usage period and durable for the life in service [27].

- **Aesthetics, appearance and finish.** Disguisable, if possible. Potentially hidden beneath some clothing. However, patient expressed interest in function over fashion [27].

4. **Postural analysis**

A minimal of one fall during a year is happens with 1 out of 3 subjects aged over 65 and above or even at higher fall rates [28]. Every second fall precedes to injuries, fractures among 5-10% falls [29]. Approximately 70% of injuries to the subject are due to falls [30] where ageing increases the complexity and number of injuries [31].

Based on the type and complexity of injuries, the treatment cost varies wherein hip fractures being the most expensive so far [32]. PD patients have lesser capability in positioning the Center of Pressure (CoP) in comparison with younger or older subjects when they lean forward or backward [33]. For management of falls, not only posture instability other factors such as balance deficits, gait disorder, freezing of gait, slippery floors, poor lightning, or inadequate footwear may influence falls. [34].

Among all other factors influencing falls, posture instability is being the major risk factor for falling, a postural analysis will help us in predicting the future falls based on the current stability status of the PD subjects upon comparison with the non-PD subjects, which will secure the patients from various fatal and non-fatal injuries or even death, therefore an analysis is endorsed with emed systems for essential outcomes.

With posture instability finding a predominant role in PD, here Static Analysis is undergone in emed system to examine the point of reflection of CoP for PD and non-PD subjects, by demonstrating the bent posture as similar to camptocormia patient as shown in figure 2.

Few of the sample data were gathered upon conducting a static analysis in emed system for PD and Non-PD demonstrated subjects for a duration of 20 seconds. The result of this analysis is presented in the form of graphs (figure 4(A), figure 4(B)) which shows the peak pressure values of Non-PD and PD subjects. The peak pressure values for all the Non-PD subject was obtained near the heel area whereas the same has been found near the toe area for PD demonstrated subjects due to the stooped posture.
Figure 4. (A) Peak pressure values of PD and Non-PD subjects- Right leg.

Figure 5. (B) Peak pressure values of PD and Non-PD subjects- Left leg.

Figure 5(A) and figure 5(B) shows sample screenshot extracted from emed systems on demonstration of PD and Non-PD posture of twelve subjects with different foot sizes. On clear observation of the sample data, the CoP (represented by a circle near to the arch area of the foot) for the individuals of PD and Non-PD subjects is completely varying.

For example, as shown in the figure 6(A) and figure 5(B), the peak pressure for Non-PD subject is 140kpa which lies near to the heels as the person is in erect position whereas, PD demonstrated subject peak pressure value of 110kpa lies near to the toe area as the subject max weight tends fall forward which interns leads to balance difficulties. In order to retain a good posture, the point of reflection CoP should fall within the appropriate area to avoid falls.
Therefore, here the TAOSB device should be customized in such a way that it will ensure the point of reflection of CoP in an appropriate position within the base area of support and not sacrificing the comfort level which can only be achieved by suitable manufacturing techniques.

4.1. Finding and observations:
As discussed in the above literature study, the TAOSB design embraces several crucial parameters, but regretfully not even a single product is available in the current market and another critical parameter CoP, which is essential to examine the stability status of the individual was not included in the design process of the literature. These parameters were not used in designing the device. This is certainly because of the need for higher levels of customization. Therefore, the design and development of the TASOB all the parameters are to be incorporated. But due to the constraints in the current manufacturing practices these were not undergone and the market available ones are the generic products. Tectonic changes such as height and weight of each individual also needs to be considered as reliability parameters for the device which keeps on changing with respect to the individual age. In order to develop TAOSB device considering all these crucial parameters, higher level of customization and a newer manufacturing technique to improvise and produce these products are needed.

5. Future work
Focusing from the aesthetic point and comfort of the patients the TAOSB device needs to be modelled using SolidWorks based upon the precise measurements and needs to be customized to each individual, furthermore keeping the strength as one of the factor prior stress analysis needs to be carried out in ANSYS Workbench for conquering adequate material strength. Human software such as OpenSim would be used to put the camptocormia effects into the simulation figure and TAOSB device can be pretested to check whether it can make the torso upright and increase better comfort level. The brace needs to be developed based upon the body fitted customization, thereby additive manufacturing technology may be suitable fast and accurate prototype.

6. Conclusion
The literature survey and case studies seen through the paper revealed the facts of PD people suffering from various fatal and non-fatal injuries, deaths because of the stooped posture or bent spine disorder. On the other hand, the market available products for PD with camptocormia or other spinal oddities are
few and they lack in providing individual body fitted customization, while the need is an aid required for bringing the torso to an upright position. Thus, this work primarily engrossed on the concept for design, analysis and development of TAOSB device adhering to the crucial parameters which are essential for individual customization of the product. Certain mechanical parameters, which includes CoP, forces and moments calculations customized to the individual height and weight are detailed. Therefore, the Design and Development of the TAOSB device with customized body fitted approach in the future would greatly enhance Camptocormia PD patient’s and people with other spinal conditions towards a better quality of life.

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