

# Posture Detection on Active and Inactive Vertebrae of Spine Biomechanics in Critical Daily Activities

Wan Aliff Abdul Saad, Mohd Azuwan Mat Dzahir\*, Mohamed Hussein,  
Zair Asrar Ahmad, Maziah Mohamad, Shaharil Mad Saad,  
Mohd Azwarie Mat Dzahir  
Department of Applied Mechanics and Design, Faculty of Mechanical  
Engineering, UTM, Malaysia

\*azuwan@mail.fkm.utm.my

## ABSTRACT

*The biomechanical principles of orthotic design assist in promoting control, correction, stabilization, or dynamic movement. All orthotic designs are based on three relatively simple principles pressure, equilibrium, and the lever arm principle. The following principles provide the foundation for all orthotic designs keeping in mind that the more complicated the orthotic application, the more confounded the various principles become. The drawbacks of the spinal orthosis cause discomfort, osteopenia (Low BMD), skin breakdown, nerve compression, poor patient compliance etc.. Without a good design implementation and strategy, the deficiency from using this spinal orthosis to the spinal patients might not be solved. Therefore, the previously developed spinal orthosis should be reviewed thoroughly in order to analyse the problem relating to the orthosis development. In addition, we were also able to classify an on-going research in this rehabilitation spinal orthosis field. According to the literature review analysis, it shows that none have tried to control the spinal motion of the vertebrae of the cervical, thoracic, and lumbar curves extensively using a multiple joint spinal orthosis, which will be the main focuses in this article review analysis.*

**Keywords:** Spinal Orthosis, Active-Inactive Vertebrae, Lower Back Pain, Posture Detection

## Introduction

Bones are architectural masterpieces. They consist of living tissue and, during human lives, the bones are thus continually going through a balanced process of being built up and broken down again. One of the most important bones in a human body is the spine, or called as vertebrae. The main functions of human vertebrae are to support the upper body's weight and house the spinal cord, which is the nerves system structure that carry signal which control the body movement and convey sensation. There are many problems related with the spine which normally known as lower back pain (LBP). The majority of low back pain cases is due to non-specific causes, and most resolve spontaneously. On the other end of the spectrum, it could indicate serious problems with the lower spine. These are known as red flags. Most notably, it is an indicator of critical causes such as cancer, infection, fracture, severe spinal nerve compression and aortic aneurysm [45].

Lower back pain is a common painful condition that is encountered both in general and specialist practice. Recent studies in Malaysia have shown similar results. In a semi-rural community survey, the rate of low back pain was found to be around 12% while in population at risk such as the commercial vehicle drivers, the rate was quite high reaching up to 60% [27]. About 11.6% out of 2600 populations in a semirural area, Malaysia were diagnosed with low back pain problem [49]. The leading causes of low back pain, in particular, are overloading and bad posture [39]. Excessive and frequent weight lifted at home or workplace also contributes to the low back pain [8], work intensity (weight lifted per hour) is a significant indicator of back injury. There are many problems face by the low back pain sufferers. Such problems are it will limit the movement of a person and reduce the motion efficiency. Low back pain can be more than just physical as it causes worryment on the physiological of the sufferers. Moreover, it caused loss in individuals' workdays and organization's productivity in Malaysia [6].

Table 1 shows the types of lower back pain injury comparison which is normally occur during sport activities and lifting a heavy load as well as its symptom. One of the main factors leading to lower back pain is high spinal loads especially for the after-spine surgery patients. It may lead to implant subsidence, pedicle screw loosening or even implant failure, and may also be a reason for low back pain [40]. Spinal orthosis is a field of study that aims to find the solutions regarding lower back pain. Many researches have been done to find the solution regarding this issue as it affected the normal human daily activities such in working environment. It has been estimated that over 20% of all private sector injuries involve the back and in 2009, sprains and strains accounted for 40% of injuries and illnesses resulting in days away from work and most often involved the back [8]. Existing spinal orthosis

products can be divided into two different classes which are the rigid orthosis and flexible orthosis. Lots of researches have been carried out on the spinal orthosis. However most of the orthosis were focusing on single joint and rigid type of orthosis. In addition, the control system for the spinal orthosis also had not been fully established.

By introducing a multiple joints spinal orthosis, the movements of the spinal motion could be support by using a simple mechanism at the joints. The spinal orthosis is designed with several joints similar to the human spine biomechanics, and each of the joint will be controlled by using a simple mechanical system (i.e., linkage, lock-system, wire string, and a motor). The control of the spinal orthosis is mainly divided by three areas (i.e., cervical, thoracic, and lumbar curves).

## **Human Spine Biomechanics**

The anatomy of the spine is quite complex. The spine, or backbone, is made up of a column of 33 bones and tissue extending from the skull to the pelvis. The spine usually called as the human vertebrae supports the upper body's weight. The vertebrae house and protect a cylinder of nerve tissues known as the spinal cord through a hollow path which known as spinal canal. The spinal cord is very important for human being as it is the nerves system structures that carry signal which control the body movement and convey sensation. Between each one of the vertebra is an intervertebral disk, or band of cartilage serving as a shock absorber between the vertebrae. These disks also give the lower back flexibility in the human motion. The vertebrae are divided into five sections which are the cervical vertebra, thoracic vertebrae, lumbar vertebrae, sacrum and coccyx. The vertebrae seem to be chained together starting from the cervical to coccyx vertebrae. The term 'degrees of freedom - DOF' is a useful concept use to describe the number motion of the spine. It is numbers of unique independent motion one vertebrae can have with respect to another. The spine has 6 DOF which are the flexion, extension, lateral bending to the right and left, and rotation to both left and right [36].

Rotational movements of the spine are movements of the vertebra around an axis [11]. Both flexion and extension occur in sagittal plane. In general, the human spine motion is made up of 3 translational and 3 rotation motions, along three axes and each of them have measurable stiffness [54].

Table 1: Types of lower back pain injury comparison

<b>Comparison of Two Types of Lower Back Pain Injury</b>					
<b>Types</b>	<b>Classification</b>	<b>Causes</b>	<b>Symptoms</b>	<b>Segments</b>	
Discs	Lumbar disc herniation	Pinched nerve(radicular pain)	Numbness, weakness, tingling and pain in the leg. The lower back pain and/or pain in the buttock	Lumbar (L4-L5)	spine and (L5-S1)
	Degenerative disc disease	Disc pain (axial pain)	Pain and possibly radiating weakness or numbness	Lumbar (L4-L5)	spine and (L5-S1)
Joints	Degenerative joint disease	Breakdown of cartilage of the joints and discs in lower back	Cause stiffness or pain in the back, and cause weakness or numbness in the legs if it is severe enough	Lumbar (L1-L5)	spine
	Compression fracture	Vertebral bone in the spine that has decreased at least 15-20% in height due to fracture	Deformity, loss of height, crowding of internal organs, loss of muscle and aerobic conditioning due to lack of activity/exercise	Thoracic (T10,T11, and T12)	spine and lumbar spine (L1)
	Spondylolisthesis	Slipping of vertebrae forward over the one below	Back/ buttock pain, pain that runs from the lower back to the leg, and numbness or weakness in one or both leg	Lumbar (L3-L4)	spine and (L4-L5/common location)

Muscles	Bruised/contusion muscles	Direct/repeated blows from a blunt object strike the body	Cause swelling and pain, the injured muscle may feel weak and stiff	Muscles in the low back
	Muscle strain (pulled back muscle)	Muscle is over-stretched or torn	Symptoms may range from a mild ache to sudden debilitating pain	Muscles in the low back
Ligaments	Lumbar sprain	Ligaments are stretched too far or torn	Symptoms include pain that can last for weeks, as well as muscle spasm	Ligaments in the low back
Nerves	Lumbar radiculopathy	Compression, inflammation and/or injury to a spinal nerve root in the low back	When the pain radiates down the back of the leg to the calf or foot, it would in lay terms be described as sciatica	Lumbar spine (L4-L5) and (L5-S1)

Table 2: Active and inactive vertebrae on human daily motions

<b>Vertebra</b>	<b>Cervical</b>	<b>Thoracic</b>	<b>Lumbar</b>
Stooping and weight lifting	Not yet covered	-Flexion [10].	-Lumbar extension delayed until the weight reach half of its height [10].
Sitting	Not yet covered	Not yet covered	-Lumbar lordosis which was nearly 50% lower on average than standing lumbar lordosis [25].
Sitting and bending	-Flexion of lower cervical vertebrae [28]. -Largest intersegmental flexion-extension occur at C4/C5 and C5/C6 [24]. -Lower region tend to contribute more during end of Range of Motion (ROM) [4].	-Flexion [28].	-Flexion of lumbar [28]. -During forward bending, lumbar flexion contributed more and the hips and lumbar spine contributed almost equally to middle forward bending. Hips had more significant contribution to late forward bending.
Standing	Not yet covered	Not yet covered	-Extension or lordosis of the lumbar spine [29]. -Greater lumbar lordosis. [25].

Standing and bending forward	- Lower region tend to contribute more during end of Range of Motion (ROM) [4].	Not yet covered	-During full extension, fourth and fifth vertebrae showed greatest movement. [2]. -Maximum total ranges of lumbar flexion and extension were 91° and 81° respectively [52].
Standing and weight lifting	Not yet covered	Not yet covered	Not yet covered

Table 3: Relation between spinal motion and other human body's parts in completing daily activities

Articles	Focus of study	Findings
Alqhtani et al., 2016 [3]	Modelling the lumbar spine using two separate regions and traditional single-joint model.	Lower lumbar spine (LLS) has greater velocity and hip ratio compared to the upper lumbar spine (ULS) for all tasks. Proved that modelling the Whole Lumbar Spine (WLS) underestimated the LLS motion by as much as 37%, and over-estimated the ULS motion by as much as 45% compared to separate regions.
Yanagisawa et al., 2015 [55]	Finding the relationship between knee joint and spinal alignment.	Proved that the knee and the spine affect each other and the spinal range of motion (ROM). The involvement of spinal ROM decreases lumbar lordosis and sacral inclination during knee FCs.
Wang et al., 2014 [50]	Effect of prolonged active sitting on the trunk motion.	Active sitting results in increased trunk motion and could have a positive effect on low-back health.
Parkinson et al., 2013 [37]	Kinematic differences within regions of the lumbar spine during STS.	Both LLS and ULS regions made different contributions to sit-to-stand (STS). There was a significant gender difference between the LLx and ULx regions when modelled the lumbar spine as two regions compared to single region.
Tully et al., 2005 [48]	Study on the sagittal movement and their relationship between thoracic, lumbar spine and hip joints during sit-to stand (STS).	During standing, forward trunk lean prior to buttock lift-off (LO) was accomplished by concurrent lumbar and hip flexion. During flexion, thoracic region begins to extend and resulting in a LO trunk angle of $45.7^\circ (\pm 5.8^\circ)$ . Following LO, the hip and lumbar spine extended and the thoracic spine flexed with the standing thoracic angle approximating the initial thoracic posture in sitting.



O'Sullivan et al., 2002 [34]	Electromyographic activation of specific lumbopelvic muscles with the adoption of common postures.	Lumbopelvic stabilizing musculature is activated in maintaining optimally aligned, erect postures, and that these muscles are less active during the adoption of passive postures (slump sitting and sway standing) compared to erect posture which resulting to excessive load at lower spine and lead to lower back pain.
Lee & Wong, 2002 [22]	Study the relationship between lumbar spine and hip.	The overall contributions during forward and backward bending were similar, however, the spine had a greater contribution to the early stage of the movement. During lateral bending, it was found to be primarily accomplished by movement of the spine, whereas the hips were the predominate sources of movement for twisting.
Crosbie, Vachalathiti, & Smith, 1997 [9]	Patterns of the lower thoracic and lumbar spinal segments and the pelvis during walking.	Proved that the spinal segments move in response to the motion of the lower limbs. It is suggested that the counter-motion of trunk and pelvis occurs about a variable locus depending on the direction of movement, primarily in the lumbar spine. This is evidenced with respect to forward flexion and lateral flexion.

Table 4: Comparison of existing rigid and flexible spinal orthosis support for lower back pain

<b>Orthosis</b>	<b>Vertebrae</b>	<b>Description and limitation</b>	<b>Control of motion</b>
Cervical	Soft Cervical Collar	Flexion and extension - 5 to 15%, lateral bending - 5 to 10%, and rotation - 10 to 17%	Entire cervical motion
	Miami J Collar	Flexion and extension - 55 to 75%, lateral bending - 60%, and rotation - 70%	Entire cervical motion
	Malibu Collar	Flexion and extension - 55 to 60%, lateral bending - 60%, and rotation - 60%	Entire cervical motion
Cervical and Thoracic	CTO	Provide significantly more restriction of motion compared with CO, spinal is covered from cervical to T5	Flexion and extension
	Halo Device	Flexion and extension - 65 to 70%, lateral bending - 30 to 35%, and rotation - 60 to 65%. Spinal is covered from cervical to T3	Flexion and extension
Thoracic	Jewett Hyperextension Brace	Limit motion from T6 to L1	Flexion
	Taylor Brace	Limit motion of mid to lower thoracic to upper lumbar region.	Flexion and Extension
	Knight-Taylor TLSO	Cover from top thoracic to medium end of lumbar region.	Flexion, Extension and Lateral
	Custom-Molded Jacket	Body Limit motion of mid thoracic to upper L3 region.	Flexion, Extension, Lateral and Rotary
Lumbar	Flexible LSO	Corsets or binders.	Entire spine

and Sacral	Chairback LSO	Limit motion of from L1 to L4, and minimal limitation for rotation.	Flexion and Extension
	Williams Flexion LSO	Limit the motion of lateral bending.	Extension and Lateral
	Knight LSO	Limit the motion of lateral bending.	Flexion, Extension and Lateral
	Custom-molded, plastic LSO	Limit the motion of lateral bending.	Flexion, Extension and Lateral
Entire region	Spinomed	Latest technology on spinal orthosis, control the movement for all motion successfully.	All

Table 5: Comparison of existing multiple joints spinal orthosis support for lower back pain

<b>Orthosis System</b>	<b>Year</b>	<b>Types</b>	<b>Actuators and Sensors</b>	<b>Segment Analysis</b>	<b>Control System</b>
Wearable Exoskeleton Power Assist System for Lower Back Support	2003	Wearable power assist system	Constant torque DC motor, position and EMG sensors	Lower back flexion and extension focusing on lifting up motion	Speed and position control, and EMG based controller using artificial neural network (ANN)
Personal Lift Assistive Device (PLAD)	2006	Assistive device system	Non-motorized system using compression springs, strain gauge and EMG sensors	Lumbar flexion and extension focusing on lifting and bending tasks	External force generator using the concept of stored elastic energy
Soft Power Suit with Semi-active Assist Mechanism	2008	Lightweight wearable power assist system	DC servo motor, bend sensor and motion capture system	Waist flexion-extension motion and knee joint	Semi-active assist mechanism using assist force control method
Smart Suit Lite	2011	Passive power assist device system	Elastic belts, force plate	Lumbar muscles (flexion, lateral flexion, rotation)	Uses motion-based assist method using skin segment and coordinate systems

Power Assist Wear for Low Back Support	2012	Wearable power assist system	Pneumatic rubber artificial muscles, TPU balloons, gyro and accelerometer sensors	Lower back flexion and extension focusing on lifting up motion	Position and pressure control system
Waist Power Assist Suit	2013	Wearable power assist system	Thin direct drive (DD) motors, surface EMG sensors	Waist flexion, extension, and rotation focusing on lifting and twist motions	Simple signal processing, motion recognition based on surface EMG with torque control
Muscle Suit	2014	Compact and lightweight wearable power assist system	McKibben artificial muscles, near infrared spectroscopy (NIRS) and pressure sensors	Arm and waist (back support), it supported the motion of the upper body	Pressure control system

## **Spinal motions and limitation**

The flexibility of the spine is limited to certain degrees and the angles differ for each vertebra. Most of the spine movements are only focused on the cervical and lumbar vertebrae and there is only slight movement occurred in thoracic vertebrae. Furthermore, the human vital organs located within this region and they are protected by strong cage of bones called as rib cage and sternum. This structure successfully increase the stability of the thoracic spine by 40% for flexion and extension, 35% for lateral bending and 31% during axial rotation [51]. Moreover, the rib cage also restricts motion and adds stiffness to the spine [12]. The stability provided by these bones reduces the mobility of the thoracic region significantly. The region of interest is only on the cervical and lumbar as both have greater mobility as they are sited at the end of the spine. For cervical, the flexion and extension range up to 80° and 50° respectively. The normal range for full flexion to full extension is 130°. The normal range of lateral flexion is 45°. The rotation either to the right or left is up to 80°. For lumbar region, the flexes during bend forwards and backward is up to 80° and 30° respectively. The lateral flexion to the left and right is up to 35°. The rotation either to the right or left is up to 45°. During compression, this region tends to have the stiffnesses as similar to thoracic and lumbar region [31]. In contrast, during other modes of loading, cervical region tend to have smaller stiffnesses as compared to others.

The lumbar are the largest of the vertebrae due to its weight-bearing function supporting the torso and head. Each of the lumbar vertebrae supports different loading due to human motions and activities. The difference in structure of each region of vertebrae explains on the load that they can sustain. In addition, the vertebrae in this region also has the higher height compared to other two regions [33]. As concluded by literature, the shear forces sustain by the lumbar region is very small compared with compressive force. Based on study conducted, the compressive braking load that the lumbar region can sustain ranged varied between 810 N to 15559 N [16]. They also found that that the lowest lumbar segment, L5 supports the greatest load compared with other lumbar segments and the probability of fractures to happen is very high at this vertebra. Moreover, the differences in compressive strength between the upper and lower lumbar vertebrae were not significant, it is clearly shown that as the spine segment moves down, the magnitude of compression forces that it need to sustain tend to increase.

## **Active and inactive vertebrae on daily activities**

The cervical and lumbar vertebrae curves posteriorly, while the thoracic vertebrae curves anteriorly. The spine curves respond differently depend on the motion that been carried out. Specifically, only some vertebrae either in the same or different region tends to respond to the human motion while the others passively fix at their place during transition of postures. As an

example, during weight lifting from a standing posture, fifth vertebrae tend to have the higher mobility as compared with the fourth and other upper lumbar vertebrae (Kumar, 1974). As shown in the Table 2 of an active and inactive vertebrae during locomotion, spine's curves that have the highest mobility is at the lumbar curve. Kumar (1974) reported that the lower lumbar vertebrae show great mobility especially when in standing and lifting weight postures. Also, it was found that the lumbar flexion tends to be delayed until the weight has reached half of the height lifted [10]. This height was defined as critical height. During standing and forward bending at which the lumbar region reach its full extension, fourth and fifth vertebrae showed greatest movement as compared to the upper lumbar region [2]. It was also found that the mobility of lumbar vertebrae tends to increase as goes down from first to fifth lumbar vertebrae.

In thoracic region, the motion is more limited due to many reasons. It was reported that the flexibility of thoracic region was more significant in flexion compared with extension [35]. Flexion and extension is more limited in the upper thoracic region. Rotation and lateral flexion to the left and right is more limited in the lower thoracic spine. Extension is limited by the ribs, anterior longitudinal ligament, contact of the spinous processes and articular facets and disc structure. Rotation is mainly limited by the ribcage (ribs plus cartilage plus articulations). The significance of these structural limitations increases with age. For cervical curve, general literatures agreed that as the age increases, the motion of this region tend to decrease as well (Ferlic, 1962). In daily activities, human only use minimal function of this region as compared with lumbar region unless the job scope requires them to rotate their head frequently. There are still lacks of researches focusing the motion of this region. The flexion of cervical curve was observed only during sitting and forward bending [28]. In addition, the largest intersegmental flexion-extension occur between at C4/C5 and C5/C6 [24]. The lower cervical spine seems to contribute more to head motion specifically during end of the ROM [4]. They also prove that the cervical spine motion contribution for right and lateral bending is mirrored to each other and it is also the same for left and right rotation spinal motion.

### **Relation between spinal motions and human locomotion**

The spine reduces the complexity of a normal human being by providing stability in doing most of their work every day, protecting vital organs and bearing external load carried by them. In addition, it also triggered other body's parts or *vice versa*. As an example, during weight lifting in standing posture, the trunk movement will activate passive muscle located behind the lumbar spine and assist in the lifting job. The load sustained by the lumbar vertebrae especially at the lower lumbar region will reduce significantly. Hip, trunk, knee joint, and other body parts will trigger the spine motion or *vice*

*versa*. Summary of the literatures, methods used during study, and important findings related to spine motion and human body's parts is shown in Table 3. Most researchers and clinicians study on the human motion especially at the spine region using two different approaches, which are the marker-less and marker-based motion capture system. Study in 2017 conclude that there are no significant difference between both approaches as they produce almost similar results [38]. The main problem encountered while implementing marker-based analysis is the validating issue as there are still lack of evidences and findings on the related study [26].

During weight lifting, different techniques use contributes to significance effect to the spinal motion especially at the lumbar region. Bending the knees during the lifting effectively reduced the lumbar range of motion and evidently increase the stability of spine [30]. Studying the lumbar spine in more specific ways such as dividing it to two different regions [3,37] reveal the significance contribution of the region toward human motion in completing different tasks every day. Lower lumbar spine shows high mobility and velocity for all activities as compared with upper region. It is also proven from literatures that the spinal motions affect the knee and lower limb in many ways. During knee flexion contracture (FC), lumbar lordosis and sacral inclination tend to decrease significantly [55]. Implementing active sitting during prolonged sitting has showed an increase of the trunk motion, resulting to healthier spine [50]. As a person change the posture from sitting to standing, concurrently the lumbar ad hip flexion is accomplished together with forward trunk lean. As the lumbar region flexed, thoracic region responds by extending until reach optimal condition. Following lift off, the hip and lumbar spine extended and the thoracic spine flexed with the standing thoracic angle approximating the initial thoracic posture in sitting [48].

### **Flexible and rigid spinal orthosis**

The spinal orthosis mechanism successfully prevents and corrects the deformities especially for those whom are suffering from Kyphosis by providing external forces. Dowager's hump or generally known as Kyphosis is an unnatural curving of the upper back that creates a hunchback appearance in the posture, which is often associated with osteoporosis. There are many causes of Kyphosis such as bad posture, disease or damage, osteoporosis, Scheuermann's disease, Potts disease and spinal tumours. The study on the effect of spinal orthosis to aid for those suffering from Kyphosis has successfully been proven. Spinomed is one of the commercial orthosis that has successfully proven to improve balance in the elderly with thoracic hyper kyphosis [5]. Daily activities either in home or workplace force the spine to sustain high compressive and shear forces, especially during act of lifting. In the lumbar region, the magnitude of the shear forces is small



compared with compression forces. The vertebrae are subjected to the greatest compressive forces compared with cervical and thoracic region [16]. The spinal orthosis act as force reducer for the spine as the excess forces that pressed the intervertebral disk by the vertebrae especially in lumbar region during lifting is significantly reduced.

The ideal spinal orthosis take account many factors and aspects such as ergonomic, comfort, functional, fits well and light in weight. The orthosis must be cosmetically acceptable and easy to use. Due to high cycle of usage, the design and features of the assist device also take account of maintenance issues and either the device can ideally locally manufactured in case of the device breakdown. All of the aspects considered are reasonably different from the 3H's predicting failure which means hot, heavy and horrible looking. The study by literature shown that most of the spinal orthoses that been used widely used a three-point pressure system [41]. The three-point pressure system implements the action-reaction relationship. The system applies external forces that have different direction but equal in direction, which will cause balance forces case to the body. The three-point reaction force can be used on mandible, occiput, sternum, thorax, armpit, shoulder, back, ribcage and pelvis.

Literature also conclude that there are various factors that have increased the use of orthoses such as early fitting, reduction in pain, associated medical problems, psychological counselling, support group interactions, and home and work modifications [44]. Generally, the commercial spinal orthosis that have been used widely are divided into three classes which are the flexible, semi-rigid and rigid. Moreover, most of the orthosis are designed for a specific function and only aid for specific region. As example, Cervical Orthosis (CO) is specified to aid the motion of spine in cervical region only. Table 4 shows the classification of each orthosis that have been used widely based on theirs focused region.

Flexible orthosis or normally known as corsets are constructed out of strong fabrics or elastic materials with a variety of stiffer supports. This type of orthosis only restricted less motion and movement as compared with rigid spinal orthosis. Rigid spinal orthosis is used when greater control of motion or posture is required. Most of them are fabricated from high temperature thermoplastics or light weight metals to reduce the amount of load carried by the user. There are wide varieties with a broad selection of pads and coverings. From many literatures and various research studies, it was found that the benefits of spinal orthoses include improving digestive system function, decreasing muscle spasm, improving independent living, improving bowel and bladder function, improving respiratory and cardiovascular system function, decreasing bone osteoporosis and preventing joint deformity.

Even though the spinal orthoses are aimed to solve the issues related with spine, some problems arise together with it. In 2012, literature found

that the spine orthoses also lead to impaired driving performance [46]. Most of the patients that used spinal orthoses due to after surgery or during rehabilitations, encountered poor driving performance through their daily activities. The evidences that proof the efficiencies of spinal orthoses usage are also few in numbers [1]. Prolonged wear of the orthoses required during therapies and care have led to the discomfort and poor acceptance by clients and physicians. For example, the Milwaukee brace which is designed to support the entire spine exteriorly or known as Cervical-Thoracic-Lumbar-Sacral Orthosis (CTLSO) is needs to be worn for 12 to 18 months, 23 hours a day, with the user can only being out of the brace for exercise or athletic activity. It is also concluded that there were many problems reported by patients using the spinal orthoses from various resources such as excessive energy expenditure and mechanical work required, time consuming problem during donning and doffing and sometimes they required assistance, experience issues related with afraid of falling etc. [46]. Such suggestions to make use of the orthoses should be provided together with solid scientific data by the studies [15].

From previous researches, it is found that the rigid spinal orthosis is poorly accepted compared with the flexible one [53]. The rigid spinal orthosis should be worn for a long period up to years until the growth has ceased. Due to poor cosmetic and physical of it, teenaged patients tend to avoid from using it. In contrast, the flexible spinal orthosis come in more attractive design and colour that looks more appealing in their eyes. It is also reported that the using of rigid spinal orthosis caused the ventilation to be greatly reduces which makes the patient even less well tolerated especially during humid and hot weather. Even though the rigid spinal orthosis was rejected due to its cosmetic and physical appearance, its clinical efficiency was very high [53]. The failure rate of rigid spinal orthosis was very low as compared with flexible spinal orthosis.

### **Multiple joints spinal orthosis**

The use of orthotic intervention in rehabilitation spans the history of humans, from the first crude fracture splint made from sticks in the forest, to the sophisticated modern dynamic orthosis fabricated from hybrid materials. Many of the principles have remained the same through time; however, the new materials and structural designs, and breadth of application to a greater number of medical conditions have contributed to the expansive utilization of orthotic intervention. The use of orthotics can be found in almost every aspect of rehabilitation today. With the appreciation and understanding of terminology, materials, generic designs, and the application of orthotics, clinicians can enhance the delivery of healthcare to their clients. The biomechanical principles of orthotic design assist in promoting control, correction, stabilization, or dynamic movement.

The drawbacks of the spinal orthosis cause discomfort, osteopenia (Low BMD), skin breakdown, nerve compression, muscle atrophy with prolonged use, decreased pulmonary capacity, difficulty in donning and doffing the orthosis, difficulty with transfers local pain, psychological and physical dependency, increased segmental motion at the ends of the orthosis, unsightly appearance, and poor patient compliance. Without a good design implementation and strategy, the deficiency from using this spinal orthosis to the spinal patients might not be solved. According to the literature review analysis, it shows that none have tried to control the spinal motion of the vertebrae of the cervical, thoracic, and lumbar curves. They are simply implemented external flexion and extension forces to help the patients/users in reducing the burden to the lower back during lifting a heavy load with a simple control system. However, wearing this spinal orthosis may encourage more optimal lifting style in term of reducing lumbar flexion. Table 5 shows the existing multiple joints spinal orthosis support for the lower back pain comparison based on time scale, type of the robotic system, actuators, sensors, segment analysis, and the control system of the spinal orthosis. Even though these orthosis were classified as multiple joints, most of these orthosis only consisted of two joint segments.

## **Results and Discussion**

To validate the data obtained from the literature, an experimental test was setup to specify the active and inactive vertebrae area during critical daily activities. To mark the position of each vertebra, a set of markers was used and placed on the test subject along the spinal (i.e., thoracic and lumbar region). For the reference angle, the position was divided into two main posture which were the sitting and standing posture. The results were obtained by using MATLAB image processing toolbox. The changes in angle of each of the vertebrae was recorded and analysed. Then the angle deviations of the vertebrae with relative to sitting and standing postures as shown in Table 6 and angle deviations between two adjacent vertebrae with relative to its initial position as shown in Table 7 were measured.

From the previous study, there is no specified angle for the thoracic vertebrae as it located between the cervical and lumbar vertebrae. The region of interest is only on the cervical and lumbar region as both of it located at the end of the spine. However, in this research our focus is only on the thoracic and lumbar region. The angle of motion of the thoracic region is small, so it can be neglected. Based on the results of the initial stage for the analysis, it is clearly shown that the most critical angle is at the lumbar vertebrae which reached up to  $86.34^\circ$  for first lumbar. For the sitting and standing postures, the most critical one was during the bending forward. It

was shown that moving while standing cause significant change in the angle of each vertebra respective to their initial position.

Table 6: Angle deviations relative with relative to sitting and standing posture

Vertebrae	Sitting		Standing	
	Holding load	Forward	Holding load	Bending
T1	4.26°	12.92°	-10.25°	-17.24°
T2	4.69°	13.36°	-8.24°	-13.71°
T3	5.87°	14.27°	-5.45°	-8.87°
T4	6.97°	15.34°	-3.05°	-4.62°
T5	8.19°	15.99°	0.52°	0.93°
T6	9.16°	16.77°	3.52°	5.36°
T7	9.77°	16.66°	6.56°	11.27°
T8	11.31°	17.76°	11.51°	18.41°
T9	12.34°	18.14°	16.10°	26.39°
T10	13.72°	18.46°	24.20°	36.63°
T11	14.69°	18.78°	38.64°	50.56°
T12	16.85°	21.26°	54.39°	65.66°
L1	17.74°	19.69°	83.24°	86.34°
L2	20.45°	21.99°	-67.38°	-80.54°
L3	23.62°	22.57°	-49.55°	-70.51°
L4	26.34°	20.40°	-35.27°	-62.63°
L5	32.13°	19.60°	-30.37°	-59.11°

The movement while standing cause the lumbar vertebrae to have great changes in angles compared with sitting. This was illustrated in Table 7. From the results, it was obvious that the last thoracic vertebra which is T12 (-49.65°) and two vertebrae from lumbar region which are L1 (41.61°) and L5 (-56.43°) shows significant change in the different of angle between two vertebrae. The obtained results were comparable with the data obtained from the literature. From the literature, the allowable angle for cervical during flexion and extension is ranged up to 80° and 50° respectively. For lumbar region, the flexes during bend forwards and backward is up to 80° and 30° respectively. The point of interest during the study was the lumbar region as it almost reached the maximum allowable flexion angle.

Table 7: Angle deviations between two adjacent vertebrae

Vertebrae	Sitting			Standing	Standing	
	Sitting	Hold load	Forward		Hold load	Bending
T1	-0.16°	-2.18°	4.74°	1.93°	-7.86°	-1.46°
T2	-5.01°	-5.52°	-5.38°	-1.60°	-7.48°	-1.72°
T3	-4.03°	-4.08°	0.11°	-0.42°	-2.32°	-1.10°
T4	-2.25°	-1.01°	-3.34°	-0.73°	-5.26°	-3.12°
T5	-0.77°	-0.09°	-2.10°	-4.57°	-3.44°	175.05°
T6	-0.70°	0.40°	-2.58°	-0.95°	-2.12°	-1.05°
T7	-1.62°	-5.10°	-0.77°	0.21°	0.82°	-2.79°
T8	-0.31°	-1.79°	0.42°	0.49°	-2.04°	1.31°
T9	-0.40°	-2.04°	0.90°	0.27°	-5.52°	-1.31°
T10	-0.40°	-0.09°	0.18°	-0.59°	-0.81°	-1.44°
T11	-0.26°	0.37°	0.17°	-0.90°	1.13°	-3.21°
T12	1.03°	-1.00°	-2.72°	0.86°	-4.03°	-49.65°
L1	-2.02°	0.17°	-0.59°	3.56°	-5.21°	41.61°
L2	-4.99°	0.23°	-1.78°	1.61°	-1.12°	-0.70°
L3	-4.99°	1.32°	-1.39°	0.34°	-9.48°	-2.13°
L4	-4.23°	-1.92°	-2.51°	0.02°	-7.10°	-9.89°
L5	15.45°	-21.99°	0.36°	-0.36°	-24.07°	-56.43°

Compared with the pressure of load in the upright standing position, reclining reduces the pressure by 50-80%, forward leaning and weight lifting by more than 100%, and the position of forward flexion and rotation by 400%. The motion during forward flexion showed high compressive and great change in angle as compared with extension. The result is acceptable as the maximum angle of flexion for the lumbar of the subject is lower than the allowable motion for the lumbar region. Thus, the lumbar region is the most critical region that required further study and research. By doing so, it can assist and improve the quality of life for those who suffer from lower back pain and injury.

## Conclusion

To the author's best knowledge, currently there is no flexible joint spinal orthosis that emphasize on the human's spine biomechanics, and then control the movements of three flexible curves (i.e., cervical, thoracic, and lumbar curves) of the orthosis. The studies of active and inactive vertebrae during

human daily motion still few in numbers. Specifically, previous researches on the spine only focussed their study at the critical vertebrae that contribute more to lower back pain such as lumbar region and put less attention to cervical and thoracic region. The inconclusiveness of previous research about the relevance between active and inactive vertebrae and back pain may lead to the heterogeneous back pain population.

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