USING THE METHOD OF DETERMINING THE VARIATION OF THE LENGTH OF THE STRETCHED CHORD, AS A MEANS OF MONITORING THE POSTURAL CHANGES OF THE ATHLETES SPINE

Cristian Radu BADEA[1], Octavian DONȚU [2], Gheorghe I. GHEORGHE [3]

The paper presents a method of monitoring postural changes, based on comparing the length of a chord stretched by the curvatures of the spine, while executing a movement or a posture, with that in a standard posture (physiological). This method was the basis for the construction of a prototype for a real-time monitoring and active postural correction device, used to correct the biomechanics of movements to reduce the risk of injuries in athletes' training. This device uses a wire-type element to detect postural changes, which behaves like a chord of a circle stretched by the curvatures of the spine.

Keywords: posture, physiological, pathological, spine, curvatures, biomechanical, neuromuscular.

1. Introduction

One of the most common conditions encountered in the vast majority of people and especially in athletes, whether beginners or advanced (performance athletes), is the change in the physiological curvatures, of the spine and also in the neutral (correct) position of the shoulders. These changes are known in the literature as postural pathologies [1]. From the point of view of the sagittal plane, the main postural pathologies are: lordosis (***see Fig.1.b*** [2]) and kyphosis (***see Fig.1.c*** [2]). The main factors of the appearance of these pathologies, in the case of athletes, are:

- the existence of an untreated anterior postural problem;
- wrong execution of general and / or specific techniques, starting from the primary learning stage up to the higher levels of training;
- asymmetric training and / or stress of the body, combined with the lack of a proper post-effort recovery.

[1] Scientific research engineer at INCDMTM-Bucharest, PhD student at University POLITEHNICA of Bucharest, Romania, e-mail: raducristianbadea@incdmtm.ro
[2] Prof., University POLITEHNICA of Bucharest, Romania, e-mail: octavdontu@yahoo.com
[3] Prof., University VALAHIA of Targoviste, Romania, e-mail: geocefin@yahoo.com

a. physiological posture b. pathological posture - lordosis - c. pathological posture - kyphosis -

Fig.1. The representations of the physiological posture and of two main pathological postures, in the sagittal plane

Determining the type and degree of the postural pathology is done by comparing the posture of the spine, of the subject in question, with an ideal model of the spine, called physiological posture (see ***Fig.1.a*** [2], ***Fig.2.a*** [2] [3] and ***Fig.2.b*** [3] [4]).

a. Physiological posture b. Pathological posture

Fig.2. Sagittal plane representation of the physiological posture and of a pathological posture

The repetition of certain postures and / or movements considered to be incorrect from a biomechanical point of view, determines the appearance of permanent postural deformities (pathological posture [3] [4] [5] [6]), if these actions are not followed by a suitable correction. Adopting a incorrect posture produces in time a shortening of the flexor muscles of the thoracic curvature and of the extensors of the lumbar and cervical curvature, as well as an elongation of the antagonistic muscles of those mentioned above. Changes at the muscular level lead to deformities in the joints involved (excessive erosion of joint capsules in positions imposed by a pathological posture, compression of the intervertebral cartilage, and pathologies derived from them - ***see Fig.2.b*** [2] [3]), as well as to the aggravation of the pre-existing postural pathology.

According to the specialized literature, the bending / straightening and / or lowering / lifting of the torso, by a person (with or without an external weight attached), is correctly executed from a biomechanical point of view (it does not lead in time to a postural pathology [7]), only when this is achieved by a hips joints flexion [8], or by securing the torso along with the lower limbs while executing a certain exercise (for example: push-ups), depending on each situation.

The purpose of the paper is to provide a simple method of monitoring the postural changes, without the need of using high-tech sensors, or assemblies of different sensors, as in the case of present devices.

2. Sensing the postural changes using the method of determining the variation of the length of the stretched chord

The principle of sensing the postural changes using the method of determining the variation of the length of a chord streched by the curvatures of the human spine, is as follows: using ***a wire-type sensing element***, that is mounted between two well-defined points on the human spine, it's possible to monitor the changes in the spine's curvatures during the execution of certain movements or stances, in relation to those of a predetermined, standard posture. Taking into account the pathology of the athlete in question, this standard posture can be either the physiological one, or another posture that it's as close as possible to the physiological one.

The spine it is considered to be represented in the sagittal plane, by means of four arcs of circle circumscribed to the physiological curvatures, appropriately named, as follows: the cervical, thoracic, lumbar and sacral arc of circle.

The above mentioned ***wire-type sensing element*** it's composed of two collinear wires having one common point and it's acting as chord streched between the upper end of the spine and the the lower end of the lumbar curvature of the spine. One of the wire, called the base wire, has elastic properties and is fixed with the lower end at the point of intersection between the arcs of circle circumscribed to the lumbar and sacral curvature of the spine (named ***reference point***). The second wire, called the thoraco-cervical, is inextensible, has an upper end fixed approximately to the spinous process of the first cervical vertebrae (***C1***) and it is collinear in the frontal plane with the projection of the axis of the spine in the mentioned plane. The point of intersection of the two wires of the ***wire-type sensing element*** is called bifurcation point, denoted P_{bf} and it's positioned, in the case of physiological posture, at the intersection between the vertebrae ***T8*** and ***T9***.

Therefore, any change in the physiological curvatures of the spine will cause a change in the radii and central angles of the arcs of circle circumscribed to the curvatures of the spine and so will cause the change of the lenght of the chord streched by the spine, represented here by the ***wire-type sensing element***. Due to the permanent contact between the ends of the ***wire-type sensing element*** and the spine, as well as the elasticity of the base wire, the bifurcation point $(\boldsymbol{P_{bf}})$ moves in the sagittal plane, and the length of the latter wire changes, with the modification of the curvatures of the spine in the mentioned plane.

2.1. The demonstration of the principle of sensing the postural changes using the method of determining the variation of the length of the stretched chord

In case of a postural change of the spine in relation to the physiological posture, the lenght of the ***chord streched by the spine*** at a time "***i***", named ***active length***, is considered to be equal to the length of the ***wire-type sensing element***, at a time "***i*"**. So, the ***active length*** is equal to the length of the thoraco-cervical wire (inextensible), plus the length of the base wire, at a time "***i***". The ***active length*** of the ***chord streched by the spine*** will be calculated for one of the most common pathologies of the spine in the sagittal plane: lordosis. The calculation is performed by approximating the physiological curvatures of the spine, while in an orthostatic position (based on the representation of the spine in physiological posture - ***see Fig.3.a*** [9]), using completely defined arcs of circle circumscribed to the its curvature. The physiological posture is considered standard. The pathological posture considered important to demonstrate the veracity of the principle, is also represented using arcs of circle, that are equal in length with those of the spine in the physiological posture and is obtained at a time "***i***", during certain movements, whose incorrect execution can cause, in time, articular problems. In order to simulate this pathological posture, the lengths of the circumscribed arcs of circle are kept unchanged, but the following parameters are modified, in turn:

- the values of the radii and implicitly of the central angles of the arcs of circle thus circumscribed in regard with the values that those have had in the physiological posture;
- the angles between the vertical (or horizontal) axis and the chord stretched by the spine represented by the arcs of circle thus circumscribed.

In calculating the ***active length*** of the ***chord streched by the human spine*** , in the sagittal plane, the following notations will be used:

L_{tot_i} - the ***active length*** of the ***chord streched by the human spine*** , in ***Case i***;

$\widehat{AiBi}$, $\widehat{BiFi}$, $\widehat{FiGi}$- the arc of cervical, thoracic and lumbar circle, respectively, circumscribed to the curvatures of the spine in ***Case i***;

$R_{C_i}, R_{T_i}, R_{L_i}\ R_S$ - radius of the cervical, thoracic, lumbar and sacral arc of circle, respectively, in ***Case i***;

$U_{C_i}, U_{T_{i,U_{L_i}}}, U_S$- the central angle of the cervical, thoracic, lumbar and sacral arc of circle, respectively, in ***Case i***;

U_{T-C} - the angle of transition from the thoracic arc of circle to the cervical arc of circle, in ***Case i***;

$U_{L-T} \equiv \sphericalangle T_i F_i L_i$ - the angle of transition from the lumbar arc of circle to the thoracic arc of circle, in ***Case i***;

$A_i D_i$ - represents the base wire, of the ***chord streched by the spine*** , in ***Case i***;

G_i - represents the reference point, in ***Case i***;

$\widehat{DiEi} + E_i G_i$ - represents the thoraco-cervical wire, of the ***chord streched by the spine*** , in ***Case i***;

VV' - vertical axis; OO' - horizontal axis;

S - the center of rotation of the coxo-femoral joint;

UR_{S-CO} - the angle of rotation at the hip joints, more precisely this is the angle at which the torso is tilted, in physiological posture, relative to the horizontal axis, in the sagittal plane.

$U_{S-L} \equiv \sphericalangle SG_i L_i$ - the angle of transition from the sacral arc of circle (considered to represent the sacral curvature), to the lumbar arc of circle (considered to represent the lumbar curvature), in ***Case i***;

The cases of intterest for this paper, that will be analyzed, are as follows:

- ***Case 1*** - physiological posture;
- ***Case 2*** - the correct posture during a forward bending movement of the human torso;
- ***Case 3*** - the incorrect posture during the execution of an exercise called ”***squating with a load***”, which leads to the occurrence of the postural pathology known as ***lumbar lordosis***.

Regardless of the situation, the arc of circle, circumscribed to the sacral curvature, cannot change its radius and / or its central angle, since the curvature in question can only be modified under certain conditions, which are not related to the object of this paper.

For ***Case 1***, that of the physiological (ideal) posture, considered to be the standard in relation to which the various postural changes will be highlighted, the point of intersection between the two arcs of circle circumscribed to the sacral and lumbar curvatures of the spine, it's denoted with the letter “***G***” and the point that represents the upper anchoring end, of the thoraco-cervical wire, of the ***chord streched by the spine***, which corresponds to the upper terminal point, of the arc of the circle circumscribed to the cervical curvature of the spine, it's denoted with the letter “***A***” (***see Fig.3***).

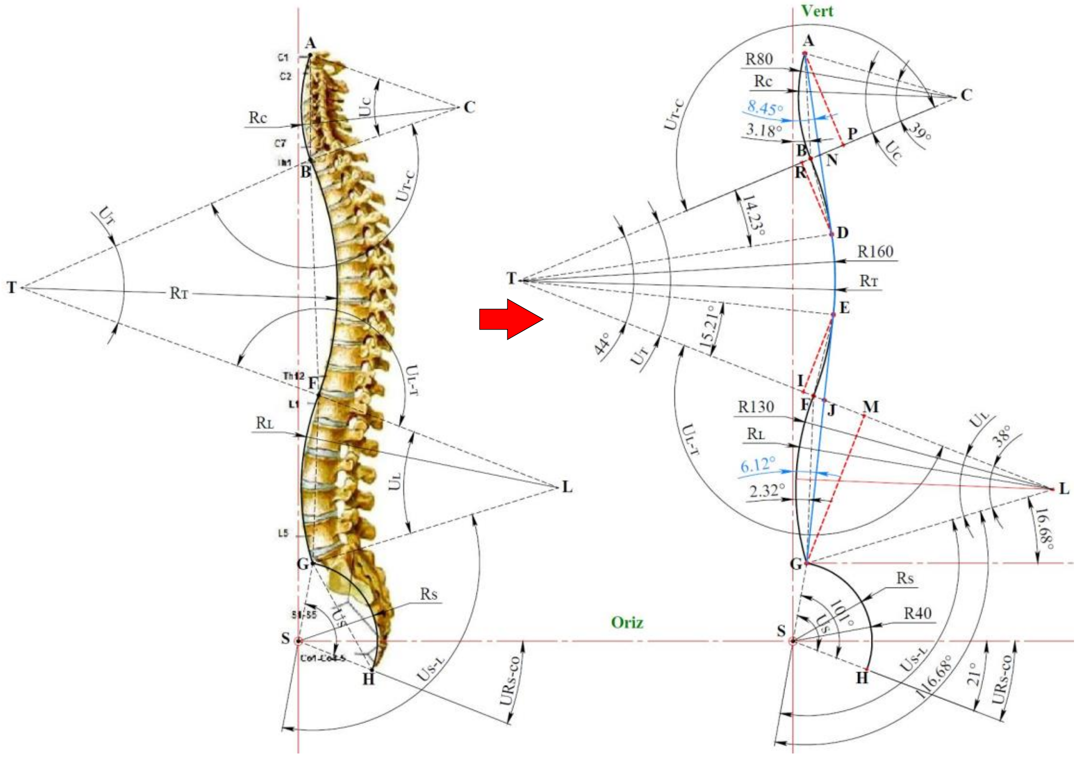
The values of all the geometric elements used are approximations of a case considered ideal, presented in Fig.3 and also of some cases that are of interest for the problem in question (***see Fig.4 and Fig.5***).

Since the physiological model of the spine (shown in ***Fig.3.a***), which is the basis of the current analysis, is not represented in real size, in order to make a correct assessment of the real postural changes, the values determined above must be corrected using a correction factor, denoted by "***K***", this actually representing the scaling factor: $$K = \frac{L_{Sc}}{L_{tot_i}},\qquad (1)$$

where L_{Sc} - represents the length, considered standard, of the chord stretched by a person's spine, measured in the physiological posture. In the case of a person with an average height, is considered $L_{Sc} = 585\text{mm}$ [10]. (2)

$$In\ this\ case \Rightarrow\ K = \frac{585mm}{259{,}59mm} = 2{,}25 \qquad (3)$$

Case 1. The physiological posture (ideal), in the sagittal plane - orthostatism - standard posture



a. The spine in the physiological posture b. The resulting circumscribed arcs of circle

Fig.3. Representation of the physiological curvatures of the human spine, whith its circumscribed arcs of circle, in the sagittal plane

L_{tot_1} – the ***active length*** of the ***chord streched by the spine*** , in ***Case 1***

$$L_{tot_1} = AD + L_{\widehat{DE}} + EG \qquad (4)$$

The known geometric elements of the studied model are:

$$\widehat{V'AB} = 3{,}18°;\ \widehat{V'AD} = 8{,}45°;\ R_C = 80mm; R_T = 160mm; R_L = 130mm; \quad (5)$$

$$U_C = 39°;\ U_T = 44°;\ U_L = 38°;\ \widehat{CBT} = 180° = U_{T-C};\ \widehat{BTD} = 14{,}23°; \quad (6)$$

$$\widehat{ETF} = 15{,}21°;\ \widehat{TFL} = 180° = U_{L-T};\ \widehat{VGF} = 2{,}32°;\ \widehat{VGE} = 6{,}12°; \quad (7)$$

$$\left.\begin{array}{r} \widehat{BAO'} = 90° - \widehat{V'AB} = 90° - 3{,}18° = 86{,}82° \quad (8) \\ \widehat{CAO'} = \widehat{BAO'} - \widehat{BAC} \quad (9) \\ \widehat{BAC} = \dfrac{180° - \widehat{ACB}}{2} = \dfrac{180° - U_C}{2} = \dfrac{180° - 39°}{2} = 70{,}5° \quad (10) \end{array}\right\} \Rightarrow$$

$$\Rightarrow \widehat{CAO'} = 86{,}82° - 70{,}5° = 16{,}32° \quad (11)$$

$$\widehat{ACO'} = 90° - \widehat{CAO'} = 73{,}68° \quad (12)$$

$$\widehat{ACO'} + \widehat{ACB} + \widehat{BCO'} = 180° \Rightarrow \widehat{BCO'} = 180° - \widehat{ACO'} - \widehat{ACB} \Rightarrow$$

$$\Rightarrow \widehat{BCO'} = 180° - 73{,}68° - 39° = 67{,}32° \quad (13)$$

$$\widehat{CBO'} = 90° - \widehat{BCO'} = 90° - 67{,}32° = 22{,}68° \quad (14)$$

$$\widehat{BAD} = \widehat{V'AD} - \widehat{V'AB} = 8{,}45° - 3{,}18° = 5{,}27° = \widehat{BAN} \quad (15)$$

$$\text{In } \Delta\, ACB:\ \widehat{CBA} = \widehat{BAC} = \frac{180° - \widehat{ACB}}{2} = \frac{180° - U_C}{2} = \frac{180° - 39°}{2} = 70{,}5° \quad (16)$$

$$\left.\begin{array}{r} AP \perp BC \Rightarrow \widehat{BAP} = 90° - \widehat{ABP} = 90° - 70{,}5° = 19{,}5° \quad (17) \\ CB \cap AD = [N] \Rightarrow \widehat{NAP} = \widehat{BAP} - \widehat{BAN} \quad (18) \\ However\ \ \widehat{BAN} = \widehat{BAD} \quad (19) \end{array}\right\} \Rightarrow$$

$$\Rightarrow \widehat{NAP} = 19{,}5° - 5{,}27° = 14{,}23° \quad (20)$$

$$\left.\begin{array}{r} \text{In } \Delta BAP:\ cos\,\widehat{BAP} = \dfrac{AP}{AB} \Rightarrow AP = AB \cdot cos\,\widehat{BAP} \quad (21) \\ AB = 2 \cdot R_C \cdot sin\left(\dfrac{\widehat{ACB}}{2}\right) = 2 \cdot 80mm \cdot sin\left(\dfrac{39°}{2}\right) = 53{,}41mm \quad (22) \end{array}\right\} \Rightarrow$$

$$\Rightarrow AP = 53{,}41mm \cdot cos 19{,}5° = 50{,}35mm \quad (23)$$

$$\text{In } \Delta NAP:\ cos\,\widehat{NAP} = \frac{AP}{AN} \Rightarrow AN = \frac{AP}{cos\widehat{NAP}} = \frac{50.35mm}{cos 14.23°} = 51{,}94mm \quad (24)$$

$$\text{In } \Delta ANP:\ \widehat{ANP} = 90° - \widehat{NAP} = 90° - 14{,}23° = 75{,}77° \quad (25)$$

$$Since\ TB\ is\ collinear\ with\ BC\,(\widehat{CBT} = 180°) \Rightarrow \widehat{TND} = \widehat{ANP} = 75{,}77° \quad (26)$$

$$\left.\begin{array}{r} \text{In } \Delta BTD: DR \perp TB \quad (27) \\ \text{However } AP \perp BC \quad (28) \end{array}\right\} \Rightarrow$$

$$\Rightarrow \widehat{RDN} = \widehat{NAP} = 14{,}23° \tag{29}$$

$$\text{In } \Delta RTD\text{: } \sin\widehat{RTD} = \frac{RD}{TD} = \frac{RD}{R_T} \Rightarrow RD = R_T \cdot \sin\widehat{RTD} \tag{30}$$

$$However \quad \widehat{RTD} = \widehat{BTD} = 14{,}23° \tag{31}$$

$$\Rightarrow RD = 160mm \cdot \sin 14{,}23° = 39{,}33mm \tag{32}$$

$$\cos\widehat{RDN} = \frac{RD}{DN} \Rightarrow DN = \frac{RD}{\cos\widehat{RDN}} = \frac{39.33mm}{\cos 14.23°} = 40{,}58mm \tag{33}$$

$$AD = AN + DN = 51{,}94mm + 40{,}58mm = 92{,}52mm \tag{34}$$

$$L_{\widehat{DE}} = \frac{\pi \cdot R_T \cdot \propto_{\widehat{DE}}}{180°} = \frac{\pi \cdot 160mm \cdot \widehat{DTE}}{180°} \tag{35}$$

$$\widehat{DTE} = \widehat{BTF} - \widehat{BTD} - \widehat{ETF} = U_T - 14{,}23° - 15{,}21° \Rightarrow \tag{36}$$

$$\Rightarrow \widehat{DTE} = 44° - 14{,}23° - 15{,}21° = 14{,}56° \tag{37}$$

$$\Rightarrow L_{\widehat{DE}} = \frac{\pi \cdot 160mm \cdot 14.56°}{180°} = 40{,}66mm \tag{38}$$

$$\text{In } \Delta FGL\text{: } \widehat{FGL} = \frac{180° - U_L}{2} = \frac{180° - 38°}{2} = 71° \tag{39}$$

$$GM \perp FL \Rightarrow \text{In } \Delta GML\text{: } \sin\widehat{MLG} = \frac{GM}{LG} \Rightarrow \tag{40}$$

$$\Rightarrow GM = LG \cdot \sin\widehat{MLG} = R_L \cdot \sin U_L = 130mm \cdot \sin 38° = 80{,}04mm \tag{41}$$

$$FL \cap EG = [J] \Rightarrow \widehat{JGM} = \widehat{FGL} - \widehat{FGJ} - \widehat{MGL} \tag{42}$$

$$\widehat{FGJ} = \widehat{VGJ} - \widehat{VGF} = 6{,}12° - 2{,}32° = 3{,}8° \tag{43}$$

$$\text{In } \Delta MGL\text{: } \widehat{MGL} = 90° - \widehat{MLG} = 90° - 38° = 52° \tag{44}$$

$$\Rightarrow \widehat{JGM} = 71° - 3{,}8° - 52° = 15{,}2° \tag{45}$$

$$\text{In } \Delta JGM\text{: } \cos\widehat{JGM} = \frac{GM}{GJ} \Rightarrow GJ = \frac{GM}{\cos\widehat{JGM}} = \frac{80.04mm}{\cos 15.2°} = 82{,}94mm \tag{46}$$

$$Since \quad \widehat{TFL} = 180° = U_{L-T} \Rightarrow \widehat{TJE} = \widehat{GJL} \tag{47}$$

$$\text{In } \Delta GJL\text{: } \widehat{GJL} = 90 - \widehat{JGM} = 90° - 15{,}2° = 74{,}8° = \widehat{GJM} \tag{48}$$

$$\Rightarrow \widehat{TJE} = 74{,}8° = \widehat{IJE} \tag{49}$$

$$EI \perp TL \Rightarrow \text{În } \Delta IEJ\text{: } \widehat{IEJ} = 90° - \widehat{IJE} = 90° - 74{,}8° = 15{,}21° \tag{50}$$

$$\text{In } \Delta ETI\text{: } \sin\widehat{ETI} = \frac{EI}{TE} = \frac{EI}{R_T} \Rightarrow EI = \sin\widehat{ETI} \cdot R_T = 41{,}95mm \Rightarrow \tag{51}$$

$$\Rightarrow EI = \sin\widehat{ETI}\cdot R_T = 160mm\cdot\sin 15{,}21° = 41{,}95mm \quad (52)$$

$$\widehat{ETI} = \widehat{IEJ} = 15{,}21° \quad (53)$$

$$\text{In } \Delta IEJ\text{: } \cos\widehat{IEJ} = \frac{EI}{EJ} \Rightarrow EJ = \frac{EI}{\cos\widehat{IEJ}} = \frac{41.95mm}{\cos 15.2160} = 43{,}47mm \quad (54)$$

$$EG = EJ + GJ = 43{,}47mm + 82{,}94mm = 126{,}41mm \quad (55)$$

$$L_{tot_1} = AD + L_{\widehat{DE}} + EG = 92{,}52mm + 40{,}66mm + 126{,}41mm = 259{,}59mm \quad (56)$$

Case 2. The posture representing a time sequence of a forward bending movement (the forward tilting) of a human torso (or of a human torso lifting motion - ***see Fig.3.a***), considered in the specialized literature, to be correct from a biomechanical point of view, as it is performed only by coxo-femoral joints flexion, without changing the curvatures of the spine and of the angles U_{L-T} și U_{T-C} (***see Fig.4***).

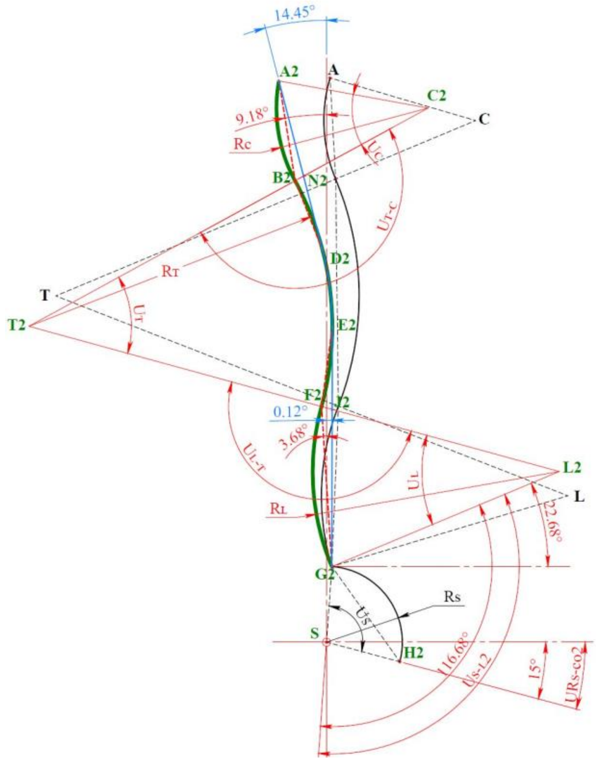


Fig.4. Representation of the physiological curvatures of the human spine, in the sagittal plane, obtained at a time "i" during a correct forward bending movement of a human torso

Due to the fact that the lower anchoring point of the base wire, of the ***chord streched by the spine*** , is identical to the "***G***" point (the point of intersection between the arcs of circle, circumscribed to the sacral and lumbar curvature, respectively - ***see Fig.4***), the change in the rotation angle at the level of the hip joints, UR_{S-CO}, does not produce a change in the ***active length*** of the ***chord streched by the spine*** .

$L_{tot_2} -$ the ***active length*** of the ***chord streched by the spine*** , in ***Case 2***

$$Since\ L_{tot_2} \text{ does not depend on } UR_{S-CO} \Rightarrow \quad (57)$$

$$\Rightarrow U_{L_2} = U_L\ , \quad R_{L_2} = R_L\ , \quad U_{L-T_2} = U_{L-T}\ , \quad U_{T_2} = U_T \quad (58)$$

$$\Rightarrow R_{T_2} = R_T\ , \quad U_{T-C_2} = U_{T-C}\ , \quad U_{C_2} = U_C\ , \quad R_{C_2} = R_C \quad (59)$$

$$(57), (58), (59), (60) \Rightarrow L_{tot_2} = L_{tot_1} = 259{,}59mm \Rightarrow \quad (60)$$

Postural deformation can be expressed as follows:

$$\Delta\mathrm{L} = K \cdot (L_{tot_1} - L_{tot_i}) \Rightarrow \quad (61)$$

$$\Rightarrow \Delta\mathrm{L} = K \cdot (L_{tot_1} - L_{tot_2}) = 2{,}25 \cdot (259{,}59 - 259{,}59)mm = 0 \Rightarrow \quad (62)$$

⇒ The ***active length*** of the ***chord streched by the spine*** , if the forward bending of the human torso is achieved only by flexing the coxo-femoral joints, is equal to the one in the physiological posture (ideal) ⇒ If the bending / lifting of the human torso does not involve changing the physiological curvatures, of the spine, the ***active length*** of the ***chord streched by the spine*** , does not change in relation to the one in the physiological posture.

Case 3. The posture representing a sequence within a exercise, in which the athlete is executing a squat, having a weight above his head (squating with a load), which causes, at the level of the torso, the flexion of the lumbar curvature, of the spine (***see Fig.5***). In this situation the execution is considered to be incorrect from the biomechanical point of view, even though it is performed without changing the thoracic and cervical curveatures, as well as the angle between the thoracic and cervical curvature, marked with "U_{T-C}" and the position of these two curvatures in relation to the vertical axis. This is because while squating, the athlete is changing not just his central angle of the lumbar arc of circle, marked with "U_{L_3}", but also the angle between the two previously mentioned curvatures, marked with "U_{L-T_3}" (***see Fig.5***). Repeating this incorrect type motion for a long time will lead to the occurrence of the postural pathology known as ***lumbar lordosis***.

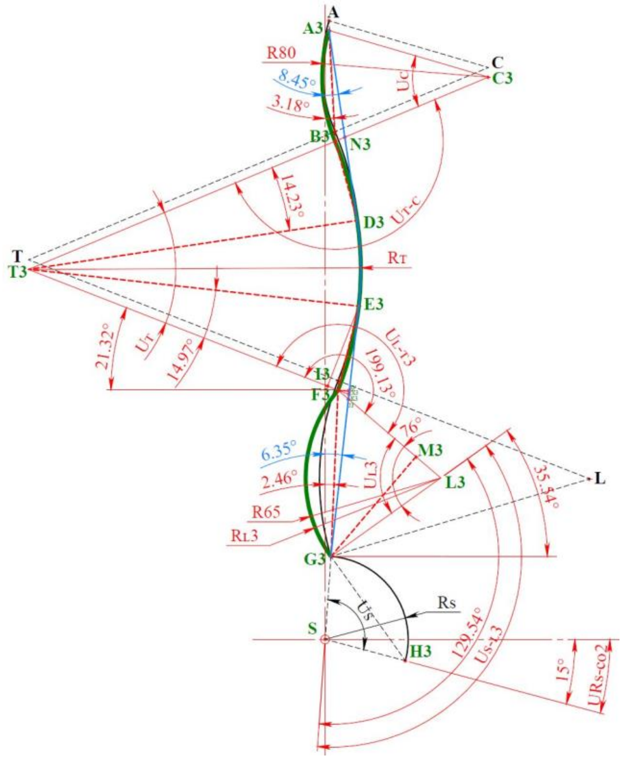


Fig.5. Representation of the curvatures of the human spine, in the sagittal plane, obtained at a time "i", during the action of supporting or lifting a weight placed above a person's torso

Known elements:

$$\widehat{V'A_3B_3} = \widehat{V'AB} = 3.18°;\ \widehat{V'A_3D_3} = \widehat{V'AD} = 8.45°;\ R_{C_3} = R_C = 80mm; \quad (63)$$

$$U_{C_3} = U_C = 39°mm;\ R_{T_3} = R_T = 160mm;\ U_{T_3} = U_T = 44°;\ R_{L_3} = \frac{R_L}{2} = 65mm \quad (64)$$

$$\widehat{C_3B_3T_3} = 180° = U_{T-C_3};\ \widehat{B_3T_3D_3} = 14.23°;\ \widehat{E_3T_3F_3} = 14.97° \quad (65)$$

$$\widehat{T_3F_3L_3} = 199.133° = U_{L-T_3};\widehat{VGF_3} = 2.46°;\ \widehat{VGE_3} = 6.35°;\ \widehat{V'GL_3} = 125.54° \quad (66)$$

$$T_3F_3 \cap E_3G = [K_3] \quad (67)$$

$$\widehat{O'G_3L_3} = \widehat{V'G_3L_3} - 90° = 35.54° \quad (68)$$

In $\Delta G_3L_3V'$: $\widehat{G_3L_3V'} = 90° - \widehat{O'G_3L_3} = 90° - 35.54° = 54.46°$ (69)

$$L_{\widehat{F_3G}} = L_{\widehat{FG}} = \frac{\pi \cdot R_L \cdot \propto_{\widehat{FG}}}{180°} = \frac{\pi \cdot 130mm \cdot 38°}{180°} = 86.22mm \quad (70)$$

$$However\ L_{\widehat{F_3G}} = \frac{\pi \cdot R_{L_3} \cdot \propto_{\widehat{F_3G}}}{180°} = \frac{\pi \cdot R_{L_3} \cdot U_{L_3}}{180°} \Rightarrow U_{L_3} = \frac{180° \cdot L_{\widehat{F_3G}}}{\pi \cdot R_{L_3}} = 76° \quad (71)$$

$$\widehat{VL_3F_3} = 180° - \widehat{G_3L_3V'} - U_{L_3} = 180° - 54.46° - 76° = 49.54° \quad (72)$$

$$\widehat{L_3F_3O'} = 90° - \widehat{VL_3F_3} = 90° - 49.54° = 40.46° \quad (73)$$

$$\widehat{T_3F_3O'} = \widehat{T_3F_3L_3} - \widehat{L_3F_3O'} = U_{LT_3} - \widehat{L_3F_3O'} = 199.13° - 40.46° = 158.67° \quad (74)$$

$$\widehat{OF_3T_3} = 180° - \widehat{T_3F_3O'} = 180° - 158.67° = 21.33° = \widehat{K_3F_3O'} \quad (75)$$

$$\left.\begin{array}{r} \widehat{J_3F_3O'} = \widehat{J_3F_3K_3} + \widehat{K_3F_3O'} \quad (76) \\ \widehat{K_3F_3O'} = \widehat{T_3F_3O} \Rightarrow \widehat{J_3F_3O'} = \widehat{L_3F_3O'} = 40.46° \quad (77) \\ L_3F_3 \cap G_3E_3 = [J_3] \quad (78) \end{array}\right\} \Rightarrow$$

$$\Rightarrow \widehat{J_3F_3K_3} = 40.46° - 21.33° = 19.13° \quad (79)$$

$$\left.\begin{array}{r} \widehat{F_3G_3E_3} = \widehat{VG_3E_3} - \widehat{VG_3F_3} = 6.35° - 2.46° = 3.89° \quad (80) \\ F_3X_3 \perp E_3G_3 \quad (81) \end{array}\right\} \Rightarrow$$

$$\Rightarrow \widehat{F_3G_3X_3} = \widehat{F_3G_3J_3} = \widehat{F_3G_3E_3} = 3.89° \quad (82)$$

In $\Delta F_3G_3X_3$: $\widehat{G_3F_3X_3} = 90° - \widehat{F_3G_3X_3} = 90° - 3.89° = 86.11°$ (83)

$$\widehat{G_3F_3L_3} = \widehat{G_3F_3J_3} = \frac{180° - U_{L_3}}{2} = \frac{180° - 76°}{2} = 52° \quad (84)$$

$$\widehat{G_3F_3J_3} + \widehat{F_3J_3G_3} + \widehat{F_3G_3J_3} = 180° \Rightarrow \quad (85)$$

$$\Rightarrow \widehat{F_3J_3G_3} = 180° - \widehat{G_3F_3J_3} - \widehat{F_3G_3J_3} = 180° - 52° - 3.89° = 124.11° \quad (86)$$

$$\widehat{F_3J_3G_3} + \widehat{F_3J_3X_3} = 180° \Rightarrow \widehat{F_3J_3X_3} = 180° - \widehat{F_3J_3G_3} \Rightarrow \quad (87)$$

$$\Rightarrow \widehat{F_3J_3X_3} = 180° - 124.11° = 55.89° = \widehat{F_3J_3K_3} \quad (88)$$

$$\widehat{J_3F_3X_3} = 90° - \widehat{F_3JX_3} = 90° - 55.89° = 34.11° \quad (89)$$

$$\widehat{J_3F_3X_3} = \widehat{J_3F_3K_3} + \widehat{K_3F_3X_3} \Rightarrow \widehat{K_3F_3X_3} = \widehat{J_3F_3X_3} - \widehat{J_3F_3K_3} \Rightarrow \quad (90)$$

$$\Rightarrow \widehat{K_3F_3X_3} = 34.11° - 19.13° = 14.98° \quad (91)$$

$$\widehat{X_3F_3O'} = \widehat{K_3F_3O'} - \widehat{K_3F_3X_3} = \widehat{O'F_3K_3} - \widehat{K_3F_3X_3} = 6.35° \quad (92)$$

$$\widehat{T_3F_3O'} = \widehat{T_3F_3L_3} - \widehat{L_3F_3O'} = U_{LT_3} - 40.46° = 158.67° \quad (93)$$

$$\left.\begin{array}{r} \widehat{E_3F_3O'} = \widehat{T_3F_3O'} - \widehat{E_3F_3T_3} \quad (94) \\ \widehat{E_3F_3T_3} = \dfrac{180° - \widehat{E_3T_3F_3}}{2} = \dfrac{180° - 14.97°}{2} = 82.52° \quad (95) \end{array}\right\} \Rightarrow$$

$$\Rightarrow \widehat{E_3F_3O'} = 158.67° - 82.52° = 76.15° \quad (96)$$

$$\widehat{E_3F_3X_3} = \widehat{E_3F_3O'} + \widehat{X_3F_3O'} = 76.15° + 6.55° = 82.51° \quad (97)$$

$$\text{In } \Delta E_3F_3X_3: \cos \widehat{E_3F_3X_3} = \frac{F_3X_3}{E_3F_3} \Rightarrow F_3X_3 = E_3F_3 \cdot \cos\widehat{E_3F_3X_3} \Rightarrow \quad (98)$$

$$\Rightarrow E_3F_3 = 2 \cdot R_{T_3} \cdot \sin\frac{\widehat{E_3T_3F_3}}{2} = 2 \cdot 160 \cdot \sin\frac{14.97°}{2} = 41.68mm \quad (99)$$

$$\Rightarrow F_3X_3 = 41.68mm \cdot \cos 82.51 = 5.43mm \quad (100)$$

$$\text{In } \Delta J_3F_3X_3: \cos\widehat{J_3F_3X_3} = \frac{F_3X_3}{F_3J_3} \Rightarrow F_3J_3 = \frac{F_3X_3}{\cos\widehat{J_3F_3X_3}} = \frac{5.43mm}{\cos\widehat{J_3F_3X_3}} \quad (101)$$

$$However \ \ \widehat{J_3F_3X_3} = \widehat{J_3F_3K_3} + \widehat{K_3F_3X_3} = 19.13° + 14.98° = 34.11° \quad (102)$$

$$\Rightarrow F_3J_3 = \frac{5.43\text{mm}}{\cos 34.11°} = 6.56mm \quad (103)$$

$$\text{In } \Delta F_3X_3J_3: J_3X_3 = \sqrt{(F_3J_3)^2 - (F_3X_3)^2} = 3.68mm \quad (104)$$

$$\text{In } \Delta X_3F_3K_3: \ tan\,\widehat{K_3F_3X_3} = \frac{K_3X_3}{F_3X_3} \Rightarrow K_3X_3 = tan\widehat{K_3F_3X_3} \cdot F_3X_3 = 1.45mm \quad (105)$$

$$J_3K_3 = J_3X_3 - K_3X_3 = 3.68mm - 1.45mm = 2.23mm \quad (106)$$

$$\text{In } \Delta E_3T_3F_3: \ E_3I_3 \perp T_3F_3 \Rightarrow \sin\widehat{E_3T_3F_3} = \frac{E_3I_3}{E_3T_3} \Rightarrow \quad (107)$$

$$\Rightarrow E_3I_3 = E_3T_3 \cdot \sin\widehat{E_3T_3F_3} = R_{T_3} \cdot \sin 14.97° = 41.33mm \quad (108)$$

$$\text{In } \Delta F_3E_3X_3: \sin\widehat{F_3E_3X_3} = \frac{F_3X_3}{E_3F_3} = \frac{5.43mm}{41.68mm} \Rightarrow \widehat{F_3E_3X_3} = \arcsin\frac{F_3X_3}{E_3F_3} = 7.48° \quad (109)$$

$$\widehat{I_3E_3F_3} = 90° - \widehat{I_3F_3E_3} = 90° - \widehat{T_3F_3E_3} = 90° - 82.52° = 7.48° \quad (110)$$

$$\Rightarrow \widehat{I_3E_3K_3} = \widehat{F_3E_3X_3} + \widehat{I_3E_3F_3} = 7.48° + 7.48° = 14.96° \quad (111)$$

$$\text{In } \Delta E_3I_3K_3: \cos\widehat{I_3E_3K_3} = \frac{E_3I_3}{E_3K_3} \Rightarrow E_3K_3 = \frac{E_3I_3}{\cos\widehat{I_3E_3K_3}} = 42.78mm \quad (112)$$

$$\text{In } \Delta G_3M_3L_3: \ G_3M_3 \perp F_3L_3 \Rightarrow sin\,\widehat{M_3L_3G_3} = \frac{G_3M_3}{G_3L_3} \Rightarrow \quad (113)$$

$$\Rightarrow G_3M_3 = G_3L_3 \cdot \sin\widehat{M_3L_3G_3} = 65mm \cdot \sin 76° = 63.06mm \quad (114)$$

$$\widehat{G_3J_3L_3} = \widehat{F_3J_3X_3} = 55.89° \quad (115)$$

$$\text{In } \Delta G_3J_3M_3: \ \sin\widehat{G_3J_3L_3} = \frac{G_3M_3}{G_3J_3} \Rightarrow G_3J_3 = \frac{G_3M_3}{\sin\widehat{G_3J_3L_3}} = 76.16mm \quad (116)$$

$$E_3G_3 = E_3K_3 + J_3K_3 + G_3J_3 = 42.78mm + 2.23mm + 76.16mm = 121.17mm \quad (117)$$

$$L_{\widehat{D_3E_3}} = \frac{\pi \cdot R_{T_3} \cdot \propto_{\widehat{D_3E_3}}}{180°} \Longrightarrow \quad (118)$$

$$\propto_{\widehat{D_3E_3}} = U_{T_3} - \widehat{E_3T_3F_3} - \widehat{B_3T_3D_3} = 44° - 14.97° - 14.23° = 14.8° \quad (119)$$

$$\Rightarrow L_{\widehat{D_3E_3}} = \frac{\pi \cdot 160 \cdot 14.8}{180°} = 41.33mm \quad (120)$$

$$A_3D_3 = AD \quad (121)$$

$$L_{tot_3} = AD + L_{\widehat{D_3E_3}} + E_3G \quad (122)$$

$$\Rightarrow L_{tot_3} = A_3D_3 + L_{\widehat{D_3E_3}} + E_3G = 255.02mm \quad (123)$$

$$L_{tot_1} = 259.59mm \quad (124)$$

$$\Rightarrow L_{tot_3} < L_{tot_1} \Rightarrow \quad (125)$$

$$\Rightarrow \Delta L = K(L_{tot_1} - L_{tot_3}) = 2{,}25(259{,}59 - 255{,}02)mm = 10{,}28mm \Rightarrow \quad (126)$$

⇒ In ***Case 3***, because the bending / lifting of the human torso involves the alteration, by flexion, of the physiological lumbar curvature, of the spine, the ***active length*** of the ***chord streched by the spine*** changes in relation to the one obtained in the physiological posture.

3. Conclusions

Using the method of determining the variation of the length of the stretched chord, it was possible to develop the prototype of a small and portable device for real-time monitoring and active postural autocorrection, having a simple structure, that does not imply the use of hi-tech sensors or some combination of various sensors (tilt [11], flex [12] [13], etc.). Due to this last aspect, the resulting device has a low manufacturing cost compared to the existing devices. Also, due to the principle of posture monitoring, the mentioned device does not restrict the user's movements, but warns him when its posture becomes incorrect, thus causing a re-training of his nervous system. This re-training represents in fact a method to increase the user's neuromuscular control. This means that the user will be able to maintain a corrected posture long after he will stop using the above mentioned device. In addition to the prototype, a national patent application was filed, which has been published on 28/08/2020, this being followed by a European patent application EP 3 760 170 A1, published on January 6, 2021 [14].

It is desired, in the future, to use this approach related to posture monitoring, to control not only the position of the spine as a whole, but also the position of each of its curvature, as well as the positions of the shoulders of a certain person, in a hope to obtain a portable, complex and complete postural monitoring device, which will allow its user to make real-time postural correction, regardless of his pathology, or the environment in which he operates: at home, at work, or at the training place.

Acknowledgements

This paper is an integral part of the research activity undertaken as a PhD student at Politehnica University of Bucharest. For this reason I would like to express my sincere gratitude to my doctoral thesis advisors, Prof. Octavian DONŢU and Prof. Gheorghe I. GHEORGHE, as well as to the thesis committee, Prof. Constantin NIŢU and Prof. Ciprian RIZESCU, for all the support given.

I would also like to thank all my colleagues at the National Institute of Research and Development in Mechatronics and Measurement Technique, with whom I have collaborated and I am collaborating, for the help provided.

R E F E R E N C E S

[1]. *Manju Gopinath, Angeline Kirubha,* Sagittal alignment of the spine: What do you need to know?, Clinical Neurology and Neurosurgery, Volume 139, December 2015, pp 295-301

[2]. https://simplifaster.com/articles/athlete-posture-sports-performance/

[3]. https://kararainahblog.wordpress.com/2016/04/06/postural-kyphosis/

[4]. *Juliana Adami Sedrez, Maria Izabel Zaniratti da Rosa, Matias Noll, Fernanda da Silva Medeiros, Claudia Tarragô Candotti,* Risk factors associated with structural postural changes in the spinal column of children and adolescents, Rev. Paulista de Pediatria, Volume 33, Issue 1, March 2015, pp 72-81

[5]. *Pierre Roussouly, Colin Nnadi,* Sagittal plane deformity: an overview of interpretation and management, European Spine Journal, Volume 19(11), Nov 2010, pp 1824–1836

[6]. *Huan Gong, Liang Sun, Ruiyue Yang, Jing Pang, Beidong Chen, Ruomei Qi, Xin Gu, Yaonan Zhang & Tie-mei Zhang,* Changes of upright body posture in the sagittal plane of men and women occurring with aging – a cross sectional study, BMC Geriatrics, Volume 19, Article number: 71, March 2019

[7]. https://losethebackpain.com/proper-body-mechanics/

[8].https://myemail.constantcontact.com/Exercise-Spotlight--Deadlift-like-a-Pro.html?soid=1112548744464&aid=p2y2FiShYyA

[9]. https://www.progressivespineandrehab.com/2015/10/chiropractic-care-of-the-upper-back/

[10]. https://theodora.com/anatomy/the_vertebral_column_as_a_whole.html

[11]. *Manju Gopinath, Angeline Kirubha*, Real Time Monitoring of Posture to Improve Ergonomics, Journal of Biomedical Engineering and Medical Imaging, Volume 2, No 2, April (2015), pp 22-25

[12]. https://www.backtosport.com.au/blogs/product-guides/upright-pro-posture-trainer-australian-review
[13]. https://www.wareable.com/wearable-tech/truposture-reminds-you-to-sit-up-straight-1762
[14]. *Cristian Radu Badea*, Device for real-time monitoring and active postural autocorrection, European Patent Application EP 3 760 170 A1, January 6, 2021