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Critical review

Prevention

What do we know about the determinants of sagittal standing posture?

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Abstract

Introduction

Effective primary strategies are expected to be a cost-efficient approach to reduce attributable morbidity caused by sagittal spino-pelvic misalignment. For such strategies to emerge we need to synthesized what is known on the causes of sagittal misalignment. This review aims to critically summarize published evidence on the determinants of non-neutral sagittal standing posture.

Discussion

Age is directly correlated with positive sagittal imbalance, but spino-pelvic age-related changes do not seem to cause relevant modifications to overall sagittal alignment. Gender differences are likely to exist, but only regarding postural patterns: men more often present an overall flat spine than women. Environmental circumstances of early life seem to have an important role in defining the organization of sagittal posture in adulthood.

Increased body mass index gathers the strongest evidence supporting its role in determining non-neutral sagittal standing posture. However, the mechanisms by which central obesity may influence sagittal spino-pelvic alignment remain largely unknown.

Despite hazardous behavioural characteristics have the most potential to be prevented, they have been less frequently studied and results are still controversial.

Conclusion

Evidence is scarce and dominated by cross-sectional evaluations and crude correlations between characteristics and isolated parameters. Future prospective studies, focused on overall postural patterns and accounting for plausible confounders are necessary in order to sustain judgement about causation of potential risk factors for sagittal misalignment.

Introduction

In the healthy adult, reciprocal sagittal curvatures of the spine are arranged in order to obtain the mechanically most efficient standing position – a neutral posture[1]. One of the fundamental determinants of the overall sagittal alignment of the spine is pelvic morphology, mainly because it defines lumbar lordosis contours, from which other curvatures and overall alignment stem[1,2,3]

Due to the interdependence between adjacent anatomical regions, the interaction between different segments of sagittal alignment should be considered in the analysis of standing posture[4,5]. Additionally, the same angular change in the same segment but in different subjects may have a different effect on overall sagittal alignment due to varying compensatory responses between distinct spino-pelvic segments[5]. Finally, the great variability observed in neutral “normative” ranges of regional spino-pelvic parameters limits the usefulness of isolated parameters when studying sagittal standing posture[3,6]. In this framework, several authors[3,4,5,6,7] have advocated that analysing sagittal postural patterns, instead of the conventional study of isolated alignment parameters, provides a more complete understanding of the complex overall spinal morphology. Consequently, different classifications of sagittal patterns have emerged[4,5,6,8] although inconsistent criteria are present and classifications were proposed in very heterogeneous populations.

If the physiological congruence between sagittal alignment parameters is disturbed or a suboptimal sagittal alignment exists, musculoskeletal spinal conditions are more likely to develop. Several studies have demonstrated associations of sagittal standing posture with pain, physical disability and reduced health-related quality of life, and positive sagittal imbalance have emerged as the most reliable radiographic predictor of clinical symptoms[9,10]. Spinal conditions are one of the leading causes of pain and disability worldwide[11,12], and their attributable burden is expected to increase dramatically during the next decades due to increasing trends of known risk factors such as ageing, obesity and sedentariness[11].

Effective primary strategies should be a cost-efficient approach to reduce attributable morbidity from sagittal spino-pelvic misalignment, but management approaches remain generally focused on modifying the prognosis of sagittal posture-related diseases after misalignment occurs, both surgically or conservatively[13]. One of the main reasons for the current neglect of primary prevention may be the limited number of characteristics that have been formally tested as potential determinants of sagittal standing posture, and also, the predicted difficulty in the modification of a small number of determinants that may be, in fact, changeable characteristics.

It is likely that the effect of known determinants of spinal pain is largely mediated by sagittal standing posture. To assess the plausibility of that mechanism it is essential that the associations between such determinants and sagittal

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misalignment are tested. Many potential hazardous determinants of sagittal non-neutral posture are correlated and may stem from more general health inequalities such as those resulting from socioeconomic status. Moreover, their effect on posture is probably cumulative throughout the life course, posing increased limitations to the identification of characteristics that contribute causally to non-neutral sagittal standing posture (Figure 1). Nevertheless, there has been a growing effort to obtain scientific evidence on this subject and it is important to review the main results and limitations of these studies.

This critical review aims to summarize published evidence on the determinants of non-neutral sagittal standing posture and on plausible underlying pathophysiologic mechanisms.

Discussion

Despite this work do not intend to systematically revise literature we have extensively searched Medline and we hand-searched the references of all relevant articles. We opted to include representative results of the published evidence by not excluding any study that contradicts our summary on the determinants of non-neutral sagittal standing posture.

Sociodemographic characteristics

An effect of age in promoting positive sagittal standing imbalance (i.e., forward displacement of the spine over the hips) has been consistently reported in adults[7,14,15,16] Age has been directly correlated with sagittal balance in asymptomatic adults aged between 21 and more than 60 years[16], 40 and 82 years[14], and 70 and 85 years[15]. Positive sagittal vertical axis in adults results from an age-related decrease in lumbar lordosis[14,15] and increase in thoracic kyphosis[16], which in turn induce increased pelvic retroversion in order to keep the gravity line relatively stable within the basis of support[16].

Despite its association with balance, evidence on the effect of ageing on sagittal spino-pelvic alignment is controversial. In 709 asymptomatic adults (age range: 18-81 years), age was significantly correlated with pelvic tilt (r=0.16), sacral slope (r=-0.10), pelvic tilt-pelvic incidence ratio (r=0.19), sacral slope-pelvic incidence ratio (r=-0.19) and pelvic tilt-sacral slope ratio (r=0.21)[17]. However, the small correlation magnitudes supported the hypothesis that physiological age-related changes in the pelvic region might not be of clinical relevance[17], which is also reinforced by findings in other studies, including our previous research[1,7].

Regarding postural patterns, even though Roussouly et al[3] proposed that the population distribution of patterns in adults should change with ageing, age was not a risk factor for non-neutral postures in our study of 489 community-dwelling Portuguese adults[7]. Additionally, in 90 Thai asymptomatic adults (age range: 21-50 years) no difference was found regarding the frequency of postural patterns between three different categories of age[6]. On the other hand, in 450 Chinese osteoporotic women (age range: 60-95 years), 20 of them presenting type 4 postural pattern (thoracic hyperkyphosis and lumbar kyphosis) had the highest mean age among all postural patterns (highest mean difference: 9.61 years), followed by 132 of them presenting the type 5 (thoracic hyperkyphosis and lumbar hypolordosis)[5].

The majority of the studies that have compared sagittal spino-pelvic alignment or balance between genders, reported no differences in individual parameters between men and women[1,2,7,14,17]. Nevertheless, Janssen et al.[18] by evaluating three-dimensional spino-pelvic orientation of 30 men and 30 women, found that the female spine was overall more dorsally inclined.

Regarding postural patterns, in a sample of 70 males and 30 females, adult men presented a type 1 postural pattern (lumbar hypolordosis) more frequently than women (27.1% vs. 13.3%; p<0.001)[5]. The same conclusion is supported by the results observed among 402 male and 364 female adolescents, where a higher than expected proportion of males was observed within the flat postural pattern (p=0.028)[4]. Consistent results were observed in our study of 178 men and 311 women from a population-based sample[7]. However, we found no difference between genders in the adjusted odds of a type 2 postural pattern (attenuated curvatures of the spine); instead, there was a small tendency for women to show the type 1 postural pattern (extremely hypolordotic and non-harmonious spine) comparatively to men, despite the fact that only 24 participants displayed this particular pattern [odds ratio (OR) adjusted for other sociodemographic, anthropometric and behavioural characteristics: 4.09, confidence interval (CI) 95%: 0.81-20.7].

The relation between formal education or occupation and sagittal standing posture has rarely been assessed. We have reported very similar patterns in the relation of education and occupation with sagittal vertical axis, pelvic incidence, pelvic tilt and pelvic tilt-pelvic incidence ratio[7]. We believe that these relations are likely to represent a true causal mechanism because of the observed differences between socioeconomic groups in respect to pelvic incidence (a fixed parameter which reflects pelvis shape): median was 3.9º higher in participants with less than or equal to four years of complete educational years (vs. those with at least 10 years; p=0.006) and 3.5º higher in blue collar occupations comparing with upper white collar occupations (p=0.052). These findings have encouraged our hypothesis that socioeconomic environmental circumstances during early stages of life is able to determine posture in adulthood, but more investigation exploring this potential effect is warranted before stronger conclusions can be drawn. Additionally, it is also important to recall the potential of occupation to influence spino-pelvic sagittal parameters by similar mechanisms to those that link occupation to musculoskeletal spinal conditions. Several physical or psychosocial work environmental factors have been suggested to be directly associated with musculoskeletal spinal complaints, such as heavy physical

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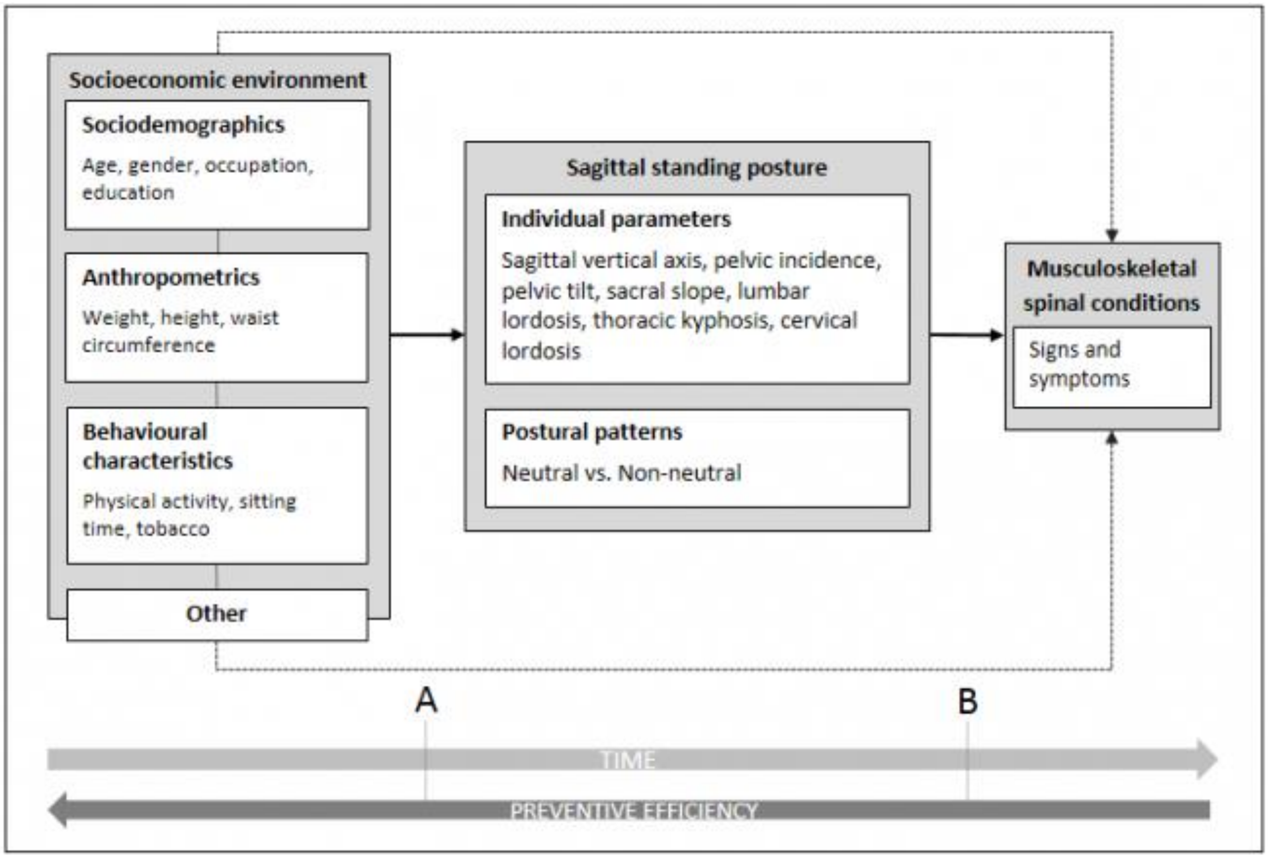

Figure 1: Framework for primary prevention of sagittal posture-related spinal conditions. Sociodemographic, anthropometric and behavioural characteristics are associated with musculoskeletal spinal conditions mainly by their effect on sagittal standing posture. (A) and (B) represent critical points in the natural history of musculoskeletal spinal conditions, after which treatment is theoretically less favourable: A – sagittal misalignment onset; B – beginning of clinical phase of disease.

load, static work postures, low level of job control or high psychological demands[19,20]) but their relation with sagittal standing posture has not yet been formally tested.

Anthropometric characteristics

Despite the limited number of studies that have analysed the effect of body mass index (BMI) on sagittal spino-pelvic alignment, overweight probably gathers the strongest evidence as a potential determinant of non-neutral sagittal standing posture. In 100 asymptomatic adults of mean BMI 22.8 kg/m^2, ranging between 17.6 and 29.5 kg/m^2, significant correlations of BMI with pelvic incidence ($r=0.41$), sacral slope ($r=0.41$) and lumbar lordosis ($r=0.33$) were found, but BMI was not associated with sagittal vertical axis, pelvic tilt or thoracic kyphosis[2]. However, in 300 asymptomatic adults of mean BMI 23.5 kg/m^2 (range: 15.0-35.0 kg/m^2)[1] and 200 "healthy" adults (25.5% of them classified as normal weight subjects)[21] no significant correlations were found between BMI and sagittal spino-pelvic parameters.

Among the eleven characteristics that we have evaluated as potential determinants of sagittal standing posture in the general adult population (22.1% participants classified as obese), BMI was the most likely causal factor[7]. A clear direct gradient between BMI categories and increased sagittal vertical axis (highest median difference between extreme groups of 12.1mm; $p=0.067$), pelvic incidence (4.3º; $p=0.141$), pelvic tilt (2.9º; $p<0.001$), and pelvic tilt-pelvic incidence ratio (0.05; $p=0.001$) was found. Additionally, overweight represented an approximately 2-fold higher risk for one of two opposite non-neutral postural patterns (hypo or hyperlordotic) and obesity was a risk factor to a more extreme hypolordotic posture (OR=6.10; CI 95%: 1.52-24.57), independently of sociodemographic and behavioural characteristics[7].

The biological plausibility for the effect of BMI on adult sagittal spino-pelvic alignment was suggested to be related with biomechanical constraints induced by increased adiposity during standing posture and gait acquisition in early life, whose influence may deform the sacrum during osseous growth and affect pelvic incidence, sacral slope and lumbar lordosis[2]. The same mechanism was supported when analysing the relation between BMI trajectory (three to 14 years old) and postural pattern at age of 14 years, where it was suggested that increased biomechanical load as the result of higher adiposity during early stages of life could lead to permanent changes of spinal structures, that then would favour the occurrence of non-neutral postural patterns throughout life[22]. This last study adds important and stronger evidence for causation between BMI and

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sagittal standing posture for two main reasons: (1) it was able to demonstrate temporality in the exposure-outcome relation, and (2) it is expected that most adolescents still present their constitutional postural pattern instead of one resulting from adaptive pelvic mechanisms that may already have taken place in adult populations. However, for logistic and ethical reasons, authors have chosen to assess posture by means of photogrammetry and not by radiology ("gold-standard"), and future research focused on the life course patterns of change in sagittal posture might keep a similar approach, especially in contexts of large samples of children or adolescents.

Although in two other studies[6,21] no association between BMI categories and postural patterns was observed, probably the main explanations for the lack of association are limited statistical power and inexistent[6] or low[21] frequency of the highest categories of obesity.

Furthermore, it is currently believed that abdominal obesity could affect neutral sagittal spino-pelvic alignment in a similar way to the adaptive mechanisms that occur during pregnancy[23], where the extra fat mass around the abdominal region shifts the center of mass in a forward direction, consequently resulting in a pelvic tilt decrease (i.e., pelvic anteversion) and sacral slope and lumbar lordosis increase, in order to restore the center of mass within the basis of support. However, we have demonstrated that 200 participants with central obesity mainly show increased pelvic retroversion, and consequently, higher risk of type 1 postural pattern (extremely hypolordotic) comparatively to their counterparts without central obesity (n=287)[7]. These findings are contradictory with the mechanisms initially postulated, but we will only be able to understand these differences with future prospective evidence aimed to track changes in pelvic parameters across time.

Behavioural characteristics

Regarding physical activity levels, these could supposedly influence sagittal spino-pelvic alignment by many different ways. Adults who do not reach minimal levels of regular physical activity have revealed a higher sagittal vertical axis than those with higher levels of physical activity (p=0.010)[7]. However, no clear protective effect of physical activity in preventing non-neutral postural patterns was found. Still, some arguments in favour of valuing the relevance of suggested protective effects were presented, based on plausibility of biological pathways, such as, ability to prevent deterioration of strength, balance, bone mineral density and to reduce adiposity[7]. On the other hand, it has been suggested that specific intense sports activities could generate sagittal postural adaptations, which would result in non-neutral standing sagittal alignment among athletes[24], for example, increased lumbar lordosis and sacral slope in soccer players. Sports activities performed during childhood could also affect sagittal alignment of the immature spine, since spinal curves increase as cumulative training time also increases[25]. Consequently, some authors[5,7,22] have suggested that physical activity likely influences overall sagittal standing postural patterns in adults, even though this has never been clearly demonstrated. Future evidence is mandatory in order to clarify the effect of physical activity on sagittal standing posture but it is essential to account for some important potential confounders such as BMI and socioeconomic status.

Comparatively to standing position, the sitting position in itself is characterized by changes in sagittal spino-pelvic alignment, as increased pelvic tilt, decreased sacral slope and lumbar lordosis[26,27]. In response to prolonged sitting, adaptations in soft tissues occur and may result in increased passive flexion stiffness and decreased lumbar range of motion[28,29], which in turn, can translate into non-neutral sagittal standing postural patterns. It was shown that adolescents presenting non-neutral standing postural patterns (sway, flat or hyperlordotic) have higher degree of slump in sitting position than adolescents presenting neutral standing postural pattern, independently of other physical, lifestyle and psychosocial variables[30]. Still, in adults, we found no relation between time spent in sitting position and individual sagittal alignment parameters or standing postural patterns[7]. However, we included only leisure time activity, whereas it is important to add occupational exposure to the time spent in the sitting position.

Although the underlying mechanisms are not completely understood, the hazardous influence of smoking (direct or second-hand) on spinal structures have been frequently used to explain the association of smoking with back pain[31], but, to the best of our knowledge, only our study has evaluated the relation between smoke and parameters or patterns of sagittal posture[7]: current smokers seems to have higher odds of accentuated sagittal curvatures independently of other sociodemographic, anthropometric and behavioural characteristics (OR=2.09; CI 95%: 0.97-4.48 comparing to never smokers). However, given the incipient level of evidence regarding tobacco as a determinant of sagittal standing posture, future studies are still needed in order to clarify the more basic aspects of this potential relation.

Conclusion

Increased BMI seems to gather the strongest evidence supporting its role in determining non-neutral sagittal standing posture. Gender differences are likely to exist, but only regarding postural patterns: men present an overall flat spine more frequently than women. Environmental circumstances of early life seems to have a role in defining the organization of sagittal posture in adulthood, highlighting the importance of focusing our attention on this window of opportunity in order to further gain insight into the determinants of sagittal posture.

Evidence is scarce and dominated by cross-sectional evaluations and crude correlations between characteristics and isolated parameters. Future prospective studies focusing overall postural patterns, using more appropriate

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statistical analysis and adjusting for plausible confounders, will allow a more informed judgment about causation of potential risk factors for non-neutral sagittal standing posture.

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