# Vertebral Metrics: Application of a New Mechanical Instrument to Evaluate the Spinal

## Métrica Vertebral: a Aplicação de uma Nova Tecnologia na Análise da Coluna Vertebral

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### ABSTRACT

**Objective:** To present the results of the first application of the new technology - Vertebral Metrics - the analysis of the 3D position of the vertex of each spinous process in pregnant women.

**Material and Methods:** The Vertebral Metrics was applied to women without associated pathology in four stages of pregnancy (12, 20, 32, 37 weeks gestation). We applied univariate linear models.

**Results:** We found that the differences that occur during pregnancy are more significant at the position y (anteroposterior). It was found also that there is a positive correlation between the biomechanical position of the vertex of each of the vertebrae with the homologous position of rest.

**Discussion/Conclusion:** Through Vertebral Metrics innovative results could be obtained in analyzing biomechanics of the spine. A device that has different applications can be easily adopted in areas such as orthopedics, neurosurgery, pediatrics and rehabilitation. It should also be noted that this instrument is not exhausted in the sample of this research because it can be further applied to the general population


**Keywords:** Biomechanics; Equipment Design; Imaging, Three-Dimensional; Posture; Pregnancy; Spine.


### RESUMO

**Objectivo:** Apresentar os resultados da primeira aplicação da nova tecnologia – Métrica Vertebral – na análise da posição 3D do vértice de cada uma das apófises espinhosas, em mulheres grávidas.

**Material e Métodos:** O Métrica Vertebral foi aplicado a mulheres, sem patologia associada, em quatro momentos da gravidez (12, 20, 32, 37 semanas de gestação). Aplicaram-se modelos lineares univariados.

**Resultados:** Observou-se que as diferenças que ocorrem ao longo da gravidez são mais significativas ao nível da posição y (anteroposterior). Verificou-se, igualmente, que existe uma correlação biomecânica positiva entre a posição do vértice de cada uma das vértebras com a posição homóloga das restantes.

**Discussão/Conclusão:** Através do Métrica Vertebral foi possível obter resultados inovadores na análise biomecânica da coluna vertebral. É um dispositivo que tem diferentes aplicações podendo ser facilmente adoptado em áreas como ortopedia, neurocirurgia, pediatria e reabilitação. É de realçar ainda que este instrumento não se esgota na amostra da presente investigação pois pode ser futuramente aplicada à população em geral


**Palavras-chave:** Biomecânica; Gravidez; Coluna Vertebral; Imagem Tridimensional.

### INTRODUCTION

Rachialgia-related disorder incidence is so high that it justifies its study as a social and epidemic disease.[1]

Painful vertebral pathology is a relevant problem in modern society. (Alexandre & Moraes, 2001) In many cases, it presents for the first time during pregnancy. About 80% of pregnant women present during pregnancy and in approximately half the symptoms remain for the rest of their lives. This situation induces a high absenteeism and consequently, under an economic perspective, it may impose a heavy burden on the labour market.[2,3]

These justify the need to design an instrument for spinal assessment in the upright position, taking into account the number of affected women and the economic consequences of this problem, in order to understand spinal pathology throughout pregnancy.

Most researchers describe rachialgia aetiology as caused by spinal biomechanical changes throughout pregnancy. Nevertheless, progress in the field has been slow due to the fact that the currently available analytical methods are invasive and therefore could not be used in pregnancy. In addition, non-invasive diagnostic instruments only allow for insufficient spinal evaluation.[4-9]

In order to fill this gap, we designed an innovative type of equipment, designated *Métrica Vertebral* (Vertebral Metrics), which has been registered as - Marca Nacional nº 401505. Vertebral Metrics is a non-invasive diagnostic instrument that allows for 3D identification of each spinal apex, from the first cervical to the first sacral vertebra, in the upright position. It also allows for an estimation of spinal curvature angles, as well as lateral deviations.[10-13]

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It should be noted that the Vertebral Metrics validation process was successfully performed in the Laboratório de Biomecânica of the Faculdade de Motricidade Humana. It proved to be a reliable and valid instrument when compared with an optoelectronic system.[14,15]

The aim of the present work is to present the results of the first application of the new technology – Vertebral Metrics (*Métrica Vertebral*) – a 3D position analysis of each vertebral spinous process in pregnancy.

## MATERIAL AND METHODS

The present work is included in a wider project intended to identify spinal biomechanical changes that occur throughout pregnancy and to understand their pathogenesis.

The application process of Vertebral Metrics starts with the skin projection of the spinous process apex using a hypoallergenic dermographic pen. Each part is adjusted so that the point of contact touches the mark drawn over each vertebra, from the first cervical vertebra to the first sacral vertebra, identifying its position in *x*, *y* and *z* axis.[10-13]

In order to reduce the application time of this tool and according with the height of the person to whom the Vertebral Metrics is to be applied, it is possible to adjust each of the 2D Positioners fitting these in a certain position in the *z* axis.[10,11]

On average, data collection process requires seven minutes to complete (Figure 1).[11]

This instrument has been approved by the Ethics Committee of the Faculdade de Ciências Médicas, the Maternidade Dr. Alfredo da Costa and the Administração Regional de Saúde de Lisboa e Vale do Tejo for application in pregnancy.

### Technical Procedures

There was a need to establish certain rules in order to reduce the influence or bias of the obtained results, as certain variable identification or control may not always be guaranteed. Therefore, the following principles had to be established:

- data collection was always recorded by the same researcher;
- data collection method was randomized;
- the assessment of each pregnant mother must be made at the same period of the day;
- Vertebral Metrics position identification must be established using marks on the floor;
- the position of the feet must always be the same at every moment of the application of Vertebral Metrics.

### Statistical analysis

We applied univariate linear models in the analysis of the *x*, *y* and *z* positions of spinous processes apex throughout pregnancy. According to this framework, univariate linear models have been used to analyse the three variables as a whole, in this fashion considered as a unique element.

The analysis of the individual contribution of *x* (lateral), *y* (anteroposterior) and *z* (superior-inferior) position of each vertebra in the equivalent positions of the remaining vertebrae was performed using Pearson bivariate correlations.

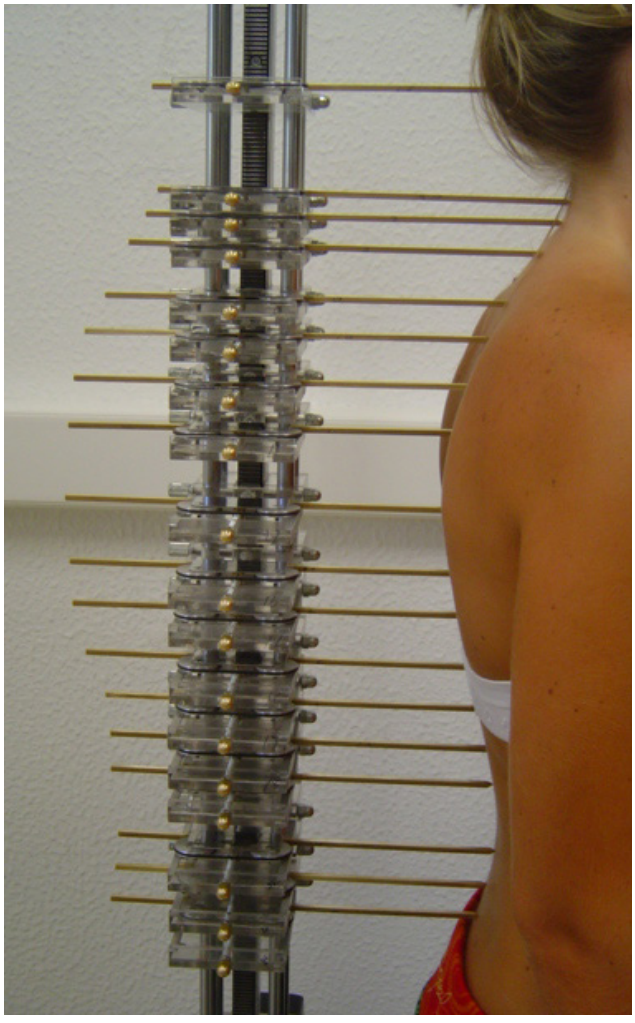


Figure 1 – Application process of Vertebral Metrics (*Métrica Vertebral*)

The average, maximum and minimum values were calculated for all statistical data, for each of the collected variables, considered valid within a 95% confidence interval (CI).

All statistical data treatment was performed with SPSS® version 17.0 (http://www.spss.com) and with R® version 2.9 (http://www.R-project.org).

### Sample Characterization

The sample in our study included pregnant healthy women (*n* = 49), with no associated pathologies, attending a health centre - Centro de Saúde de Sete Rios. Data collection was performed at 12, 20, 32 and 37 weeks of pregnancy.

In order to ensure a representative sample, a probability sampling method using a random sample was used.

Upon identification of our potential group of patients, we contacted the pregnant mothers in order to invite them to participate in the present work during their visit to the health centre. They were informed about the objective of the

study, required collaboration regarding data collection and consent was obtained.

Our group of pregnant mothers included 49 women with ages between 19 and 42, with a median age of 30. The prevalent nationality was Portuguese (73.5%), almost all women were Caucasian (91.8%), primigravidae (89.8%) and had not undergone any abdominal surgery (83.7%).

## RESULTS

We present the results obtained from the Vertebral Metrics analysis of 3D position variation of each vertebra in *x*, *y* and *z* planes throughout pregnancy.

Regarding the *x* position, we observed the following:

- at the cervical spine, there were only significant differences at C1 and C2 between the 12 and 20 weeks of pregnancy. We observed that the highest value in the confidence interval of 95% was at C1 (±3 mm). We also observed that this dispersion around medium???? decreases throughout pregnancy;
- at the thoracic spine, there were significant differences at T2 to T6 between 12 weeks and the remaining stages of pregnancy. At T1, T7, T8, T9, T11 and T12, we observed that the significant differences only occurred between two assessment stages;
- at the lumbosacral spine, there were only significant differences at L1 and L2 and these only occurred between 12 and 20 weeks of pregnancy.

We observed that the significant differences between the vertebrae at the four assessment stages were more evident at the thoracic level.

A positive correlation was observed at the *x* position of the spinous processes apex, between all the vertebrae in the same region of the spine, with a very strong correlation coefficient. This fact was constantly observed throughout pregnancy, with the only exception at 32 weeks of pregnancy and in the lumbar region (Figure 2).

When we correlated the *x* position between all the vertebrae, from the first cervical to the first sacral vertebra, we obtained a positive correlation between them. We also observed that the vertebrae which are close to each other present higher coefficients.

Due to this fact, it is possible to observe that the *x* position of each vertebra depends both on the position of the previous and subsequent vertebra and so on. This means that a change at the *x* position of one of the vertebrae, is associated with surrounding point variation.

Regarding the *y* position, we observed the following:

- at the cervical spine, there were significant differences between every vertebra, between 12 weeks and the remaining stages of pregnancy, with the exception of C4, where this difference only existed between 12, 20 and 32 weeks of pregnancy;
- at the thoracic spine, there were significant differences in every vertebra, between 12 weeks and one of the assessment stages in the third trimester of pregnancy (at 32 or at 37 weeks). There were only differences at T11 between the first assessment and the remaining stages;
- at the lumbosacral spine, there were only significant differences at L1 and L2 and just between 12 and 20 weeks of pregnancy.

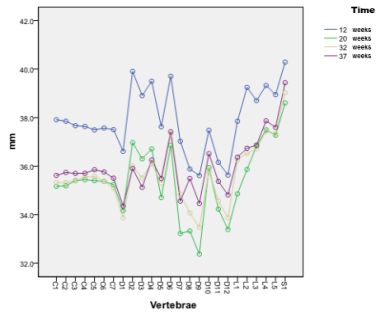
The correlation coefficient at the *y* position between all vertebrae from the same region at 12, 20, 32 and 37 weeks of pregnancy was significant. Correlation was very strong at cervical vertebrae and less strong at thoracic vertebrae (and those anatomically farther apart, as for instance between T1 and T10) and at lumbar vertebrae (for instance between L1 and L4). Nevertheless, although there was a lower coefficient, it was nonetheless significant (Figure 3).

The medium value at the *y* position changed over time, reflecting a decrease in medium value, mainly at the lumbar vertebrae level.

In what concerns *z* position, we observed the following:

- at the cervical spine, there were only significant differences in all vertebrae at 37 weeks of pregnancy, when compared with other stages of assessment;
- at the thoracic spine, there were no significant differences at T5 to T12 between assessment stages. There were only differences at T1 to T4 between the first assessment stage and some of the remaining assessments;
- at the lumbosacral spine there were no significant differences in all vertebrae during pregnancy.

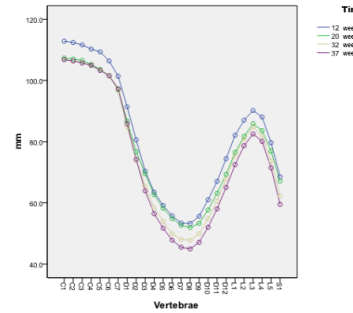
The correlations between each vertebra in each region were very strong at all assessment stages and are presented in Figure 4. The variations between 12, 20, 32 and 37 weeks of pregnancy in each vertebra were minor. As it would be expected, the cervical vertebrae presented the




| Plane X | | Coefficient |
|---|---|---|
| C1 to C7 | 12 s | 0.92-0.99 ** |
| | 20 s | 0.98-0.94 ** |
| | 32 s | 0.97-0.99 ** |
| | 37 s | 1.00-0.94** |
| D1 to D12 | 12 s | 0.95-0.42** |
| | 20 s | 0.92-0.47** |
| | 32 s | 0.95-0.47** |
| | 37 s | 0.92-0.52** |
| L1 to S1 | 12 s | 0.90-0.42 ** |
| | 20 s | 0.91-0.42 ** |
| | 32 s | 0.85-0.37** |
| | 37 s | 0.95-0.29 * |

* p < 0.05; ** p < 0.01

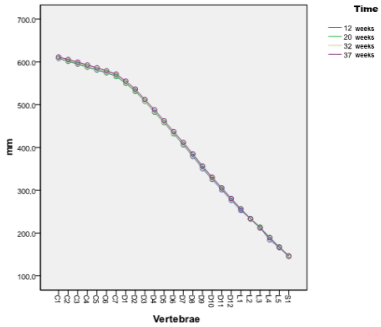
Figure 2 – Presentation of the medium x position of each vertebra (from C1 to S1) at 12, 20, 32 and 37 weeks of pregnancy: Correlation coefficients between vertebrae (x position) in cervical, thoracic and lumbosacral regions (right).




| Plane Y | | Coefficient |
|---|---|---|
| C1 to C7 | 12 s | 0.99-0.92** |
| | 20 s | 0.99-0.91** |
| | 32 s | 0.99-0.94** |
| | 37 s | 0.99-0.95** |
| D1 to D12 | 12 s | 0.98-0.58** |
| | 20 s | 0.99-0.80** |
| | 32 s | 0.98-0.59** |
| | 37 s | 0.60-0.98** |
| L1 to S1 | 12 s | 0.98-0.43** |
| | 20 s | 0.98-0.90** |
| | 32 s | 0.98-0.80** |
| | 37 s | 0.79-0.98** |

* p < 0.05; ** p < 0.01

Figure 3 – Presentation of the medium y position of each vertebra (from C1 to S1) at 12, 20, 32 and 37 weeks of pregnancy: Correlation coefficients between vertebrae (y position) in cervical, thoracic and lumbosacral regions (right).




| Plane Z | | Coefficient |
|---|---|---|
| C1 to C7 | 12 s | 1.0 - 0.99** |
| | 20 s | 1.0-0.99** |
| | 32 s | 0.99-0.99** |
| | 37 s | 1.0-0.99** |
| D1 to D12 | 12 s | 0.99-0.96** |
| | 20 s | 0.98-0.76** |
| | 32 s | 0.99-0.97** |
| | 37 s | 0.99-0.97** |
| L1 to S1 | 12 s | 0.99-0.87** |
| | 20 s | 0.99-0.96** |
| | 32 s | 0.99-0.95** |
| | 37 s | 0.99-0.94** |

* p < 0.05; ** p < 0.01

Figure 4 – Presentation of the medium z position of each vertebra (from C1 to S1) at 12, 20, 32 and 37 weeks of pregnancy: Correlation coefficients between vertebrae (z position) in cervical, thoracic and lumbosacral regions (right).

highest values, while the first sacral vertebra had the lowest value.

When we correlated all vertebrae at each stage, the coefficient varied between 1 and 0.93, meaning that the *z* position of each vertebra was strongly related with the position of the remaining vertebrae.

From the analysis, we should remark that *x*, *y* and *z* position of each vertebra depends on the position of the other vertebrae. When considering the medium values in the different assessment stages, we concluded that one change of one position corresponded to a similar variation on the remaining vertebrae, in which all vertebrae adjust accordingly, moving in a correlated fashion.

## DISCUSSION

Data collection and analysis were only possible due to the development of an innovative instrument for a global spine assessment, in upright position – the Vertebral Metrics system; nevertheless, we should emphasize that present discussion is based on the obtained results.

When analysing the *x*, *y* and *z* apex position of each spinous process, we found a complete absence of studies in this area and therefore we could not have any reference points to draw any comparisons. For this reason, the present research may be considered as innovative and is intended to be a reference for further research.

The differences that occurred throughout pregnancy were significant at the *y* position (antero-posterior), what may relate to the postural adaptation that occurs during pregnancy.

There is also a positive biomechanical correlation between the position of the apex with the same position in the remaining vertebra, meaning that whenever there is a change on one position, the other apices will adapt accordingly allowing the necessary physiological stability and postural adjustment.

From data analysis we conclude that changes in the variables of the study were more relevant between 20 and 32 weeks of pregnancy.

A possible explanation for the observed results is a combination of two factors: on the one hand, until the first stage of assessment (12 weeks of pregnancy), uterine growth is confined to pelvic girdle, thereby not causing any significant changes in the spine; on the other hand, pregnancy stages between 20 and 32 weeks not only correspond to the larger time interval between assessments but it also coincides with the time of stronger growth of the foetus, contributing to changes in joint kinematics and subsequently in the trunk region.

This dynamic behaviour may also relate to the adaptation in the referred curves in order to promote physiological stability that ensures a stable platform for human visual and vestibular systems.[10,11]

## CONCLUSION

The main objective of Vertebral Metrics is to contribute to a better understanding of biomechanical changes of the spine. Its application is made possible in the following areas of research:

To identify spinal biomechanical changes throughout pregnancy: cervical lordosis, thoracic kyphosis and lumbar lordosis angles; *x*, *y* and *z* positions of the apex of each spinous process, from the first cervical to the first sacral vertebra;

To compare data in the four stages of assessment (12, 20, 32 and 37 weeks of pregnancy) and to estimate any possible significant differences that may occur in some of the abovementioned domains;

The quantitative characterisation of spinal biomechanical changes is fundamental to define preventive strategies and to intervene in this domain. In order to better understand this phenomenon, we analysed its possible correlation with a set of associated variables, whether considered as a cause or as an effect.

We hope, with Vertebral Metrics, to contribute to a better identification of spine pathologies in the upright position. With improved diagnosis it will be possible to define better oriented approach strategies to the specific problems of each patient. It is a device with different applications in Orthopaedics, Neurosurgery, Paediatrics and Rehabilitation. As a general perspective we predict the use of this instrument does not end with the present research, and that it may be applied to general population, in the future.[12-15]

The Vertebral Metrics represents an innovation in the field of prevention, as it may be applied several times and non-harmfully. It is low-cost, easy and portable and demands few logistic requirements. These advantages allow it to be used in different contexts, including outpatient care: public and private (health centre / public and private clinics.

## CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests when writing this manuscript.

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