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BIOMECHANICAL MODEL OF THE HUMAN SPINE AS AN ARCH

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INTRODUCTION

The human spine is the main structure to support human body weight and external loads, to allow the torso to reach a variety of positions and to protect the spinal nervous system. Lumbar back pain and disorders might be related to spine curvature and disc pressure, and it is an objective of this work to include consideration of these Issues in the SAMMIE computer aided ergonomics design system. Such a design system would then be used in evaluating a wide range of situations including manual handling, car seat design, etc. The human spine is a statically indeterminate structure. The work reported here generates a criterion for the failure of the human spine, and describes the method used to determine a better or even the best fitting thrust line using optimisation techniques. This is considered to be a better predictor, when compared to the previously published arch model under the same load conditions[1].

REVIEW AND THEORY

Many attempts have been made to represent the spine using elastic analysis applied to structural models including levers, simple beams and cantilever beams. Some work is reported in the literature that models the spine as a single arch[1]. Stability of the spine under a variety of loading conditions can then be determined using plastic analysis methods, in compliance with the criterion that stability requires that the thrust line should be located within all cross sections of the arch. Lever models typically describe the spine as rigid levers with balancing reaction forces at the sacrum with no proper consideration of spinal curvature. This form of analysis is unable to explain how vertebral disc pressure increases with increasing intra-abdominal pressure and can produce results that are not proper. For example, the holding of a 90kg weight in a stooped posture leads to a predicted reaction force of 6.6 kN[3] which is sufficient to fracture the end-plates of the vertebral body (whose bearing strength is about 6 kN). Clearly this situation, although well outside normal working practices, is sustainable without damage as shown in the extreme by weightlifters. This discrepancy is considered to arise from the way in which lever models ignore spinal curvature. In contrast this paper describes the spine as an arch under assumptions that compressive forces can be transmitted in the spine only, the spine has enough compressive strength and sliding failure cannot occur In the spine. This provides a good explanation of disc and intra-abdominal pressure, and produces a calculated reaction force of 1.3-1.5 kN for the situation described above. The body weight, external loads and/or supporting forces from the seat back in a sitting posture were treated as forces applied at appropriate points on the arch spine. Muscle and ligament forces were treated as internal reaction forces applied to both ends of the spine. As an arch spine model[1], a criterion of the failure of the spine need to be generated and the best fitting thrust line need to be found using optimisation techniques.

PROCEDURES

In this developed single arch spine model, the loads applied to the arch spine are in general directions rather than being limited to a single (vertical) direction as in previous studies[2], which was developed based on the established use of vertical direction loads applied to an arch to provide a more realistic set of loads for the spine in typical working postures. A criterion for the failure of the arch spine is established. An infinite number of thrust lines for a single arch can be obtained as it is a statically indeterminate structure. There is one thrust line, however, which is the best fitting for the arch or spine. Hence there is an optimisation problem. A definition of the "best fitting" thrust line is that the resultant thrust line is the closest one to the central line or reference line of the arch or spine. It is not difficult to reach a criterion for the failure of the spine, if the best fitting thrust line among of all thrust lines in an arch spine can be found but it is not located within the "core"[2] of the spine, then hinges form[2] and spinal failure or disorders can occur. The principles and methods of optimisation for a better, or even the best fitting thrust line in the arch spine are presented. The methods used to calculate a better or best fitting thrust line of the arch spine from force polygons, are described as an optimization, whose objective function is that the thrust line is as close as possible to the central line or reference line of the arch spine. Four objective functions are described as follows:

a) $f1=Minimise[\max d_i]$, i=1, n;
b) $f2=Minimise[\sum d_i^2]$, i=1, n;
c) $f3=Minimise[\sum w_i \times d_i]$, i=1, n;

d) $f4=Minimise[w_1 \times d_n + w_2 \times \max d_i]$, i=1, n-1
where d is the distance between current calculated thrust line and the spine reference (or centre) line and w is a weighting factor for the optimization calculation. The best result of several locally optimised values of the above four objective functions was chosen as the final optimisation result.

RESULTS AND DISCUSSION

Examples are given for optimisation of thrust lines from the corresponding force polygon in Fig.1. A comparison between optimised thrust line in this paper and the one of previously published arch model under the same conditions[1] is shown in Fig.2. It should be noticed that the optimised thrust line is closer than the one in reference[1] to the central line or reference line of the arch spine. The reaction force calculated is about 1.3-1.5 kN. The developed arch model with optimisation is shown to be a better predictor of spinal loading.

Spine disorders may occur in both situations and the one in reference[1] may be even more serious than as given in this paper, according to the criterion of the failure of the spine d.3veloped in this paper. It might due to posterior extrusion of fibrocartilage from disc, stretch of ligament and cause of back pain in these situations. If a lordosis can be introduced and the "core" can contain a thrust line, the spine disorders may be avoided. This means lordosis and abdominal pressure work together to strengthe'1 the spine. Further work is concemed with the extension of a single arch spine into a S shaped multi-arch spine, extension of the 20 model into 3D and integration with the SAMMIE computer aided ergonomics design system.

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ACKNOWLEDGMENTS

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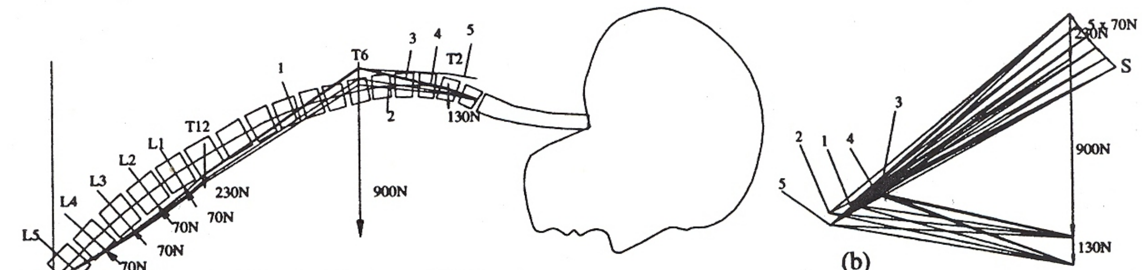

(a) Fig.1: Optimisation of the thrust lines, (a) thrust line; (b) force polygon

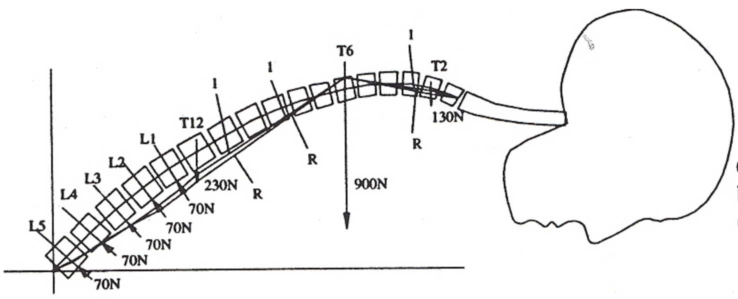

Fig.2:
Comparison of two thrust lines between the one in reference [4] (line R) and the optimised one (line 1)