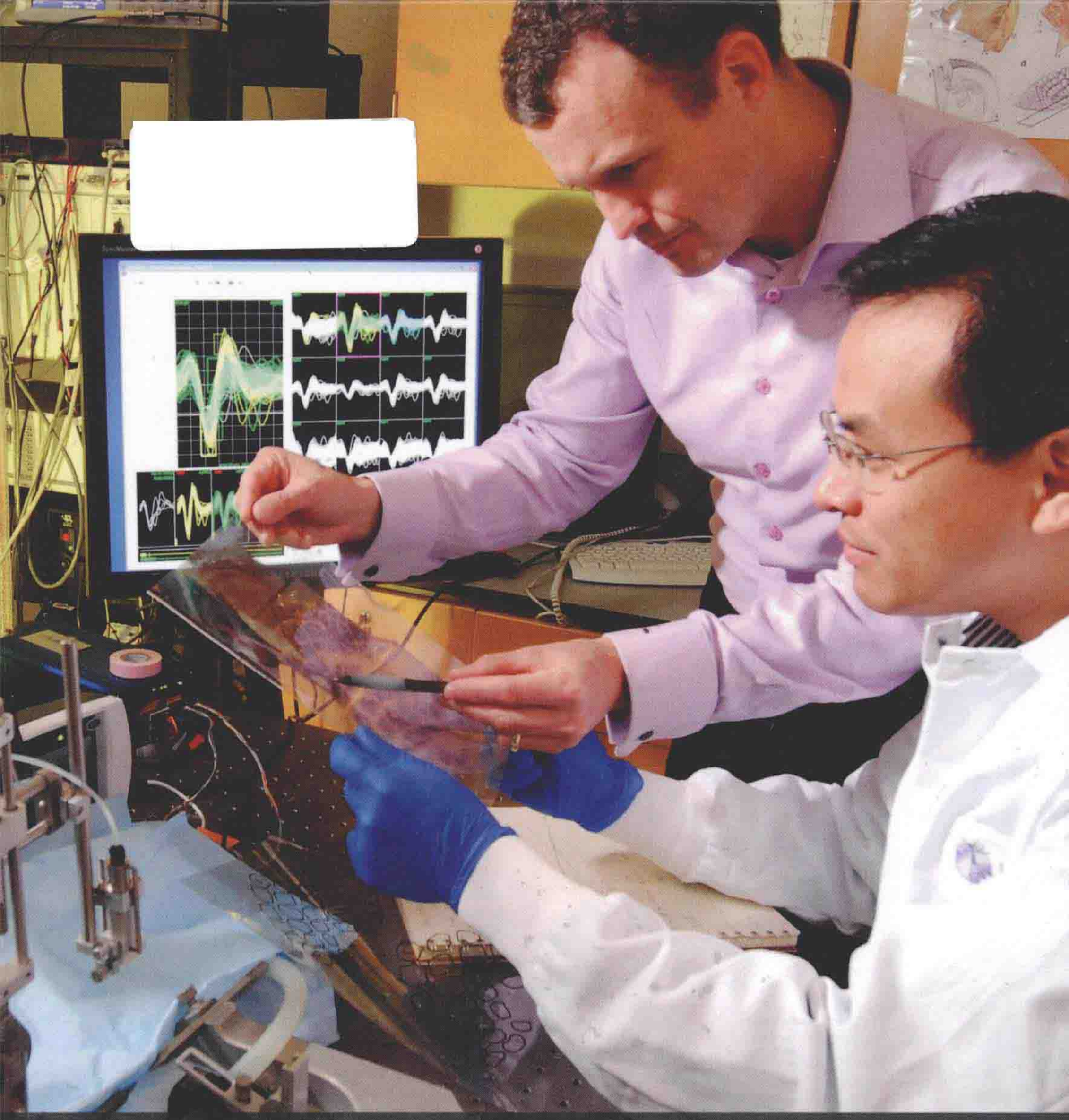

Advances in

# Biomedical Science and Engineering

Mark Walters

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## About the Book

This book provides a comprehensive account of the advances in biomedical science and engineering. Biomedical science is a vast field dealing with disease progression, paradigms and therapeutic measures. For instance, efficacy of red palm oil and phytomedicines to fight HIV and diabetes by increasing antioxidant activities is analyzed under biomedical sciences. Mathematical drafting of physiological systems and their assessment comes under physiological engineering. Even in hospital management, both biomedical science and engineering are required in order to run hospitals efficiently. This book will benefit students and experts to enhance their knowledge in the above stated topics.

## About the Editor

Mark Walters, a Bioengineering Scholar from Oklahoma State University, specializes in Stem Cell Characterization, Biomechanics and Management of Research Laboratory. He has been a part of various renowned Universities, contributing and helping the student fraternity. His expertise in Biomedical Engineering sector has resulted in various excellent academic works. He is committed to this field and believes in free exchange of knowledge to the world.

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# Preface

This book provides a comprehensive account of the advances in biomedical science and engineering. Biomedical science is a vast field dealing with disease progression, paradigms and therapeutic measures. For instance, efficacy of red palm oil and phytomedicines to fight HIV and diabetes by increasing antioxidant activities is analyzed under biomedical sciences. Mathematical drafting of physiological systems and their assessment comes under physiological engineering. Even in hospital management, both biomedical science and engineering are required in order to run hospitals efficiently. This book will benefit students and experts to enhance their knowledge in the above stated topics.

This book is a result of research of several months to collate the most relevant data in the field.

When I was approached with the idea of this book and the proposal to edit it, I was overwhelmed. It gave me an opportunity to reach out to all those who share a common interest with me in this field. I had 3 main parameters for editing this text:

1. Accuracy - The data and information provided in this book should be up-to-date and valuable to the readers.

2. Structure - The data must be presented in a structured format for easy understanding and better grasping of the readers.

3. Universal Approach - This book not only targets students but also experts and innovators in the field, thus my aim was to present topics which are of use to all.

Thus, it took me a couple of months to finish the editing of this book.

I would like to make a special mention of my publisher who considered me worthy of this opportunity and also supported me throughout the editing process. I would also like to thank the editing team at the back-end who extended their help whenever required.

**Editor**

# Contents

# Biomedical Science: Disease Pathways, Models and Treatment Mechanisms

# 1

# Biomedical Engineering Professional Trail from Anatomy and Physiology to Medicine and Into Hospital Administration: Towards Higher-Order of Translational Medicine and Patient Care

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## 1. Introduction

### 1.1 Theme

For Biomedical Engineering (BME) to be a professional discipline, we need to address the professional needs of anatomy and physiology, medicine and surgery, hospital performance and management.

The role of BME in Anatomy is to demonstrate how anatomical structures are intrinsically designed as optimal structures. In Physiology, the BME formulation of physiological systems functions can enable us to characterize and differentiate normal systems from dysfunctional and diseased systems. In order to address Medical needs, we need to cater to the functions and disorders of organ systems, such as the heart, lungs, kidneys, and the glucose regulatory system. In Surgery, we can develop the criteria for candidacy for surgery, carry out pre-surgical analysis of optimal surgical approaches, and design surgical technology and implants. In Hospital management, we can develop measures of cost-effectiveness of hospital departments, budget development and allocation.

For BME in Anatomy, we depict how the spinal disc is designed as an intrinsically optimal structure. For BME in Medicine, we formulate the engineering system analyses of Organ system functions and medical tests,

- in the form of differential equations (DEqs), expressing the response of the organ system in terms of monitored data,
- in which the parameters of the DEq are selected to be the organ system's intrinsic functional performance features.

The solution of the organ system's governing DEq is then derived, and made to simulate the monitored data, in order to:

- evaluate the system parameters,
- and obtain the normal and disease ranges of these parameters.

These parameters can then be combined into a Non-dimensional Physiological Index (NDPI),

- by which the system can be assessed in terms of just one "number",
- whose normal and disease ranges can enable effective medical assessment.

Herein, we demonstrate how this methodology [1, 2] is applied to:

- Treadmill test, for evaluating cardiac fitness;
- Lung ventilation modelling, for assessment of status of mechanically ventilated COPD patients;
- Derive a Cardiac Contractility index, which can be determined non-invasively (in terms of auscultatory pressures) and applied to assess left ventricular contractile capacity;
- Glucose Tolerance tests, to detect diabetic patients and borderline patients at risk of becoming diabetic;
- Non-invasive determination of Aortic Pressure profile, systemic resistance and aortic elastance (*Eao*, to characterize the LV systemic load).

Finally, we have also shown the application of this concept and methodology to hospital management. There is a considerable (and hitherto under developed) scope for application of Industrial Engineering discipline for effective hospital administration, in the form of how to determine and allocate hospital budget to optimise the functional performances of all the hospital departments. This leads us to what can be termed as the *Hospital Management System*.

Herein, we have shown how to formulate a performance index (PFI) for ICU. This index divided by the Resource index gives us the cost-effectiveness index (CEI). The Management strategy is to maintain certain acceptable values of both PFI and CEI for all hospital departments, by judicious allocation of staff to the departments. This enables the determination of the Optimal Resource index (RSI) and hospital budget (HOB) to maintain a balance between PFI and CEI for all the hospital departments. This can constitute the basis of Hospital Management.

## 2. Anatomy: Spine analysed as an intrinsically optimal structure

### 2.1 Spinal vertebral body (an intrinsically efficient load-bearer)

The spinal vertebral body (VB) geometry resembles a hyperboloid (HP) shell (fig 2) which is loaded by compressive and torsional loadings, portrayed in fig 1 as resolved into component forces along its generators.

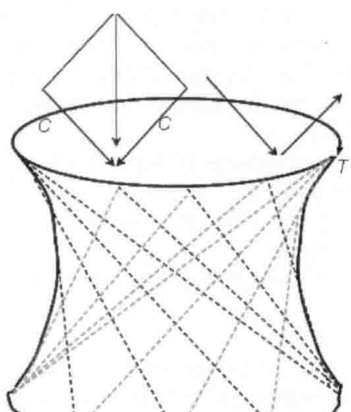
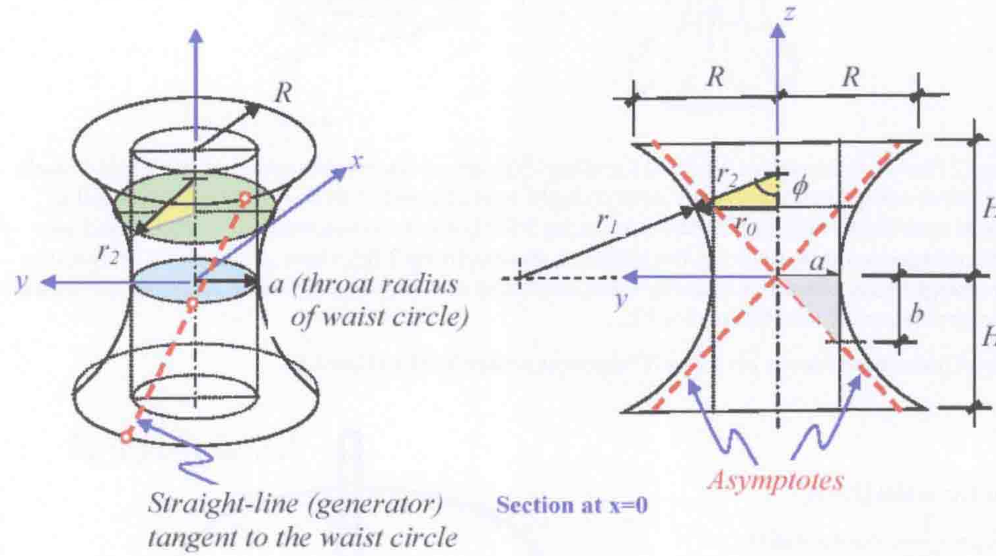



Fig. 1. Vertebral body, a hyperboloid (HP) shell formed of 2 sets of generators [3].

**Stress analysis of the VB under Axial Compression [3]:**
We now analyse for stresses in the HP shell (generators) due to a vertical compressive force *P*, as shown in figures 3 and 4.Assume that there are two sets of '*n*' number of straight bars placed at equal spacing of $(2\pi a/n)$ measured at the waist circle, to constitute the HP surface, as shown in figure 3 (right). Due to the axi-symmetric nature of the vertical load, no shear stresses are incurred in the shell, i.e. $\sigma_{\phi\theta}=0$, as in figure 3 (left). We then delineate a segment of the HP shell, and consider its force equilibrium (as illustrated in figure 4), to obtain the expressions for stresses $N_\phi$ *and* $N_\theta$ as depicted in figure 4.




$r_1$: radius of curvature of meridian

$r_2$: slanted radius of horizontal section having radius $r_o$

*Kinematic Relationship:*

$$r_o = r_2 (\sin\phi)$$

$$r_1 = -\left(\frac{b^2}{a^4}\right) r_2^3$$

*Equation of HP curves:*

$$\frac{x^2+y^2}{a^2} - \frac{z^2}{b^2} = 1$$

$$At\ x = 0,\quad \frac{y^2}{a^2} - \frac{z^2}{b^2} = 1$$

*Equation of asymptotes:*

$$z = \pm\left(\frac{b}{a}\right) y$$

Fig. 2. Geometry of a Hyperboloid (HP) shell. In the figure z = b, and y = a. We define tan β = a/b [3].

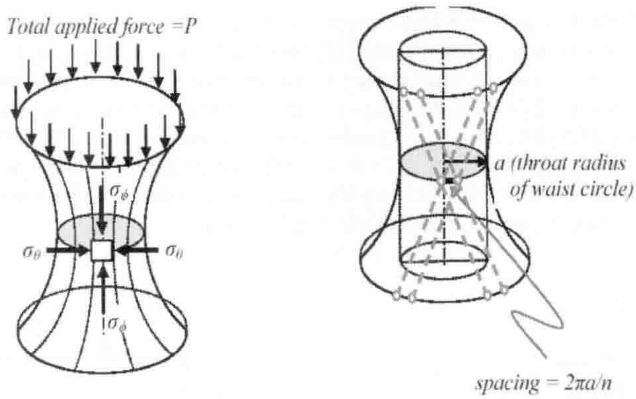



Fig. 3. Stress Analysis for Vertical Loading: Stresses at the waist section of the VB HP Shell: (a) stress components (b) equivalent straight bars aligned with the generators) placed at equal spacing to take up the stresses. In fig 3 (left) due to axi-symmetric vertical load, no shear stresses are incurred in the shell, i.e. $\sigma_{\phi\theta} = 0$. In fig 3 (b), there are 2 sets of '$n$' number of straight bars placed at equal spacing of ($2\pi a/n$) measured at the waist circle, to constitute the generators of the HP surface [3].

**Equilibrium of Forces on a Shell Segment under Vertical load P:**

At the waist ($r_o$= a),

$$N_\phi = \frac{P}{2\pi a}, \text{ compressive}$$

Now since, $\frac{N_\phi}{r_1} - \frac{N_\theta}{r_2} = p_r$

Hence,

$$N_\theta = \left(\frac{a^2}{b^2}\right)\frac{P}{2\pi a} = \frac{P\tan^2\beta}{2\pi a}$$

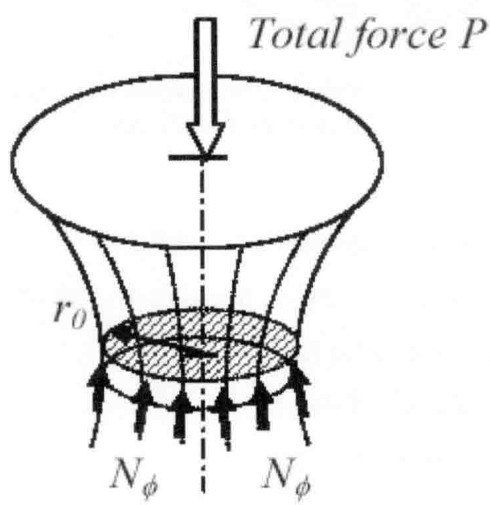



Fig. 4. Equilibrium of Forces on a Shell Segment: Analysis for stresses $N_\phi$ *and* $N_\theta$ due to the vertical force $P$ [3,2].

Then based on the analysis in Fig 5, we obtain the expression for the equivalent resultant compressive forces $C$ in the fibre-generators of the VB HP shell. Thus it is seen that the total axial loading is transmitted into the HP-shell's straight generators as compressive forces. It is to be noted that the value of $C$ is independent of dimensions R and a.