Modelling of the electrode-auditory nerve fibre interface in cochlear prostheses

by

Tania Hanekom

Submitted as partial fulfilment of the requirements for the degree

Philosophiae Doctor

in the

Faculty of Engineering, Built Environment and Information Technology

University of Pretoria, Pretoria

June 2001

Modelling of the electrode-auditory nerve fibre interface in cochlear prostheses

by

Tania Hanekom

Advisor : Prof PJ Cilliers

Departement : Electrical, Electronic and Computer Engneering

Degree : Philosophiae Doctor

KEYWORDS

cochlear implant; intracochlear electrode array; electrode configuration; electrode geometry; modelling; finite element method; potential distribution; neural excitation patterns; multipolar stimulation; three-dimensional

ABSTRACT

The objective of this thesis is to provide additional insight into the electrode array-nerve fibre interface that exists in the implanted cochlea and to facilitate investigation of new electrode arrays in interaction with the cochlea and auditory nerve fibres. The focus is on potential distributions and excitation profiles generated by different electrode array types and factors that could have an influence on these distributions and profiles.

Research contributions made by the thesis are the creation of a detailed 3-D model of the implanted cochlea that accurately predicts measurable effects in cochlear implant wearers and facilitates effortless simulation of existing and new electrode array variations; the establishment of the important anatomical structures required in a 3-D representation of the implanted cochlea; establishment of evidence that array location is the primary parameter that controls spread of excitation; definition of the critical focussing intensity of intracochlear electrode pairs; confirmation that

monopolar stimulation could deliver focussed stimulation to approximately the same degree than that delivered by widely spaced electrode configurations and that the use of monopolar configurations over bipolar configurations are therefore advantageous under certain conditions; explanation of the effect that encapsulation tissue around cochlear implant electrodes could have on neural excitation profiles; extension of the information available on the focussing ability of multipolar intracochlear electrode configurations; and establishment of evidence that a higher lateral electrode density could facilitate better focussing of excitation, continuous shaping of excitation profiles and postoperative customization of electrode arrays for individual implant wearers.

Modellering van die elektrode-ouditiewe senuweevesel-intervlak in kogleêre prosteses

deur

Tania Hanekom

Promotor	:	Prof PJ Cilliers
Departement	:	Elektriese, Elektroniese en Rekenaar-Ingenieurswese
Graad	:	Philosophiae Doctor

SLEUTELWOORDE

kogleêre inplant; intrakogleêre elektrodeskikking; elektrodekonfigurasie; elektrodegeometrie; modellering; eindige element metode; potensiaalverspreiding; senuweeopwekkingspatrone; multipoolstimulasie; drie-dimensioneel

OPSOMMING

Die doel van hierdie proefskrif is om addisionele inligting omtrent die elektrodeskikking-senuweevesel-intervlak wat in die geïnplanteerde koglea bestaan te voorsien en om die ondersoek van nuwe elektrodeskikkings in wisselwerking met die koglea en gehoorsenuweevesels te fasiliteer. Die fokus is op potensiaalverspreidings en senuweeveselopwekkingspatrone wat deur verskillende tipes elektrodeskikkings geskep word en die faktore wat hierdie verspreidings en patrone kan beïnvloed.

Die navorsingsbydrae wat deur die proefskrif gemaak word kan opgesom word as die skep van 'n gedetailleerde drie-dimensionele model van die geïnplanteerde koglea wat die tendense van meetbare effekte in persone met kogleêre inplantings akkuraat kan voorspel en maklike simulasie van bestaande en nuwe elektrodeskikkingvariasies fasiliteer; bevestiging van die belangrike anatomiese strukture wat nodig is om in 'n drie-dimensionele voorstelling van die geïnplanteerde

koglea in te sluit; vestiging van bewyse dat skikkingposisie die primêre parameter is wat die verspreiding van senuweeveselopwekking beheer; definisie van die kritiese fokuseringsintensiteit van intrakogleêre elektrodepare; bevestiging dat monopolêre stimulasie gefokusde stimulasie kan lewer tot dieselfde mate as wyd gespasieerde elektrodepare en dat dit onder sekere omstandighede voordelig is om monopolêre stimulasie te gebruik eerder as bipolêre stimulasie; verklaring van die effek wat enkapsuleringsweefsel om intrakogleêre elektrodes op senuweeaktiveringspatrone het; uitbreiding van beskikbare inligting oor die fokuserende vermoë van multipoolelektrodekonfigurasies; vestig van bewyse dat 'n hoër laterale elektrodedigtheid beter opwekkingsfokusering, kontinue vorming van opwekkingspatrone en postoperatiewe aanpassing van elektrodeskikkings vir individuele persone kan moontlik maak.

I wish to express my thanks to

My colleague and husband, Johan, for encouragement, love, valuable comments on the work in this thesis and patience with the chaos in our house while at the same time working on his own PhD.

My family who gave up much time that I should have spent with them to enable me to complete this thesis.

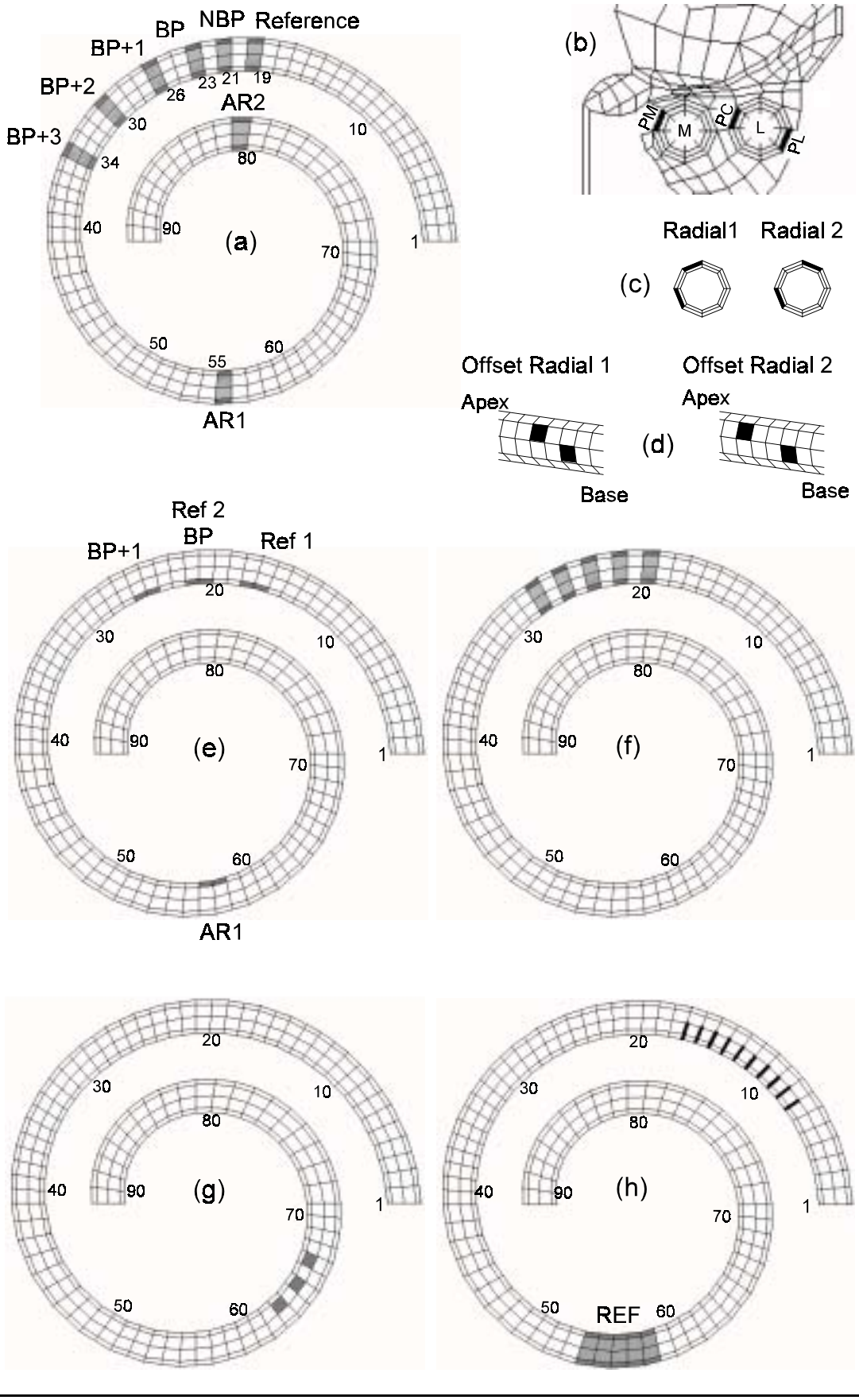
Our Heavenly Father for much grace and help.

My mother for patiently editing the language of this manuscript and of the articles that resulted from it.

Contents

List of abbreviations

2-D	two-dimensional
3-D	three-dimensional
AF	activating function
AR	apical reference
BP	bipolar
BP+1	bipolar + 1
BP+2	bipolar + 2
BP+3	bipolar + 3
CFI	critical focussing intensity
CGND	common ground
BL	banded electrode array at lateral location relative to the modiolus
DOF	degree of freedom
FE	finite element
F-fibre	used when referring to results generated with the full nerve fibre model
GSEF	generalized Schwarz-Eikhof-Frijns (nerve fibre model)
LP	lumped parameter
MONO	monopolar
OR	offset radial
BM	banded electrode array in a medial location relative to the modiolus
R	radial
SAS	simultaneous analogue stimulation
SE	Schwarz-Eikhof (nerve fibre model)
T-fibre	used when referring to results generated with the truncated nerve fibre model
UF	unimodal focussing ability



Summary figure of electrode configurations on previous page.

(a) Locations of electrode contacts for NBP, BP, BP+1, BP+2, BP+3, AR1 and AR2 banded (BM and BL) and point (PM, PC and PL) electrode configurations. Electrode contacts for banded electrode configurations are shown. The reference electrode is used as the stimulating electrode for monopolar stimulation. For widely spaced quadrupolar and tetrapolar electrode configurations (Chapter 5), the Reference electrode and BP, BP+1, BP+2 and BP+3 electrodes are used.

(b) Location of electrode contacts for point electrode configurations (PM, PC and PL) on the perimeter of the electrode carriers. The location of the medial (M) electrode array and the lateral (L) electrode array are also indicated.

(c) Location of electrode contacts on perimeter of electrode carrier for radial electrode configurations.

(d) Location of electrode contacts on perimeter of electrode carrier for offset radial electrode configurations.

(e) Location of electrode contacts for Hifocus-like electrode configurations. The BP and BP+1 configurations use Ref 1 as return electrode while AR1 uses Ref 2 as return electrode. Ref 2 is used as the stimulating electrode contact for monopolar stimulation.

(f) Electrode contact locations for the narrowly spaced quadrupolar and tetrapolar electrode configurations studied in Chapter 5.

(g) Location of electrode contacts for the tripolar electrode configurations studied in Chapter 5. The radial electrode configuration is similar to Radial 2 in (b) except that the segments are displaced anticlockwise with one segment.

(h) Location of the electrode contacts (thick lines) for the pseudo-continuous electrode configuration studied in Chapter 5. The reference electrode (REF) for a AR-type return electrode is shaded.