
Contents

Certificate	i
Supervisors' certificate	iii
Declaration by the candidate	v
Copyright transfer certificate	vii
Acknowledgements	ix
Table of Contents	x
Abstract	xxi
1 Introduction	1
1.1 History of cryotherapy	1
1.1.1 Terminologies of cryotherapy	3
1.1.2 Diversity in cryotherapy	6
1.1.3 Modern Cryotherapy	8
1.1.4 Pros and cons of cryotherapy	11
1.1.4.1 Pros	11
1.1.4.2 Cons	12
1.1.5 Thesis structure	12
2 Literature Review	13
2.1 Spray characteristics of cryogen	13
2.2 Influence of equipment modification on cryoablation	19
2.3 In-vivo experiments in cryotherapy	20
2.4 Numerical modeling of cryoablation	22
2.5 Role of adjuvant in cryoablation	25

3 Characterization of performance of multihole nozzle in cryospray and optimisation of its spray parameter	28
3.1 Materials and Method	29
3.2 Results and discussions	31
3.2.1 Uncertainty Analysis	32
3.2.2 Validation of thermal images	33
3.2.3 Comparison of cryoablation between SHN and MHN	35
3.2.3.1 Axial temperature distribution	36
3.2.3.2 Movement of axial ice front	40
3.2.3.3 Radial temperature distribution	41
3.2.4 Comparison among MHNs	45
3.2.4.1 Axial temperature distribution	45
3.2.4.2 Cooling rate	49
3.2.4.3 Radial temperature distribution	50
3.2.4.4 Conclusion	51
4 Establishing relation between in-vivo and in-vitro Cryospray experiments through thermal characteristics	53
4.1 Materials and Method	54
4.2 Results and discussions	56
4.2.1 Radial temperature distribution	56
4.2.2 Axial temperature distribution	59
4.2.3 Histology	60
4.3 Conclusion	62
5 Nano-cryospray: Thermal effect of adjuvants on cryoablation	63
5.1 Materials and Method	64
5.2 Characterisation of nanofluid	65
5.3 Uncertainty Analysis	71
5.4 Results and discussion	72
5.4.1 Influence of adjuvant on cryoablation with SHN	72
5.4.1.1 Axial Temperature Distribution	72
5.4.1.2 Radial temperature distribution	73
5.4.2 Influence of adjuvant on cryoablation with MHN	76
5.4.2.1 Axial Temperature Distribution	77
5.4.2.2 Radial temperature distribution	81
5.5 Conclusion	82

6 Numerical study on the spray and thermal characteristics of cryospray process	83
6.1 Mathematical model and numerical approach	83
6.1.1 Governing equations	84
6.1.1.1 Continuous phase (air)	84
6.1.1.2 Discrete phase (liquid nitrogen droplets)	86
6.1.1.3 Phase change in gel phantom	87
6.1.2 Boundary condition and operating parameters	88
6.1.3 Numerical approach and grid distribution	91
6.1.4 Grid independence and time independence	92
6.1.5 Code validation	93
6.2 Results and discussion	94
6.2.1 Temperature variation	94
6.2.2 Lethal front propagation	99
6.2.3 Freezing front propagation	102
6.3 Conclusion	102
7 Conclusions	106
7.1 Scope for future study	108
Bibliography	111
Author's Personal Profile and Publication List	129
addcontentslinetocsectionList of Figures	