LIST OF FIGURES

Figure No.	Figure Caption	Page No.
Figure 1.1	Illustration of typical strain, stress, and the actuation energy densities of different material (Lagoudas, 2008)	2
Figure 1.2	Typical actuation frequency chart of different actuators used for direct coupling (Lagoudas, 2008)	3
Figure 1.3	Thermally induced phase transformation in SMAs	5
Figure 1.4	A simple model of martensitic transformation: Stress free shape recovery on the application of heat	6
Figure 1.5	Schematic diagram of shape memory effect	7
Figure 1.6	Schematic diagram of SMA spring actuation	9
Figure 1.7	Shape memory effect and the associated crystalline changes presented as a phase diagram	9
Figure 1.8	Superelasticity and the associated crystalline changes presented in a phase diagram	10
Figure 1.9	Schematic representation of large deformation and recovery of shape memory wire above the austenite final temperature (A_f)	11
Figure 1.10	Loading cycle of superelastic shape memory alloy (Lagoudas, 2008)	11
Figure 1.11	Publications of shape memory alloy and nitinol from 1975 to 2016	12
Figure 1.12	Prosthetic hand (a) Prosthetic hand equipped with servo motors (b) Detailed sketch of the shape memory alloy actuator (Loh et. al., 2005)	13
Figure 1.13	Nitinol stents (a) First coil stent in initial form before placement (b) Expended shape after placement in lumina of blood vessels (Dotter et. al, 1983) (c) Initial shape of Abbott Acculink stent made by Abbott. (d) Stent shape after placement, complex pattern and tapered design (e) Illustration of kink resistance of a Nitinol biliary stent (www.abbott.com) (f) Digestive tract stent encased in gelatin and its proper sheath used to treat esophagus anomalies (g) Bunch of self-expanding stents when gelatin has been dissolved with warm, sterile saline solution (h) Procedure to insert the self-expanding nitinol stent through a tracheal tube by flexible tube (Yanagihara et. al, 1997) (i) The memotherm® prostatic stent/bulbar stent used for treating subvesical obstructions in urinary tract (Image courtesy of Bard, Angiomed, Karlsruhe, Germany) (j) Demonestration of Stent actuation with hexagonal matrix design (Boston Scientific Co. Natick, MA)	15

	(k) Rectosigmoidal nitinol stent used for treating	
	rectosigmoidal cancer (Tack et. al, 1998).	
Figure 1.14	RITA multitine electrode system (Rita Medical Systems, Mountain View, California)	18
Figure 1.15	Simon vena cava filter used for trapping blood clot in blood	19
C	vessels (Duerig et. al, 1999)	
Figure 1.16	Kink resistant of nitinol in medical devices (a) Intra-Aortic	20
C	balloon pump (Image courtesy: Teleflex, Carrington Mill	
	Boulevard, Morrisville, NC) (b) Nitinol baskets in final	
	configuration during deployment (Kesler et al, 2008) (c)	
	Nitinol angioplasty guide wires (Image from Radiac	
	Abrasives, A Tyrolit Company, Salem, IL)	
Figure 1.17	Ptentiodynamics result: Ryhanen revealed that nitinol is	22
	nontoxic, nonirritating, and fundamentally similar as stainless	
	steel and Ti-6Al-4V alloy (Ryhnen, 1999).	
Figure 1.18	Schematic stress-strain curves of Hair, NiTi, bone, and tendon	23
	(Stoeckel et al., 2003).	
Figure 1.19	Magnetic resonance Image of stent (a) Stent (b) Laser-cut	24
T ' 1 0 0	closed cell (Sinus) (OptiMed, Ettlingen, Germany).	~ .
Figure 1.20	Hip Joint Anatomy (a) 3D view of hip joint (b) cross sectional	24
E'	view of hip joint	25
Figure 1.21	schematic illustration of long bone, showing cortical and	25
Figure 1 22	Total hin arthronlasty and its component	27
Figure 1.22	A Smith-Petersen Vitallium mould arthronlasty from 1030	27
Figure 1.25	(left): a Wiles stainless steel endoprosthesis from 1938	20
	(centre): a Judet Brothers acrylic endoprosthesis from the late	
	1940s. (Source: Reynolds et al., 2007)	
Figure 1.24	Charnley low-friction THR with small stem and ultra-high	29
8	molecular weight polyethylene (UHMWPE) socket from	-
	1962. picture from (Reynolds et al., 2007)	
Figure 1.25	Modern total hip prosthesis components a) Acetabular cup	32
	with a ceramic, a metal and a polyethylene liner (Courtesy of	
	United Orthopedic Corporation, Taiwan and Exactech	
	Gainesville, Florida, United States) b) Hip stem (Courtesy of	
	Exactech Inc. Gainesville, Florida, USA) c) Acetabular screw	
	(Courtesy of Depuy, Warsaw, IN, USA.)	
Figure 1.26	The percentage of revision surgeries on both primary	33
	cemented and cementless THR in younger patients with	
	respect to the duration of implantation ("Australian	
E' 1 27	Urthopaedic", 2014).	4.5
Figure 1.27	IHK OI 55-year-old temale patient a) IHK surgery b)	45
	Migration of screw and acetabular cup, due to osteoporosis	
	after 2.8 years of surgery (Source: Zhu, et al., 2015).	

Figure 1.28	Adverse effect of osteoporosis and treatments by modular implants a) Image of 79-year-old patient with bone	46
	discontinuity in acetabulum due to reduced bone mineral	
	density b) Repair by modified implant in THR surgery c)	
	Acetabular roof-ring anchored with total hip prosthesis d)	
	Fracture due to primary osteoporosis (Bottai et al., 2015) e)	
	Illustration of U-shaped ischial supporting flange (Peters et al.)	
	f) Implementation of U-Shaped flange with sacetabular screws	
	in THR revision (Peters et al.) g) Implementation of titanium	
	mesh to support the bone graft in bone defect (Sloof et al.,	
	1999) h) Acetabular augment blocks to treat diverse acetabular	
	defects (Del Gaizo et al., 2012) i) Loosening of implant in	
	patient (Bottai et al., 2015)	
Figure 1.29	Schematic illustration of basic screw design parameters (Joel	48
0	et al, 1996)	
Figure 1.30	Schematic illustration of pullout test for metallic medical bone screws.	49
Figure 1.31	Screw pullout profile in normal and osteoporotic bone (Battula et al, 2006)	50
Figure 1.32	Typical screw thread versus Pullout strength curve (Zhang et al, 2006)	50
Figure 1.33	Illustration of a) square shape b) buttress shape and c) V shape	51
	screws	
Figure 1.34	Conventional screw and Cannulated screw anatomy	52
Figure 1.35	Schematic illustration of expanding mechanism of expandable	54
	screw	
Figure 1.36	Load-displacement curve of both expandable screw and	55
	standard titanium screw Acetabular Cup	
Figure 2.1	Thread insert and installation procedure a) Thread inserts are	58
	always necessary when applying threaded fasteners in soft	
	metal detail component. Typical procedure shown to place	
	these inserts into oversized holes b) Cross sectional view of	
	inserts after placement in hole. c) Cross sectional view of a	
	type of insert made from hard material like stainless steel.	
Figure 2.2	Typical load distribution on threads with inserts and without inserts in screw.	59
Figure 2.3	Draft view of screw (a) Standard acetabular screw layout	60
	design (b) Hexagonal head of screw to anchor with acetabular	
	cup (b) Blunt tip of acetabular tip to prevent vascular injury	
Figure 2.4	Schematic of screw-nitinol insert system outside the body	61
-	(T_{witro}) (a) 3D view of acetabular screw (b) Nitinol	
	components assembly, which comprises of pseudoelastic (PE)	
	and shape memory (SM) elements (c) Screw-insert assembly	
	showing actuation of nitinol elements insert -screw framework	
	outside the body (d) Top view of insert	

Figure 2.5	Schematic of screw-nitinol insert system inside the body (T_{vivo}) (a) Schematic view of expanded/original form of nitinol insert (b) Screw-nitinol insert assembly after placement inside the hip during THR and enlarged view of nitinol elements which is pseudoelastic (PE) and shape memory (SM) respectively	62
Figure 2.6	Nitinol insert with retractable and expandable components (a) figure above is 3D perspective of retracted form of insert and below is its top view (b) figure above is the 3D view of expanded form of insert and below is its top view	64
Figure 2.7	Exploded view of press-fit acetabular cup a) Conventional press-fit acetabular cup b) Novel press-fit acetabular cup with nitinol rig and metal cage	65
Figure 2.8	Bottom view of nitinol rig assembly which is composed of shape memory element (SM) and pseudoelastic element (PE).	66
Figure 2.9	Activation of expandable-retractable rig (a) Superelastic Exterior part of the acetabular cup with expandable rig at initial form outside the body. (b) high-temperature austenite form of the acetabular cup with expandable rig inside the body.	67
Figure 2.10	Expandable-retractable nitinol rigs in a) retracted form and b) expanded form	68
Figure 3.1	Empirical stress-temperature phase diagram showing different paths of transformation; detwinned Martensite M_d , twinned Martensite in the positive M_{tp} and negative M_{tn} directions,	81
Figure 3.2	and Austenite A . The path conditions for transformation to Martensite or Austenite.	83
Figure 3.3	Prepared block in Creo parametric (PTC, Inc., Massachusetts, USA) for preliminary solution (Left), illustration of boundary conditions (Right)	94
Figure 3.4	Schematic illustration of element type (PLANE 182)	95
Figure 3.5	Meshed plane in Ansys for preliminary analysis (Element size=10 mm)	95
Figure 3.6	Preliminary output of simulation of superelastic behavior of Nitinol	96
Figure 3.7	Meshed plane in Ansys for preliminary analysis	97
Figure 3.8 Figure 3.9	Schematic illustration of element type (SOLID185) Preliminary output of simulation of shape memory behavior of Nitinol at temperature 285.15 K	98 99
Figure 3.10	Preliminary output of simulation of shape memory behavior of Nitinol at temperature 253.15 K.	100

Figure 3.11	The SMA helical insert is fused to the holes on the surface of the screw.	104
Figure 3.12	Linearized insert elements assembly to circular tubing and beam assembly	105
Figure 3.13 Figure 3.14	Initial memorized shapes of the nitinol wire and tube assembly Assembly at (A) the straight condition (at the time of surgery) (B) Desired low temperature form (37°C) after activation of the tube: the assembly is bent upwards (at the time when bone degrades) (b) Desired high temperature form (52°C) after activation of the wire: the assembly is re-bent downwards	105 107
	(removing screw for any reason)	100
Figure 3.15 Figure 3.16	Different stages of the wire-tube assembly operation. Discretization of wire tube assembly with SOLID185 (3D 8- Node Structural Solid) with large deformation effect enabled.	109 109
Figure 3.17	Variation of temperature at 1 st , 2 nd and 3 rd stage.	110
Figure 3.18	Loading and boundary condition of nitinol wire tube assembly.	111
Figure 3.19	Typical Martensite distribution in the assembly (ζ_d shown here).	112
Figure 3.20	The deflection of the wire under a tip load at the first stage $(1^{st} stage)$.	112
Figure 3.21	The deflection of the tube under a tip load at the first stage (1^{st} stage).	113
Figure 3.22	Illustration of state of equilibrium	113
Figure 3.23	Load-displacement plots for the wire-tube assembly at the first stage.	114
Figure 3.24	The load-deflection for wire at body temperature (2 nd Stage)	114
Figure 3.25	The load-deflection for tube at body temperature (2 nd Stage)	115
Figure 3.26	Load-displacement plots for the wire-tube assembly at the 2 nd stage	115
Figure 3.27	The deflection of the wire under a tip load at the 3 rd stage.	116
Figure 3.28	The deflection of the tube under a tip load at the 3 rd stage.	116
Figure 3.29	Load-displacement plots for the wire-tube assembly at the 3 rd stage.	117
Figure 3.30	First principle strain of wire-tube at the instance of their maximum deformation (8% max. to superelastic tube)	118
Figure 3.31	Screw assembled with nitinol wires	119

Figure 3.32	Experimental setup for measuring pull out strength of screw; setup shows the screw is inserted in the cellular rigid polyurethane foam block and fixed on the UTM.	120
Figure 3.33	Results of the axial tensile test: force versus displacement. The tensile strength is selected at the force required to displace the screw in the block as much as the screw thread pitch.	121
Figure 4.1	Schematic showing anatomy of the pelvic region	128
Figure 4.2	Complete vessel anatomy of pelvis region	129
Figure 4.3	Developed schematic of pelvis along with its associated neural and vessel anatomy	130
Figure 4.4	Effect of screw fixation on the neuro-vascular structure	132
Figure 4.5	Surgical approaches with respect to the patient position during Total Hip Arthroplasty.	134
Figure 4.6	Conventional approaches for hip replacement. (a) Posterior (b) Lateral (c) Anterior approach interval.	137
Figure 4.7	Types of acetabular fractures	138
Figure 4.8	Ilioinguinal approach to hip joint during hip surgery	139
Figure 4.9	Schematic of the quadrant system proposed by RC Wasielewski et al for screw fixation in safe zone.	140
Figure 4.10	Illustration of superimposed acetabular quadrant system along with intrapelvic vessels as defined by RC Wasielewski et al., 1990	141
Figure 4.11	Flowchart describing the progress of work with associated software	142
Figure 4.12	Hounsfield scale showing a range of Hounsfield Unit for body system	144
Figure 4.13	Schematic illustrating the process of data acquisition	144
Figure 4.14	DICOM patient based coordinate system	145
Figure 4.15	Difference between predefined bone scale and soft tissue scale for setting the contrast in Mimics 18.0 (Materialise, Leuven, Belgium)	147
Figure 4.16	Image showing bone scale volume rendered data	148

Figure 4.17	Histogram illustrating the threshold range for bone (CT)	149
Figure 4.18	Illustration of the region grow process	150
Figure 4.19	CT scan images of lower limb are thresholded with Bone (CT) scale. (a) Frontal view (b) Tansversal view of thresholded pelvic bone in a green mask	153
Figure 4.20	Investigation of each scanned slice using Region Grow followed by manual segmentation to develop accurate 3D model	154
Figure 4.21	Data conversion from 2D CT images to 3 D model using Mimics Software	155
Figure 4.22	Developed 3D model of pelvis and its associated neuro-vascular structure	156
Figure 4.23	Model optimization in 3-matic Medical 9.0	157
Figure 4.24	Effect of applying local smoothing on developed 3D pelvis model	157
Figure 4.25	Geometry illustrating the difference between good and bad quality elements used for meshing	158
Figure 4.26	Typical workflow of model optimization in 3-matic Medical	158
Figure 4.27	Schematic showing the 3D model with remesh parameters	160
Figure 4.28	Assembly of acetabular cup with twelve screws on pelvis	161
Figure 4.29	2D Sketches converted to 3D model: above is the draft view of acetabular cup and below is the schematic screw	165
Figure 4.30	Illustration of the planes and axis for placement of acetabular cup.	167
Figure 4.31	Schematic representing the cup inclination, cup version angles as well as cup interference for fixation of the cementless pressfit cup into the pelvis	171
Figure 4.32	Assembly of eccentric screw on the acetabular cup with eccentric holes.	172
Figure 4.33	Illustration of SCP-1 with screw eccentricity of 0° and cup anteversion angle (a) 15° (b) 20°	172
Figure 4.34	SCP-2 containing four profiles. (a) Cup anteversion angle: 15°, screw eccentricity: 17° (b) cup anteversion angle: 15°,	173

	screw eccentricity: 34° (c) cup anteversion angle: 20° , screw eccentricity: 17° (d) cup anteversion angle: 20° , screw eccentricity: 34°	
Figure 4.35	SCP-3 containing four profiles. (a) Cup anteversion angle: 15° , screw eccentricity: 17° (b) cup anteversion angle: 15° , screw eccentricity: 34° (c) cup anteversion angle: 20° , screw eccentricity: 17° (d) cup anteversion angle: 20° , screw eccentricity: 34°	173
Figure 4.36	SCP-4 containing four profiles. (a) Cup anteversion angle: 15° , screw eccentricity: 17° (b) cup anteversion angle: 15° , screw eccentricity: 34° (c) cup anteversion angle: 20° , screw eccentricity: 17° (d) cup anteversion angle: 20° , screw eccentricity: 34°	174
Figure 4.37	SCP-2 containing four profiles. (a) Cup anteversion angle: 15° , screw eccentricity: 17° (b) cup anteversion angle: 15° , screw eccentricity: 34° (c) cup anteversion angle: 20° , screw eccentricity: 17° (d) cup anteversion angle: 20° , screw eccentricity: 34°	174
Figure 4.38	The ideal fixation and angular eccentric fixation of screws.	176
Figure 4.39	3D computational model of osseous and arterial structures. Schematic diagram illustrating the quadrant system proposed by Wasielewski et al.	176
Figure 4.40	Schematic of the intrapelvic bony surface anatomy fitted with acetabular cup and screws.	178
Figure 4.41	Graphs showing the distance measured from screw S0, S1, S4 and S7 to Obturator artery	184
Figure 4.42	Graphs showing the distance measured from screw S5, S6, S8 and S9 to External iliac vein	185
Figure 4.43	Graphs showing the distance measured from screw S5, S6, S8 and S9 to External iliac artery	186
Figure 4.44	Graphs showing the distance measured from screw S0, S2, S3 and S12 to Inferior gluteal artery	187
Figure 4.45	Graphs showing the distance measured from screw S3 and S12 to Superior gluteal artery	188