Evaluation of Internal Implant Failure in Long Bones Fractures

by

Izzawati Binti Basirom
(1741412456)

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AO	American Orthopaedic
AO-OTA	American Orthopaedic Trauma Association
BC	Bicortical Conventional
BIC	Bone-Implant Connection
BL	Bicortical Locking
BSc-model	Bone and screw model
BW	Body weight
CAD	Computer-Aided Design
CINT	C-Integral
CT	Computed Tomography
LC	Locking Compression
DCP	Dynamic Screw Plate
DELR	Radius of First Row Element
DEM	Displacement Extrapolation Method
DOF	Degree of freedom
EPFM	Elastic Plastic Fracture Mechanics
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
GUI	Graphic User Interface
IFM	Interfragmentary movement
ISQ	Implant Stability Quotient
JINT	J-Integral
KSCON	Element around the crack tip has a better stress and strain singularity
LCP	Locking Screw Plate
DC-LCP	Dynamic and Locking Compression Plate
LEFM	Linear Elastic Fracture Mechanics
NTHET	Number of Element Around the Circumference
ORIF	Open Reduction Internal Fixation
RFA	Resonance Frequency Analysis
S-model	Simple Crack Propagation Model

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Sc-model	Full threaded screw model
SE	Strain Energy
SED	Strain Energy Density
SEDTP	Strain Energy Density Transfer Parameter
SERR	Strain Energy Release Rate
SETP	Strain Energy Transfer Parameter
SIF	Stress Intensity Factor
SSD	Stress Shielding Damage
STP	Stress Transfer Parameter
Th-model	Screw thread model
TPFM	Two-Parameter Fracture Mechanic
UC	Unicortical Conventional
S.s	Stainless steel
Ti	Titanium
UL	Unicortical Locking
XFEM	Extended Finite Element Method

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LIST OF SYMBOLS

A	Transferability Parameter
$\measuredangle F$	Fracture Angle
σ_{avg}	Average Principle Stress
σ_n	Principle Stress by Direction (n=1,2, and 3)
ε	Strain
a	Crack Length
n	No of the crack tip element
D, d	Distance
D_n	Bone Properties Based on Densest Class
E	Young Modulus
E_{ij}	Elastic Modulus with Radial; Axial; Tangential;
E_n	Bone Properties Based On Pathology Grade
G_{12}	Shear Modulus with Radial; Tangential; Axial (ij=1, 2, and 3)
K	Stress Intensity Factor (Sif)
r	Crack Length
ρ	Density
θ	Angular Function
w, W	Width
σ	Normal Stress
σ_t	Stress in Screw Thread
σ_b	Stress in Bone
GB	Gross and Brown Formulation
BS	Brown and Srawley Formulation
J	J-integral
J_{el}	J-integral For Elastic Plastic
K_o	SIF
K_1	SIF For Mode I
K_c	Critical SIF
$K_{I\,S}$	SIF For Mode I (S-model)
$K_{I\,S_{FEA}}$	SIF for Mode I of S-model based on FEA
$K_{I\,S_{GB}}$	SIF for Mode I of S-model based on Grown and Brown Formulation

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$K_{I\ S_{BS}}$	SIF for Mode I of S-model based on Brown and Srawley Formulation
$K_{I\,THE}$	SIF for Mode I Based on Empirical Theory
$K_{I\ Th}$	Stress Intensity Factor for Mode I (Th-model)
$K_{I\ Th_{FEA}}$	SIF for Mode I of Th-model based on FEA
$K_{I\ Th_{GB}}$	SIF for Mode I of Th-model based on Grown and Brown Formulation
$K_{I\ Th_{BS}}$	SIF for Mode I of Th-model based on Brown and Srawley Formulation
$K_{I\ Sc}$	SIF for Mode I Sc-model
$K_{I\ Sc_{FEA}}$	SIF for Mode I of Sc-model based on FEA
$K_{I\ Sc_{GB}}$	SIF for Mode I of Sc-model based on Grown and Brown Formulation
$K_{I\ Sc_{BS}}$	SIF for Mode I of Sc-model based on Brown and Srawley Formulation
$K_{I\ BSc}$	Stress Intensity Factor for Mode I BSc-model
$K_{I\ BSc_{FEA}}$	SIF for Mode I of BSc-model based on FEA
$K_{I\ BSc_{GB}}$	SIF for Mode I of BSc-model based on Grown and Brown Formulation
$K_{I\ BSc_{BS}}$	SIF for Mode I BSc-model based on Brown and Srawley Formulation
$K_{II\ S}$	SIF for Mode II (S-model)
$K_{II\ Th}$	SIF for Mode II (Th-model)
$K_{II\ Sc}$	SIF for Mode II (Sc-model)
$K_{II\ BSc}$	SIF for Mode II (BSc-model)
G_S	SERR for S-model
$G_{S_{FEA}}$	SERR for S-model Based on FEA
$G_{S_{BS}}$	SERR for S-model Based on Brown and Srawley Formulation
$G_{S_{GB}}$	SERR for S-model Based on Grown and Brown Formulation
$G_{S_{Conv}}$	SERR for S-model Conversion Formulation
G_{Th}	SERR for Th-model
$G_{Th\ FEA}$	SERR for Th-model based on FEA

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$G_{Th_{BS}}$	SERR for Th-model based on Brown and Srawley Formulation
$G_{Th_{GB}}$	SERR for Th-model based on Grown and Brown Formulation
$G_{Th_{Conv}}$	SERR for Th-model Conversion Formulation
G_{Sc}	SERR for Sc-model
$G_{Sc_{FEA}}$	SERR for Sc-model based on FEA
$G_{Sc_{BS}}$	SERR for Sc-model based on Brown and Srawley Formulation
$G_{Sc_{GB}}$	SERR for Sc-model based on Grown and Brown Formulation
$G_{Sc_{Conv}}$	SERR for Sc-model Conversion Formulation
G_{BSc}	SERR for BSc-model
$G_{BSc_{FEA}}$	SERR for BSc-model based on FEA
$G_{BSc_{BS}}$	SERR for BSc-model based on Brown and Srawley Formulation
$G_{BSc_{GB}}$	SERR for BSc-model based on Grown and Brown Formulation
$G_{BSc_{Conv}}$	SERR for BSc-model Conversion Formulation
P_n	Position Screw from Left ($n = 1, 2, ...8$)
Y_{Tada}	Correlation Factor-Based Tada Theory
Y_{GB}	Correlation Factor-Based Gross's Theory
Y_{BS}	Correlation Factor-Based Brown and Srawley Theory
Y_S	Correlation Factor-Based S-model
Y_{Th}	Correlation Factor-Based Th-model
Y_{Sc}	Correlation Factor-Based Sc-model
Y_{BSc}	Correlation Factor-Based BSc-model
χ	Effective Distance
σ_{ef}	Effective Stress
σ_{yy}	Maximum Principle Stress (y-direction)
$\Phi(r)$	Load Functions
α	Slope of The Stress Distribution
$f_{ij}(\theta)$	Angular Function

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δ_{ij}	Kronecker’s Determinant
(σ_T^i)	Stress Ratio Between the Midpoint of The Screw Thread
(σ_B^i)	The Bone Above the Screw Thread
N	Total Number of Screw Threads
υ	Poisson’s Ratio
r	Crack Length Radius
ΔL	Changes in Length
L	Initial Length
ρ	Density
ε_{IF}	Interfragmentary Strain
Δ	Change Displacement
L	Independent Variable
L_n	Length from Origin to Point 1 ($n = 1, 2, ...n$)
a / n	Radius of First-Row Element
xx	Screw Length
υ_{ij}	Poisson Ratio Radial; Tangential; Axial (j=1, 2, and 3)
κ	Plane Strain
l_i	Length of Element (i= x or y-direction)
υ_n, u_n	Displacement Vector (ij=1, 2, ...n)
τ_a	Shear Stress of Single Crack
x_n	Coordinate Directions
Γ	Path Around Crack Tip
W	Strain Energy Density
T_i	Traction Vector
n_j	Unit Vector Normal To Γ
ds	Length Increment Along the Contour Γ
$\sigma_{ij},\varepsilon_{ij}$	Stress and Strain Tensor

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Penilaian Kegagalan Implan Dalaman terhadap Kepatahan Tulang Panjang

ABSTRAK

Kestabilan penetapan implan dalaman sangat penting untuk meningkatkan penyembuhan tulang dan osseointegrasi. Ketidak stabilan implantasi dalaman boleh menyokong kepada komplikasi kegagalan implan. Secara klinikal, kegagalan implantan masih belum dijelaskan. Kelongaran implan dan kerosakkan tulang di sekitar disebabkan oleh pengagihan tekanan yang tidak baik dan dapat diperbaiki dengan menggunakan beberapa kajian terhadap parameter tulang dan implan seperti konfigurasi skru, kedalaman tembusan, jenis skru, dan pemuatan mekanikal, dan keadaan tulang. Oleh itu, penyelidikan mengenai interaksi mekanikal elastik antara skru dan tulang yang bertempat pada antara muka tulang implan masih tidak jelas. Oleh itu, kajian ini bertujuan untuk menjelaskan mekanisme interaksi diantara antara muka tulang-implan terhadap pelbagai klinikal konfigurasi fiksasi dalaman. Sebagai penyelesaian yang dicadangkan, satu siri simulasi implan biomekanik dilakukan dengan menggunakan analisis elemen hingga (FE). Tiga dimensi model fiksasi dalaman (3D) dirancang berdasarkan amalan fiksasi klinikal yang sebenar untuk menyerupai taburan tegangan-regangan, ragangan antara kerangka (IFM), parameter pemindahan tekanan (STP), parameter pemindahan ketumpatan tenaga regangan (SEDTP), faktor intensiti tekanan (SIF) pada antara muka implan tulang pada tahap penyembuhan tulang yang berbeza. Penyelidikan lebih lanjut berkaitan interaksi skru tulang mengenai kestabilan fiksasi implant dan mempertimbangkan arah beban, pergerakkan mikro, modulus muda tulang sekitar, dan pelonggaran implan tulang. Satu set simulasi pengkomputeran mekanik fraktur dilakukan untuk meramalkan faktor intensiti tekanan (SIF) berdasarkan prinsip mekanik kepatahan linar elastik (LEFM) dan mekanik kepatahan elastik plastic (EPFM). Berdasarkan FEA, bahagian tengah tulang femur mencapai nilai tekanan yang maksima 42.396 MPa. Sudut patah $\measuredangle F = 0°$, sudut sifar orientasi skru dan bahan keluli tahan karat mempunyai kerosakan tulang di sekitarnya yang minimum tekanan, 152.10 MPa. Jenis skru yang paling stabil adalah Kumpulan BC (cerun=$1.64x10^{-3}$) dan 134 konfigurasi telah mencapai kestabilan mutlak (IFM <2%). Konfigurasi C134 adalah paling stabil berdasarkan ujian normaliti ($p \geq 0{,}05$) dan nilai varians malar minimum, (F=0.0059) menunjukkan peramal baik untuk penilaian kestabilan. Modulus tulang berdasarkan mobiliti mikro korelasi berkurang kira-kira 50% apabila ISQ meningkat dari 60% menjadi 70%. Interaksi geometri mempengaruhi tekanan pemanduan K_1 / K_o , hasil penguatan berlaku. Faktor ketetapan menghasilkan SERR, $G_{(Th,Sc,BSc)}$ yang lebih besar, dan mengakibatkan kemerosotan kestabilan mekanikal. Oleh itu, normalisasi SERR, mempunyai kesan yang signifikan terhadap geometri dan kekangan. Sebagai kesimpulan, indeks kestabilan implantasi dalaman diperkenalkan bergantung kepada berbagai faktor fiksasi klinikal, implan biomekanik, dan keadaan tulang melalui banyak jenis model angka yang dikembangkan. Untuk penyelidikan masa depan, jangkitan tulang implan, bahan implan, dan morfologi permukaan implan, faktor liang pada tulang harus dipertimbangkan mengenai penilaian kestabilan fiksasi implan dalaman.

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