

ANALYSIS OF POLYMERIC POLYCENTRIC PROSTHETIC KNEE JOINT

RANJEET KUMAR



**DEPARTMENT OF APPLIED MECHANICS
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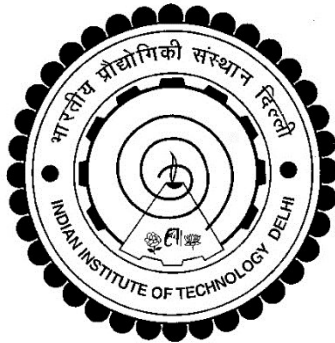
RANJEET KUMAR

Department of Applied Mechanics

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER 2019

Dedicated

To

My beloved family members and my supervisors

CERTIFICATE

This is to certify that the thesis entitled “**Analysis of Polymeric Polycentric Prosthetic Knee Joint**” being submitted by **Mr. Ranjeet Kumar** to the Indian Institute of Technology Delhi for the award of degree of **Doctor of Philosophy** in Department of Applied Mechanics is a record of bonafide research work carried out by him under our supervision and guidance. The research reports and the results presented in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

Dr. Naresh Bhatnagar

Professor

Department of Mechanical Engineering

Indian Institute of Technology Delhi

New Delhi-110016, India.

Dr. Puneet Mahajan

Professor

Department of Applied Mechanics

Indian Institute of Technology Delhi

New Delhi-110016

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Guru Sakshat Param Brahma Tasmai Shri Gurave Namah”*

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Ranjeet Kumar

DISCLAIMER

Design and manufacturing of polymeric components of proposed prosthetic knee joint using injection molding in the present work has been carried out by Dr. MH Alaei and other team members under the supervision of Prof. Naresh Bhatnagar, Mechanical Engineering at IIT Delhi.

Ranjeet Kumar

ABSTRACT

Transfemoral amputation or loss of major lower limb joints such as knee and ankle results in functional loss and psychological depression due to reduced mobility and high energy expenditure during walking. More than 4 lakh transfemoral amputees has been estimated in India, which accounts for 8% of total physical disability. Majority of them belong to the economically weaker section, and approximately 90-95% of amputees do not receive any prosthesis due to high cost.

The present study aims to design a low cost, reliable and functional polycentric prosthetic knee joint for the transfemoral amputees. The design based on geometric data of the available knee joints was analysed using Finite Element (FE) method. Based on the findings of the FE analysis, the initial model was modified. A prototype of the knee joint was manufactured using 3D printing technology, and a single subject human trial was performed using this. Based on the trial, the junction of pylon adaptor was modified and tested on the human subject. The patient successfully walked with the new design without any failure of the joint. As the 3D printed prototype lacked strength, it was manufactured using the injection molding process. The mechanical strength of the final product was tested for compression, flexural, torsion and fatigue strength as per ISO 10328:2006 standard. The results reveal that the proposed design fulfils the ISO requirement without any failure with a service life of 2 years.

The clinical trial, including joint analysis of the proposed design, was performed after obtaining due approval from Human Ethics Committee. Kinematic, kinetic energy efficiency and quality of life were assessed and compared with the existing single-axis prosthetic knee. The kinematic performance of the proposed knee in terms of pelvic obliquity, knee varus angle, hip and ankle movement, and foot progression angle showed improved trends as compared to existing single-axis design. Kinetic data also indicates improvement in moments, ankle power and ground reaction forces. The energy expenditure was reduced, and the overall quality of life was improved using the proposed design as compared to the existing single-axis knee joint.

The proposed polymeric polycentric prosthetic knee joint is lightweight, reliable and offers a better option to the transfemoral amputees belonging to the low-income strata of the society.

सार

चलने के दौरान कम गतिशीलता और उच्च ऊर्जा व्यय के कारण घुटने और टखने जैसे प्रमुख निचले अंगों के जोड़ों में ट्रांसफेमोरल विच्छेदन या नुकसान होता है। भारत में अनुमानित 4 लाख से अधिक ट्रांसफेमोरल एम्प्यूटेस हैं, जो कुल शारीरिक विकलांगता का 8% है। उनमें से अधिकांश आर्थिक रूप से कमजोर वर्ग के हैं, और लगभग 90-95% एम्प्यूटेस उच्च लागत के कारण किसी भी कृत्रिम अंग को प्राप्त नहीं करते हैं।

वर्तमान अध्ययन का उद्देश्य ट्रांसफेमोरल एम्प्यूटेस के लिए कम लागत, विश्वसनीय और कार्यात्मक पॉलीसेंट्रिक कृत्रिम घुटने के जोड़ को डिजाइन करना है। उपलब्ध घुटने के जोड़ों के ज्यामितीय डेटा के आधार पर डिजाइन का विश्लेषण परिमित अल्पांश (एफई) विधि का उपयोग करके किया गया है। एफई विश्लेषण के निष्कर्षों के आधार पर, प्रारंभिक मॉडल को संशोधित किया गया है। 3-डी प्रिंटिंग तकनीक का उपयोग करके घुटने के जोड़ का एक प्रोटोटाइप बनाया गया, और इसका उपयोग करके एक एकल विषय मानव परीक्षण किया गया है। परीक्षण के आधार पर, नायलॉन एडाप्टर के जंक्शन को मानव विषय पर संशोधित और परीक्षण किया गया। रोगी संयुक्त रूप से किसी भी विफलता के बिना नए डिजाइन के साथ सफलतापूर्वक चल गया। 3-डी प्रिंटेड प्रोटोटाइप में ताकत की कमी थी, इसीलिए इसे इंजेक्शन मोल्डिंग प्रक्रिया का उपयोग करके निर्मित किया गया। आईएसओ 10328:2006 मानक के अनुसार अंतिम उत्पाद की यांत्रिक शक्ति को संपीड़न, फ्लेक्सुरल, मरोड़ और थकान की शक्ति के लिए परीक्षण किया गया। परिणामों से पता चलता है कि प्रस्तावित डिजाइन 2 साल के सेवा जीवन के साथ किसी भी विफलता के बिना आईएसओ आवश्यकता को पूरा करता है।

नैदानिक परीक्षण, प्रस्तावित डिजाइन के संयुक्त विश्लेषण सहित, मानव आचार समिति से उचित अनुमोदन प्राप्त करने के बाद किया गया है। कीनेमेटिक, काइनेटिक ऊर्जा दक्षता और जीवन की गुणवत्ता का आकलन किया गया और मौजूदा एकल-अक्ष कृत्रिम घुटने के साथ तुलना की गई। पैल्विक तिर्यकदृष्टि, घुटने के कोण, कूल्हे और टखने के प्रगति के मामले में प्रस्तावित घुटने के गतिज प्रदर्शन, और मौजूदा एकल-अक्ष डिजाइन की तुलना में पैर की प्रगति कोण में सुधार के रुझान दिखाई दिए। काइनेटिक डेटा भी मोमेंट, टखने की शक्ति और जमीनी प्रतिक्रिया बलों में सुधार का संकेत देता है। ऊर्जा व्यय कम हो गया, और मौजूदा एकल-अक्ष घुटने के जोड़ की तुलना में प्रस्तावित डिजाइन का उपयोग करके जीवन की समग्र गुणवत्ता में सुधार किया गया है।

प्रस्तावित पॉलिमरिक पॉलीसेंट्रिक प्रोस्टेटिक घुटने का जोड़ हल्का, विश्वसनीय है और यह समाज के कम आय वर्ग से संबंधित ट्रांसफेमोरल एम्प्यूटेस को एक बेहतर विकल्प प्रदान करता है।

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ACRONYMS

ABS	acrylonitrile butadiene styrene
Add	adduction
Abd	abduction
ALIMCO	Artificial Limb Manufacturing Corporation of India
Antev	anteversion
ASPL	automatic stance phase lock
BCE	before Common Era
CAT-CAM	contoured adducted trochanteric-controlled alignment method
CoM	centre of mass
Dors	dorsiflexion
Ext	extension
Extr	external rotation
Flex	flexion
L5	5 th lumbar vertebra
GRF	ground reaction force
GRFap	anteroposterior ground reaction force
GRFml	mediolateral ground reaction force
IC	ischial containment
IP	intelligent prosthesis
ICR	instantaneous centre of rotation
Intr	internal rotation
ICRC	International Committee of the Red Cross
ISO	International Organization for Standardization
MPK	microprocessor knee
NMPK	non-microprocessor knee
PCI	physiological cost index
PPPKJ	Polymeric Polycentric Prosthetic Knee Joint
PPRP	post-polio residual paralysis
PC	polycarbonate
Plant	plantarflexion
QoL	quality of life

Retrov	retroversion
S1	1 st sacral vertebra
SACH	solid ankle cushioned heel
3D	three dimensional
TA	trochanteric ankle
VGRF	vertical ground reaction force
Var	varus
Val	valgus

LIST OF SYMBOLS

'L'	distance from hip joint to bottom part of the heel
' α '	perpendicular distance from TA line to the ICR
' β '	length from Kc to ICR
'K _c '	knee centre
'M _h '	moments about hip
'S'	shear resistance to torsion
'y'	distance from knee centre to bottom part of the heel
'l'	length of longest link
's'	length of shortest link
'p'	length of remaining one link
'q'	length of other remaining link