Design of a Lower Extremity Exoskeleton to Improve Gait in Patients with Knee Osteoarthritis by Reducing Knee Joint Loading

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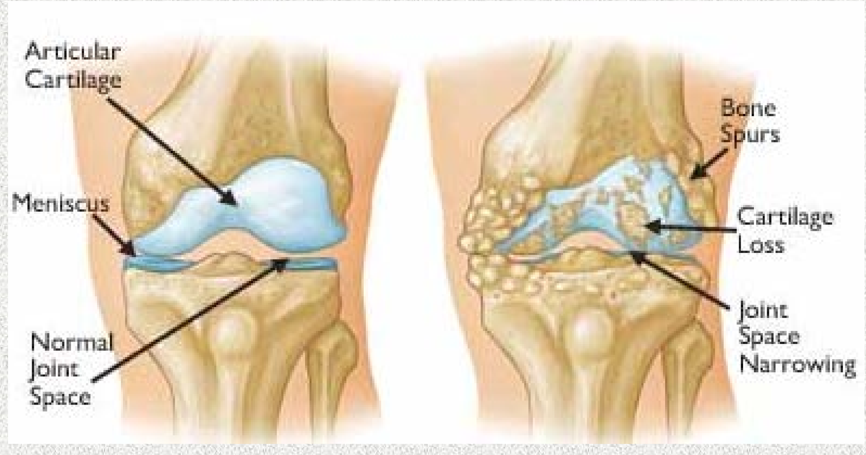
ABSTRACT

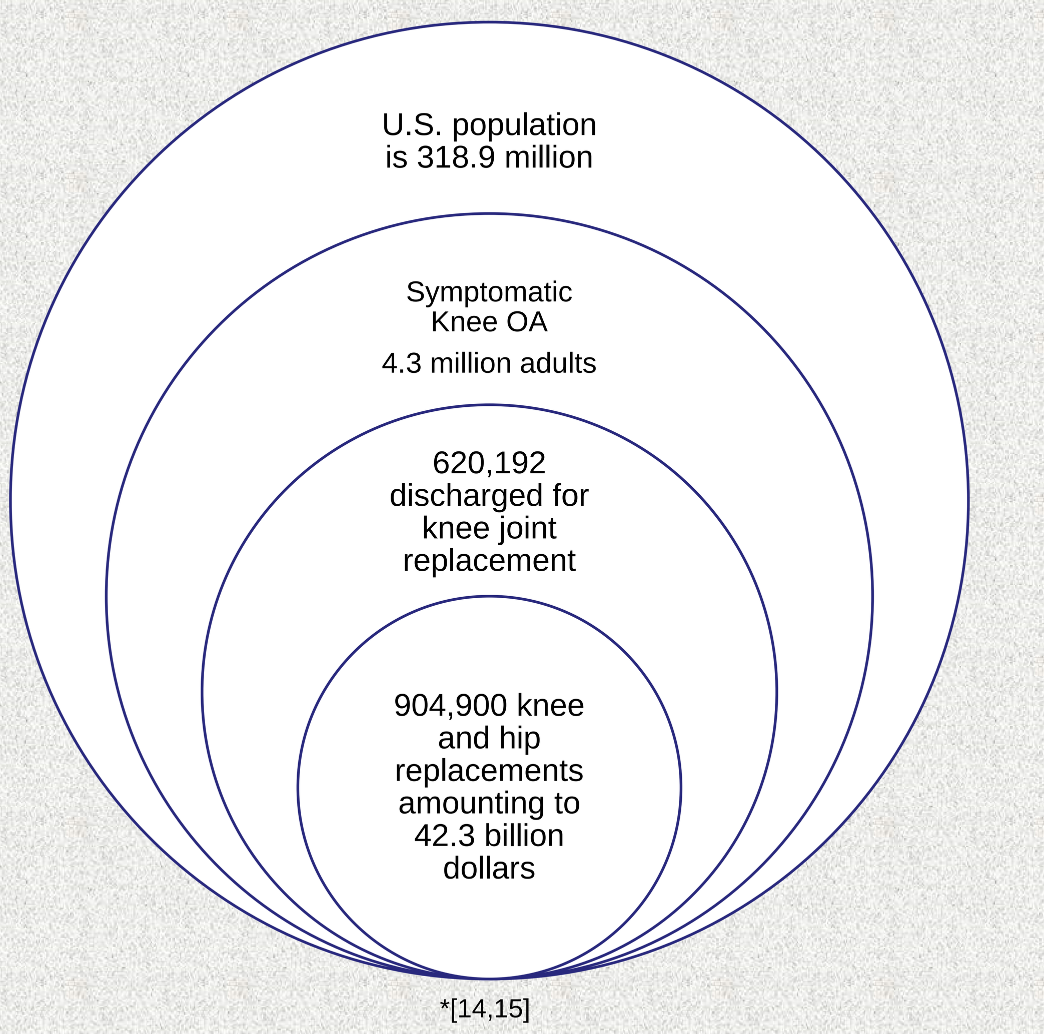
➢The purpose of this research is to create a lightweight and durable lower extremity exoskeleton that is comfortable for senior citizens.
➢Propose an unpowered, lower extremity exoskeleton composed of a system of mechanical components that closely model human gait kinematics in order to provide necessary compensatory power and stability for elderly patients with knee osteoarthritis.
➢Hypothetically, the inclusion of static structural components will increase the stability of the patient during selected stances, while dynamic elastic components will aid in shear force reduction in the knee joint during heel strike and muscle power generation during toe-off.

INTRODUCTION

- Knee osteoarthritis is a common cause of disability in people over 65 [2]
- Knee osteoarthritis symptoms [12]
  - Decreasing movement ability
  - Pain and stiffness
  - Since cartilage is worn, bone rubs against bone, causing abnormal formations in knee such as bone spurs or swelling
  - When walking, may become unstable
- Gait in patient with knee OA [5, 7]
  - Wider step from foot to foot so patient can have firm stability on floor
  - Smaller steps making it take longer to get to destination
  - Increased length of stopping time between steps to regain stability
  - Due to these conditions, performing sit-to-stand tasks lead to falls more often, causing injury and hospitalization.



COMPARISON OF KNEE JOINT WITHOUT AND WITH KNEE OA [10]

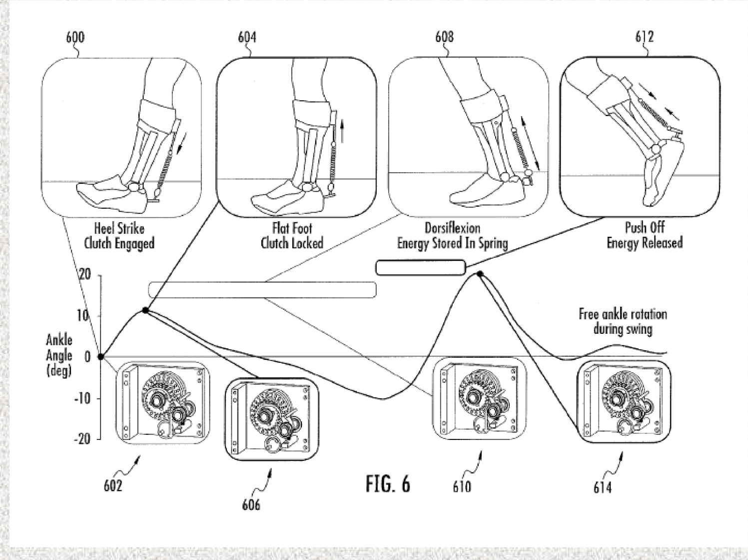


MATERIALS AND METHODS

Resources
- Hardware: Breadboards, microprocessor development boards, materials for exoskeleton.
- Software: Multisim, LabVIEW, MATLAB, Biopac, COMSOL, Biomechanics software, Autodesk Inventor and ANSYS for simulation and modeling,
- Statistical Analysis: ANOVA
- OPENSIM – simulator based on Hill's Muscle Model
- To create Solid Models: use 3D printing for mini model for the purpose of testing for interference, elastic springs, cords, etc.
  - Will limit use of 3D printer to commercially available products
- Eventual exoskeleton may be composed of products such as a carbon fiber and aluminum composite

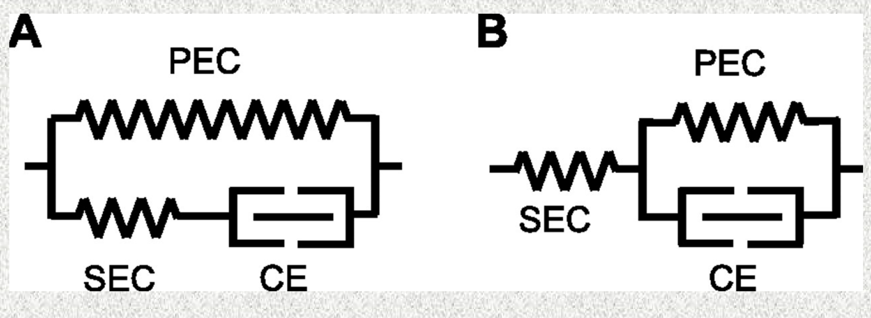
DESIGN CONCEPTS

➢The exoskeleton design may involve springs and lightweight materials
➢Main focus is on three of the gait cycles: Heel strike, mid-stance, and toe-off
➢Lean away from EMG based systems because of signal processing difficulty and motion artifact
➢Hill's muscle modeling is a common representation of muscle response in a mechanical sense among exoskeleton research.
- Hill's muscle model is a three element muscle model
  - contractile element (CE)- Active force
  - a series elastic element (SE)- passive force
  - parallel elastic element (PE)- passive force
  - The force produced by contractile element transmits to the muscle through the series elastic element



CALF SPRING DURING GAIT CYCLE [9]

GAIT CYCLE OF FOCUS [13]



HILL'S MUSCLE MODEL BASIC CIRCUIT DESIGN [11]

Exoskeleton	Purpose	Properties	Dimensions
Berkeley Lower Extremity Exoskeleton (BLEEX)	load carrying human exoskeleton used by soldiers, disaster relief workers, etc.	walks at the average speed of 0.9 m/s while carrying a 34 kg payload	
Hybrid Assistive Limb (HAL) -5 (Type-B)	help a patient with paraplegia walk upright	payload up to 75 kg	Height: 1600 mm Weight: 23 kg
Human Universal Load Carrier (HULC)	Used by soldiers for combat loads Heavy load is transferred to ground	payload up to about 91 kg	Height: 5'4'' to 6' 2'' Weight without batteries: about 10 kg

DISCUSSION

Lower Extremity Exoskeleton
➢**Portability**–so far most developed exoskeletons are tethered (electronically, pneumatically, etc.) [1]
- Some include power increasing weight or crutches for balance
- Other forms for less bulk end up with on-board systems that increase weight and decreases overall efficiency
- Our focus is an autonomous and unpowered exoskeleton

➢**Interfacing**–motion artifact/noise with EMG based system, signal conditioning, microprocessing, algorithm modeling [1]
- Not dealing with data collection

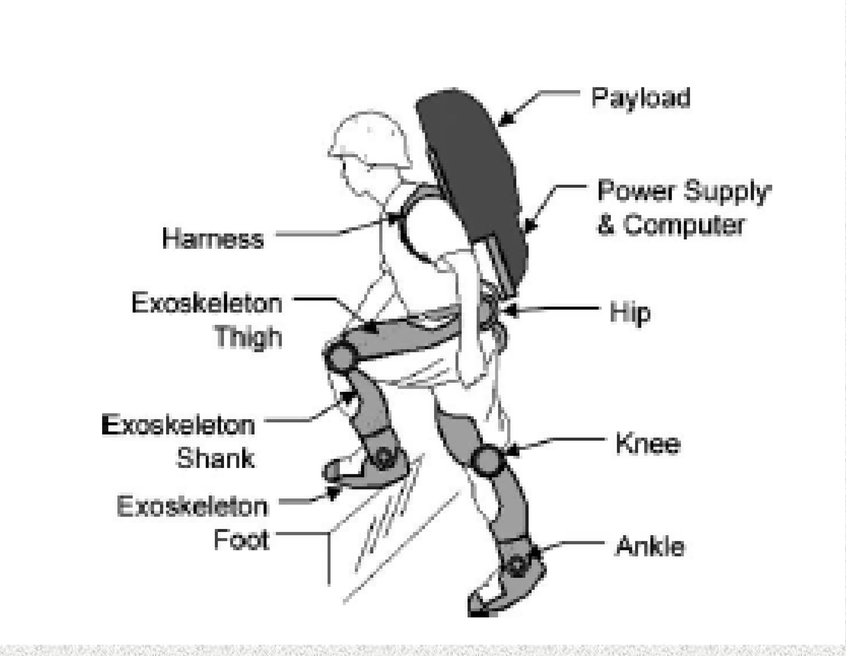
➢**Mechanical Structure**–range/rate of motion limited by actuators, kinematic constraints [1]
- Patient ability taken into account due to knee OA
- Adjustable frame

➢**Anatomical/Physiological variation**–optimal fiber length varies based on height (needs constant calibration) affects muscle torque [1]
- Will make it easier for patients to walk, alleviates symptoms

DISCUSSION – continued

➢Studying factors attributing problematic issues provide solutions to improving the mobility of knee OA patients
- Main focus- Knee joint loading in muscles
- Muscles in lower extremity joints tend to decrease in power due to knee OA symptoms [6]

➢Power and stability can be increased in the lower extremity using powered and unpowered lower extremity exoskeletons [4, 8]
➢Such projects have shown up to a 7% increase in metabolic efficiency during gait cycles [4]
➢In previous exoskeletons researched, most use some form of Hill's muscle model.
➢BLEEX [3,8]
- Transfers the weight to the ground instead of the user
- Uses linear actuation
- Design of the exoskeleton around the wearer allows for it to follow the wearer's movements



BERKELEY LOWER EXTREMITY EXOSKELETON (BLEEX) [8]

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