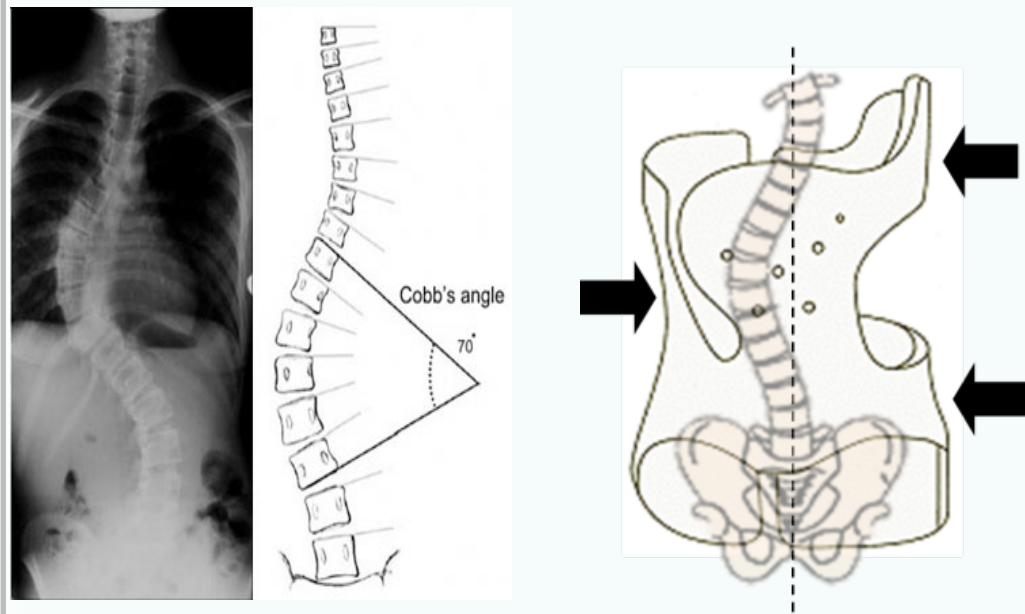


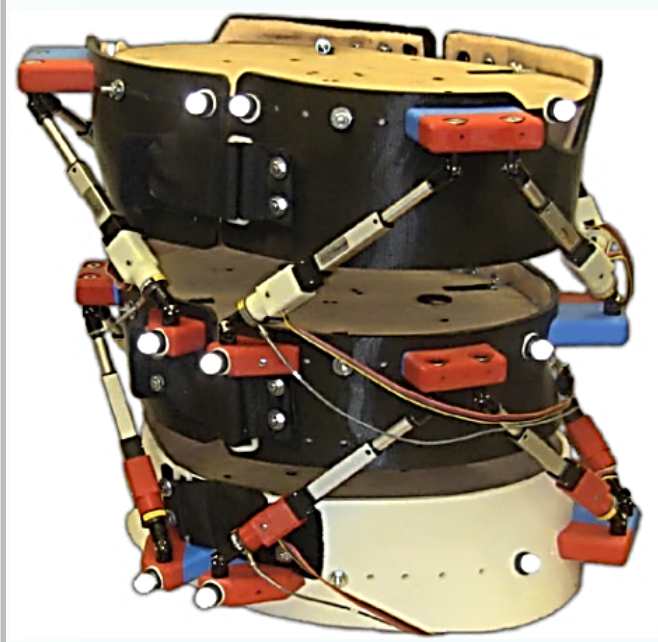
Introduction



- Scoliosis is a spine disease that cause abnormal curvature of spine
- Current treatment is rigid bracing which aims to restore spine alignment by providing corrective forces at the apex of the curvatures

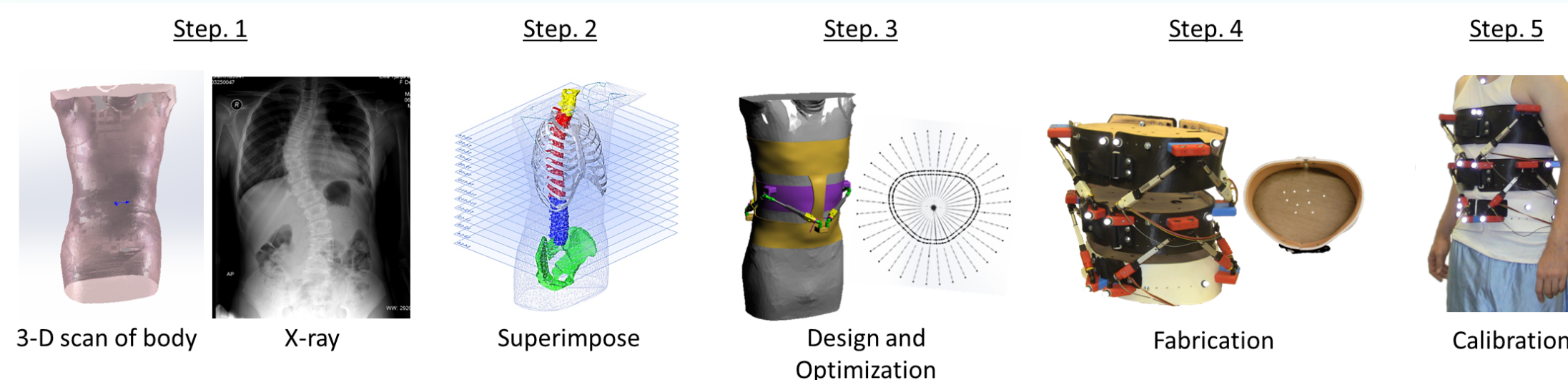
- It has shown to be effective in treating scoliosis but has several limitations
 - Requires extensive hours of treatment (18-23 hours a day)
 - Passive and rigid design lacks the ability to adapt to changes in spine over the course of treatment
 - Posture correction without knowing how much force is applied can cause excessive local pressure on the human body
 - Highly restrictive, interferes with activities of daily living and can cause postural muscle atrophy
- The goal of this research is to address these issues by designing a wearable dynamic spine brace capable of modulating corrective actions on the human body by controlling either the pose or the force of the brace while providing a larger range of torso motion to improve the quality of care

Novel features of dynamic brace

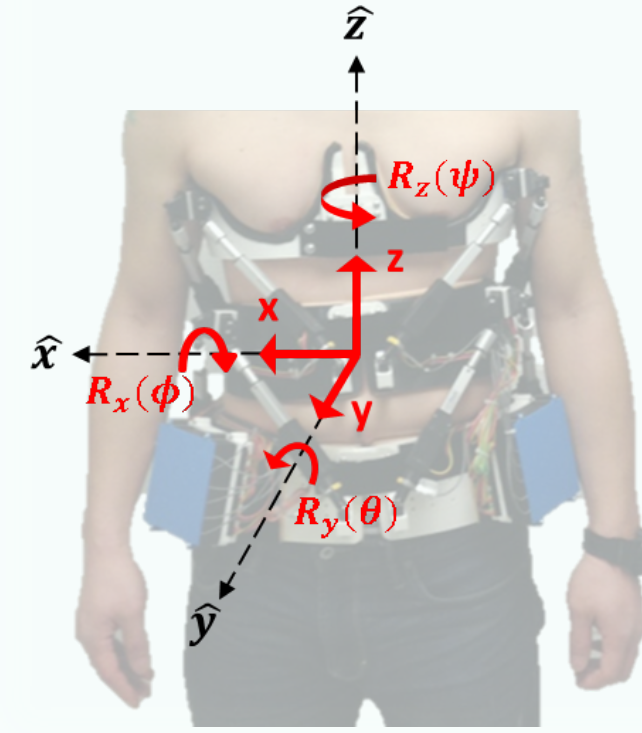


- Dynamic modulation of pose or force through inbuilt sensors
- Real time monitoring/control of the forces
- Adaptable and adjustable to accommodate changes in the patient's body and spine
- Less restrictive than rigid braces allowing for a greater range of motion of the torso

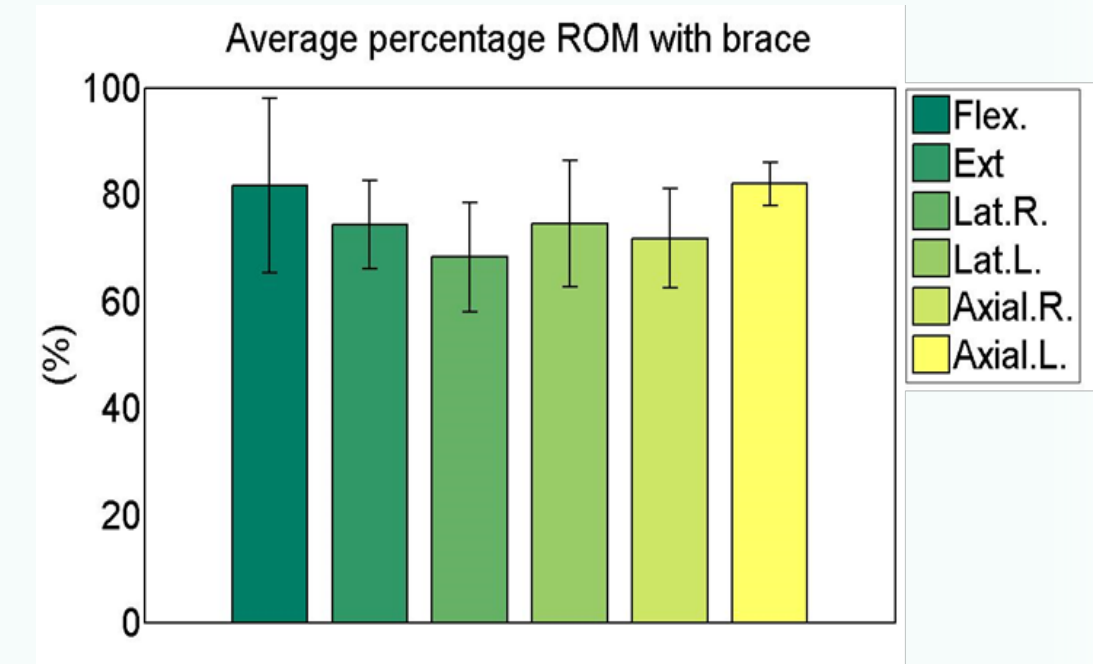
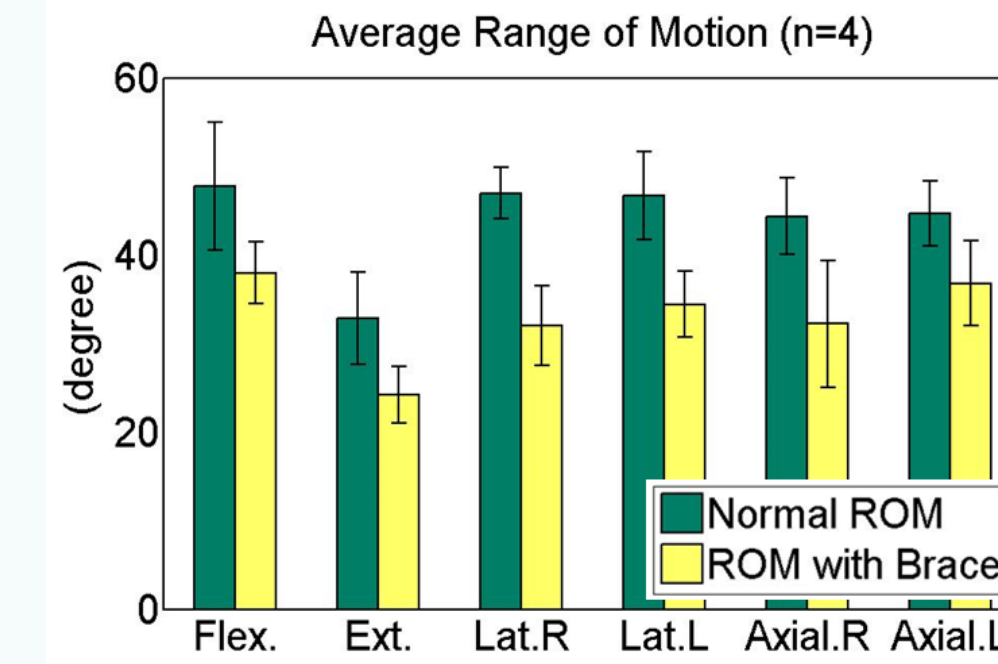
- Two Stewart Platforms in series (12 active degrees-of-freedom)
- Single axis load cells at the base of each motor
- Potentiometer based position feedback
- Brace segments based on optical 3D scan of subject



Range of Motion Testing



- Subject wore markers on the pelvis and manubrium
- The test was conducted without the brace and with the subject wearing the brace in transparent mode
- Majority of natural range of motion of torso was maintained while subjects were wearing the brace in transparent mode



Torso Stiffness Characterization

Experiment Goal

- Determine the forces required to displace the torso by small amounts in each degree of freedom (collinear stiffness)
- Characterize the coupling between different degrees of freedom

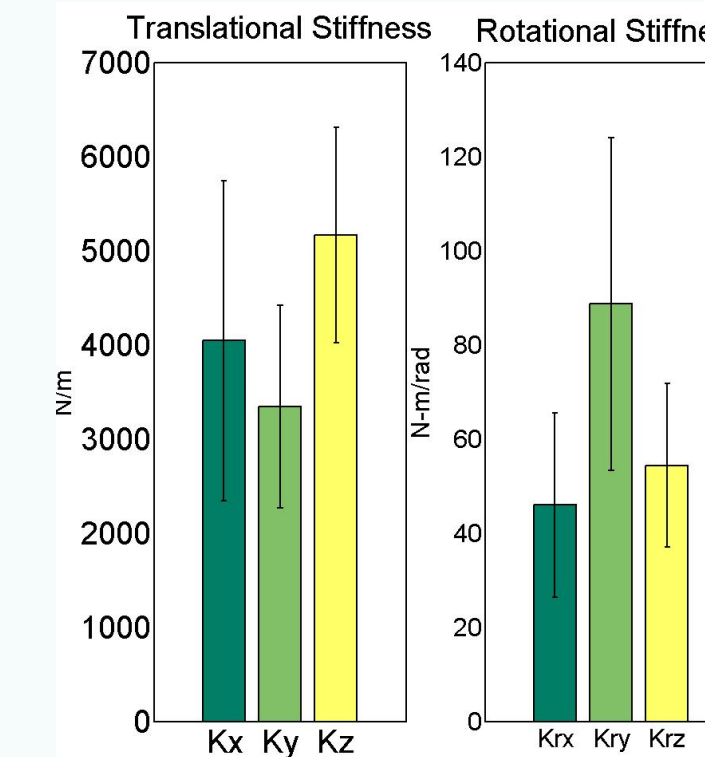
Experiment Method

- 10 healthy, adult male subjects
- 6 steps on each direction, repeated three times each
- Step size: translation (5mm), rotation (0.05 rad)

Collinear Stiffness Results

- Trends in accordance with the trends reported in literature for the collinear stiffnesses of the human spine

Average Collinear Stiffnesses



Stiffness Trends

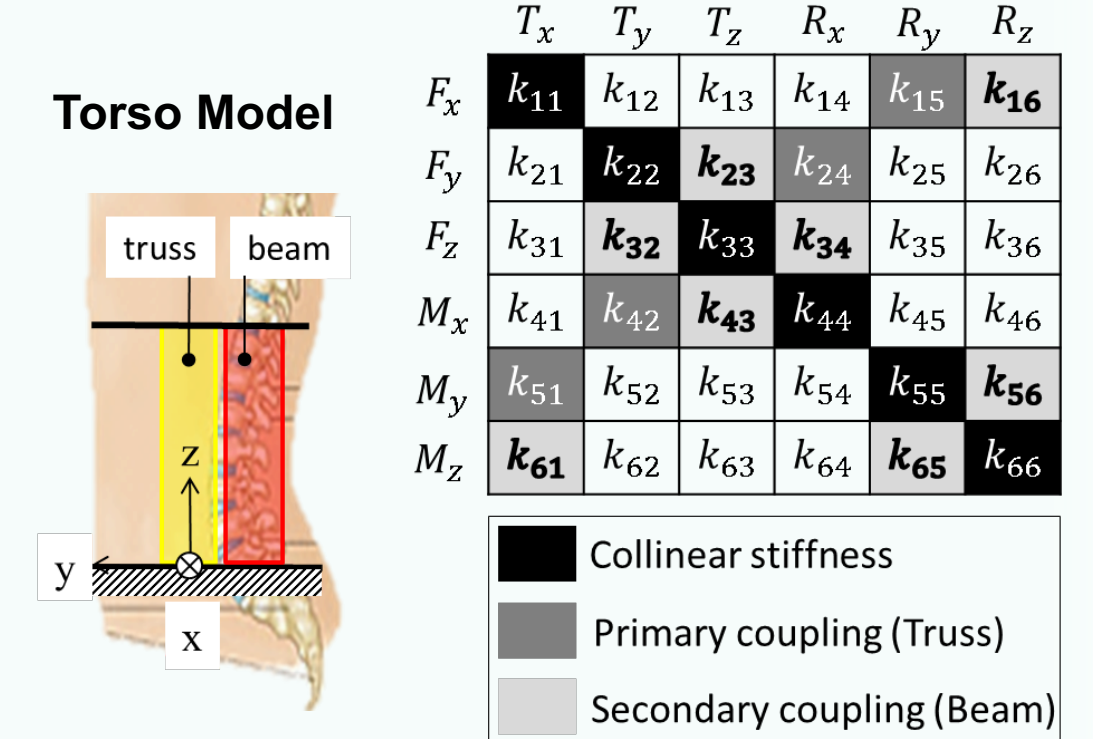
$k_z > -k_y$ $> k_x > +k_y$	$k_{Rz} > +k_{Rx}$ $> k_{Ry} > -k_{Rx}$	White et al.
$k_z > k_x > k_y$	$k_{Ry} > k_{Rx} > k_{Rz}$	Costi et al.
$k_z > k_x > k_y$	$k_{Ry} > k_{Rx} > k_{Rz}$	Present Study

Coupling Effects Results

- Torso can be modeled as a truss and beam (spine is the stiffest)
- Stiffness matrix captures
 - Collinear stiffness characteristics
 - Coupling effects between the degrees of freedom

$$F = K\Delta X$$

$$\begin{bmatrix} F_x^{(1)} & \dots & F_x^{(n)} \\ \vdots & \ddots & \vdots \\ F_z^{(1)} & \dots & F_z^{(n)} \end{bmatrix} = \underbrace{\begin{bmatrix} k_{11} & \dots & k_{16} \\ \vdots & \ddots & \vdots \\ k_{61} & \dots & k_{66} \end{bmatrix}}_K \begin{bmatrix} \Delta x^{(1)} & \dots & \Delta x^{(n)} \\ \vdots & \ddots & \vdots \\ \Delta \psi^{(1)} & \dots & \Delta \psi^{(n)} \end{bmatrix}$$

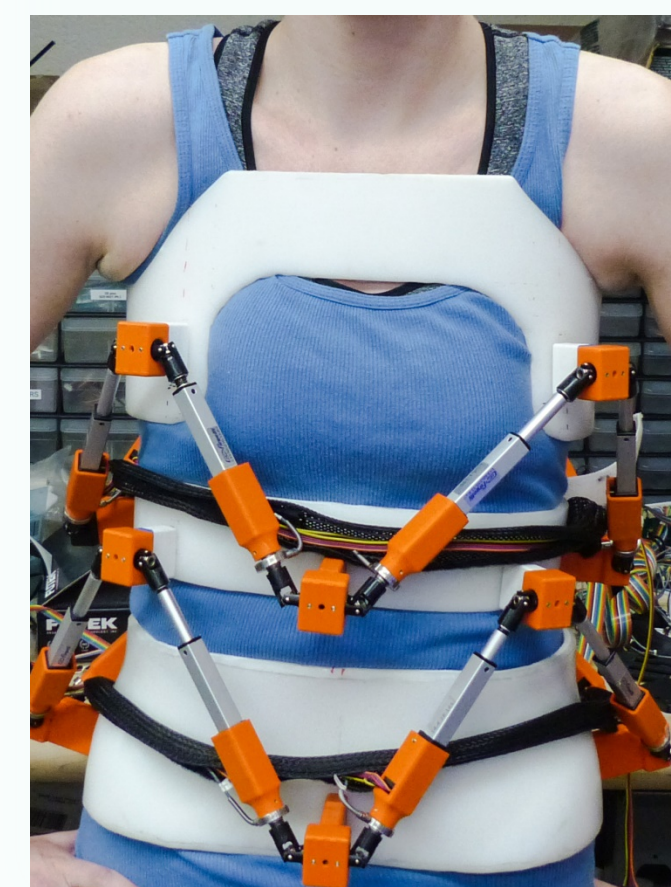


Experimental Average Stiffness Matrix

	T_x	T_y	T_z	R_x	R_y	R_z
F_x	3245.058	112.024	48.607	-17.984	-310.918	16.830
F_y	4.241	2777.159	-320.599	176.364	-31.891	-25.351
F_z	-9.618	-287.419	4372.962	-85.701	-3.604	72.893
M_x	-16.321	105.569	-66.112	38.557	0.675	-3.656
M_y	-311.539	-45.302	1.428	-3.644	82.915	-2.702
M_z	-80.680	-48.675	55.706	-4.803	16.313	44.317

- Matrix is asymmetric (viscoelasticity)
- Inter-subject variability in the magnitude of stiffness
- Coupling effects consistent over the group.

Female Brace



- Scoliosis curves tend to appear during adolescent years, and disproportionately affects women
- Ring design adjusted for adolescent females
- Brace segments cut from an off the shelf Boston Brace module
- 10 cm of adjustability in the circumference in each ring
- Electronics moved off the brace, and overall weight reduced from 9 lbs. to 6 lbs.

Future work



- Characterize stiffness of spine within the torso using low-dose x-rays
- Track changes in torso stiffness over the course of bracing treatment
- Compare stiffness of healthy adolescents to those with scoliosis
- Experiments using force feedback for physical therapy training
- Expand range of brace sizes