Marcus Neuroscience Institute
BAPTIST HEALTH SOUTH FLORIDA

Augmented Reality, Artificial Intelligence, and Emerging Technologies in Neurosurgery

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Disclosures

Timothy O'Connor, M.D., symposium director for this educational activity, is a consultant for Medtronic and OnPoint Surgical. He has indicated that the presentation or discussion will not include off-label or unapproved product usage.

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Objectives

- Discuss the emerging technologies being developed for complex spine and brain surgery.
- Describe how artificial intelligence can be used for preoperative planning and customized patient implants.
- Explain how augmented reality guidance systems can be used to increase intraoperative accuracy, advance minimally invasive surgeries and improve patient safety.

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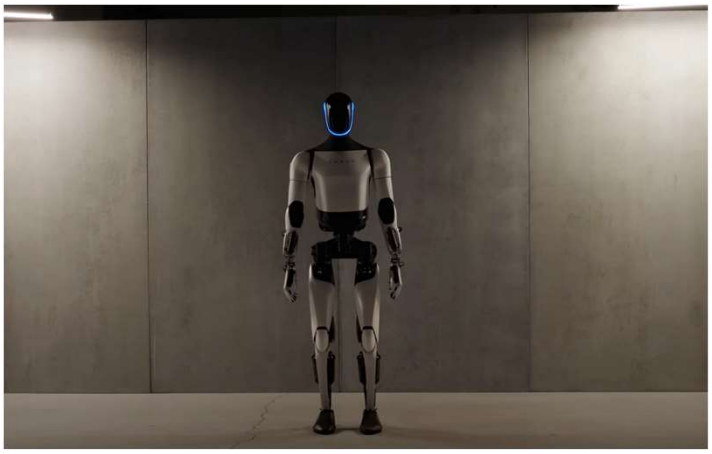
Types of Robotics Today

- Industrial
  - Materials handling
  - Welding
  - Inspection
  - Manufacturing
- Laboratory applications
- Autonomous vehicles
- Spacecraft systems



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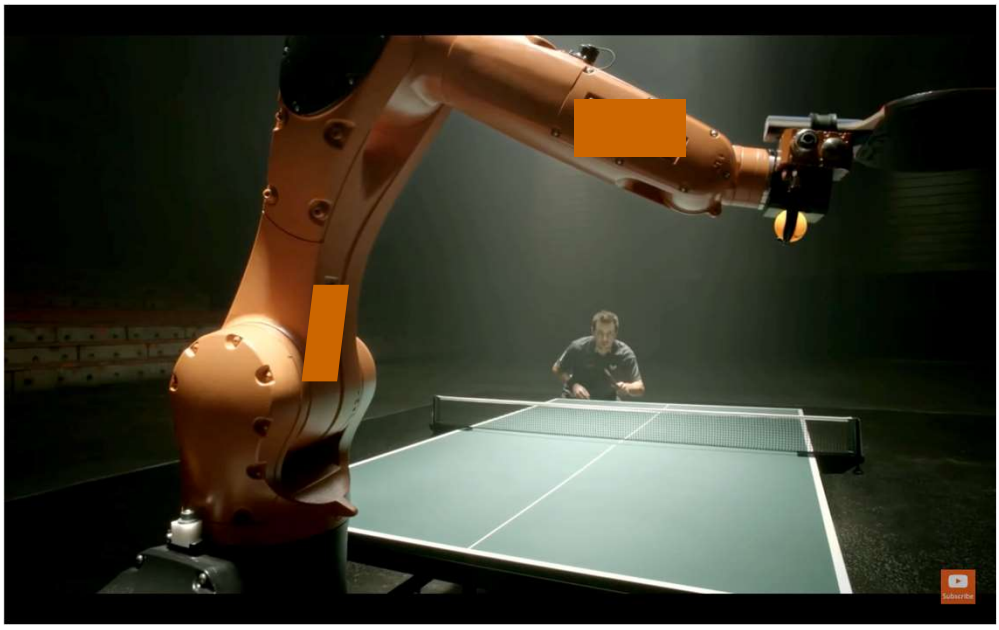

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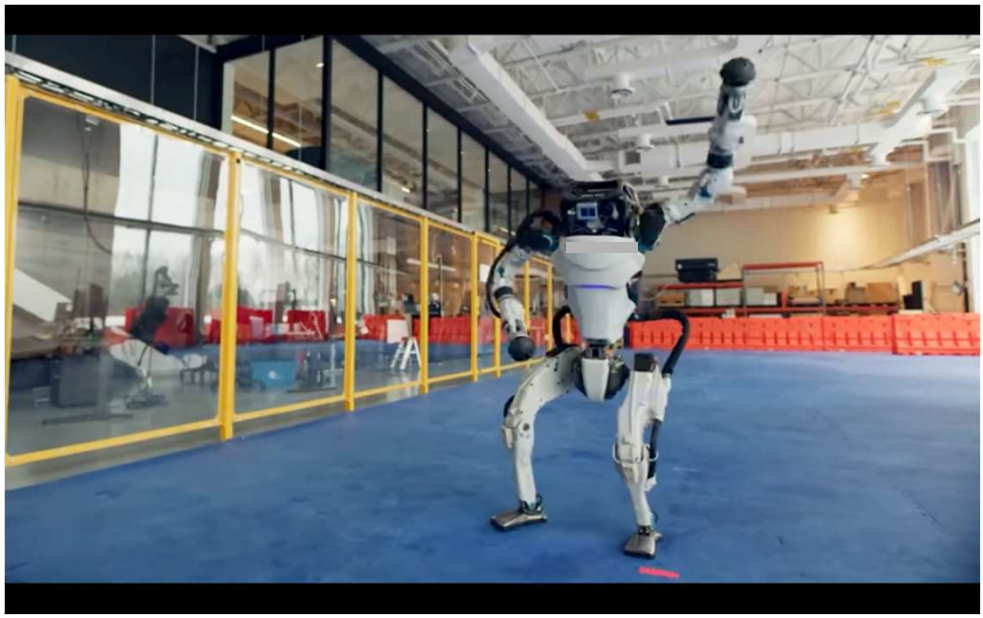

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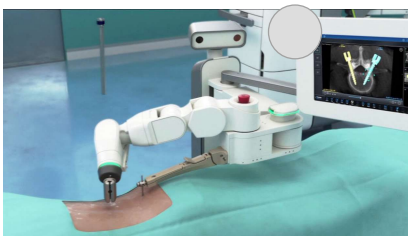
Current Medical Robotic Technology



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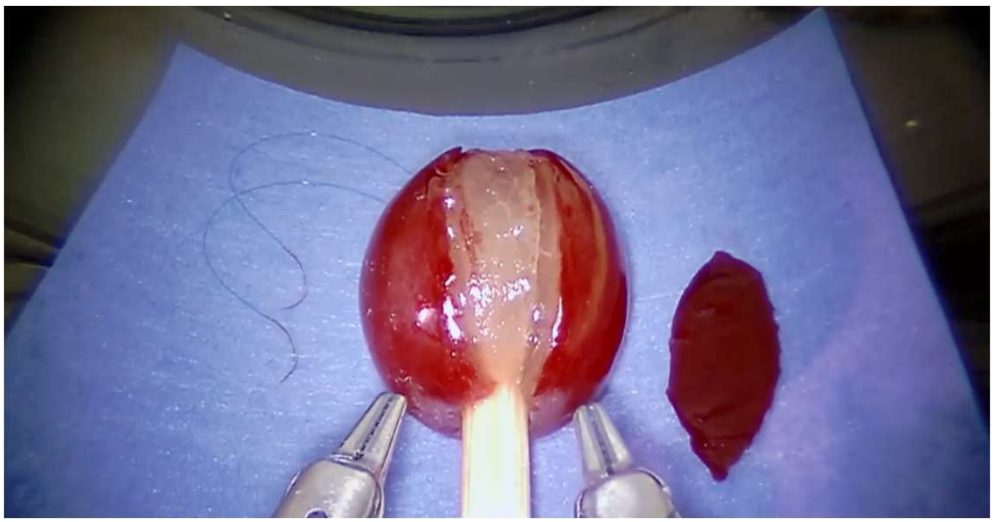

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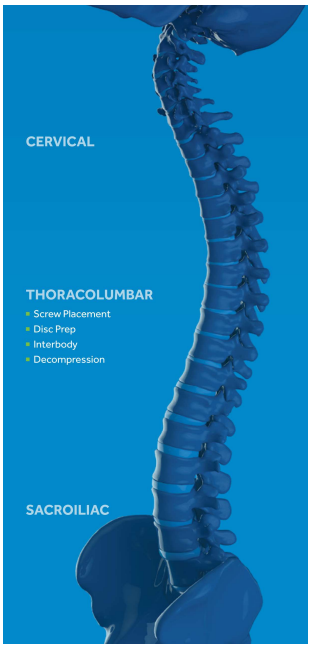
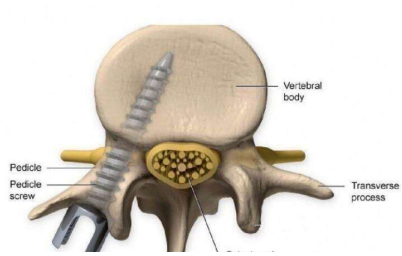
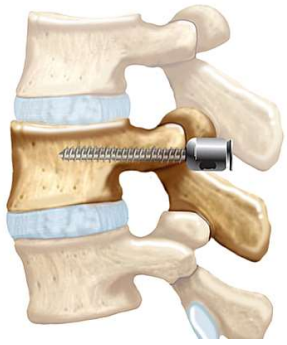

CERVICAL
THORACOLUMBAR
Screw Placement
Disc Prep
Interbody
Decompression
SACROILIAC


Vertebral body
Pedicle
Pedicle screw
Transverse process



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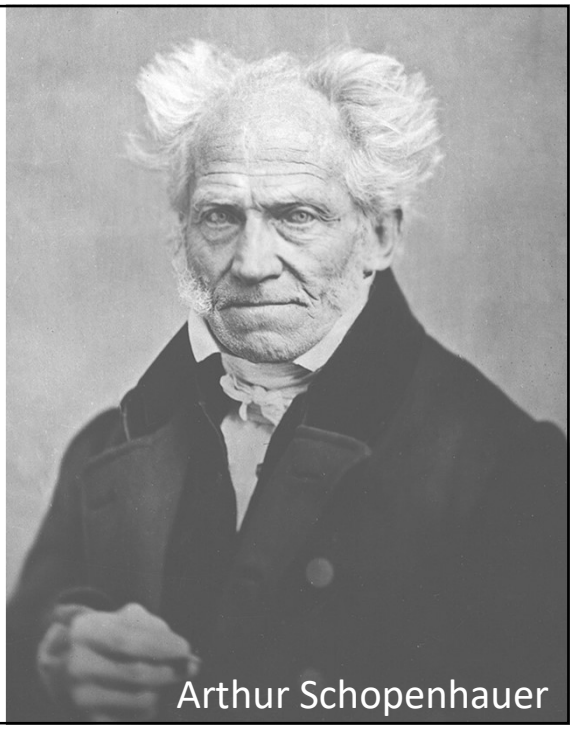
All Truth Passes Through Three Stages

- First, it is ridiculed
- Second, it is violently opposed
- Third, it is accepted as being self-evident


Arthur Schopenhauer

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Operating Room and Aviation in the 1920s

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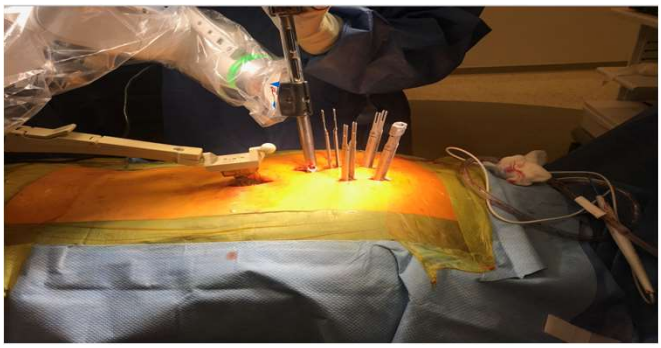
Operating Room and Aviation, Modern Day



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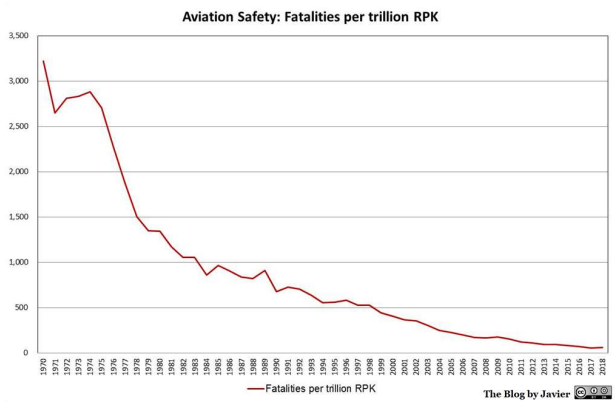
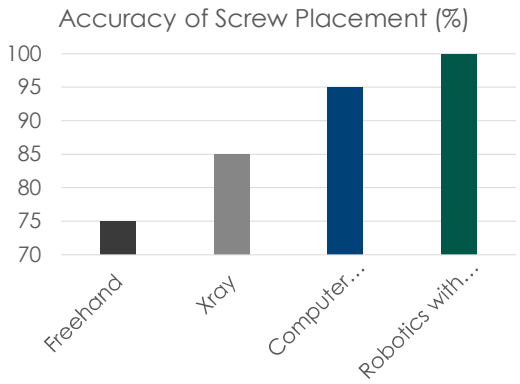
Tragically, of the 40 pilots hired when the post office took over airmail operations in the early 1900s, at least half had died by 1920

The Post Office flies the mail by the centennial of flight



1970 → 2018



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1st Generation Spine Robot

- 1st robotic spinal system approved by the FDA
- Used in ~ 840 cases in 14 hospitals from 2005-2009
- The system consists of 2 units:
  1. A miniature 50 x 80mm, cylindrically shaped robot (250g)
     - Able to move in 6 degrees of freedom
  2. Bone mounted robot

Source: Overly et al. Navigation and Robotics in Spinal Surgery: Where Are We Now? Neurosurgery 2007; 80:586–599
https://www.micromo.com/applications/medical-lab-automation-equipment/application-case-study-micro-precise-surgery-assistant

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Computerized workstation

Robot with attached surgical instrument

From: Sukovich et al. Miniature robotic guidance for pedicle screw placement in posterior spinal fusion: early clinical experience with the SpineAssist. Int J Med Robotics Comput Assist Surg 2006; 2: 114–122

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2nd Generation

- 2011
- Uses the same cylindrically shaped robot
- Software upgrades to improve the registration process to minimize time→ ***faster registration***
- Improved instruments and workstation

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3rd Generation

- 2016
- Procedures Performed to Date: 41,500
- Implants Placed to Date: 280,000

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Reduction in Complications and Revisions
Robotic Spine Surgery Clinical Value Beyond Instrumentation

- Surgical Planning
- Anatomy Recognition Engine
- Modality Registration

Spine

RANDOMIZED TRIAL

Minimally Invasive Robotic *Versus* Open Fluoroscopic-guided Spinal Instrumented Fusions

A Randomized Controlled Trial

ELSEVIER

THE SPINE JOURNAL

Clinical Study

Biomechanical advantages of robot-assisted pedicle screw fixation in posterior lumbar interbody fusion compared with freehand technique in a prospective randomized controlled trial—perspective for patient-specific finite element analysis

Ho-Joong Kim, MD[a], Kyoung-Tak Kang, PhD[b], Sung-Cheol Park, MD[a], Oh-Hyo Kwon, MD[a], Juhyun Son, MS[b], Bong-Soon Chang, MD[a], Choon-Ki Lee, MD[a], Jin S. Yeom, MD[a,c], Lawrence G. Lenke, MD[d]

WILEY

ORIGINAL ARTICLE

A prospective, randomized, controlled trial of robot-assisted vs freehand pedicle screw fixation in spine surgery

Ho-Joong Kim[1] | Whan-Ik Jung[1] | Bong-Soon Chang[2] | Choon-Ki Lee[2] | Kyoung-Tak Kang[3] | Jin S. Yeom[1]*

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Weighted-Average Accuracy for 7,634 Robotic-Guided Screws = 96.5%

	Author	Year	Study type	Device	# Screws	# Safe Screws	Accuracy Rate
1	Hu	2013	Retrospective	RNS	960	949	98.9%
2	Onen	2014	Prospective	RNS	136	134	98.5%
3	Kim	2015	RCT**	RNS	158	158	100.0%
4	Hyun	2016	RCT**	RNS	130	130	100.0%
5	Fujishiro	2015	Cadaveric study	RNS	216	216	100.0%
6	Kuo	2016	Retrospective	RNS	317	313	98.7%
7	Macke	2016	Retrospective	RNS	662	614	92.8%
8	Keric	2017	Retrospective	RNS	1857	1799	96.9%
9	Molliqaj	2017	Retrospective	RNS	439	410	93.4%
10	Tsai	2017	Retrospective	RNS	662	655	99.0%
11	Minfeng	2016	Retrospective	RNS	83	82	98.8%
12	Hu	2016	Retrospective	RNS	35	35	100.0%
13	Solomiichuk	2017	Retrospective	RNS	192	162	84.4%
14	Bederman	2013	Retrospective	RNS	27	27	100.0%
15	Urakov	2017	Retrospective	RNS	101	89	88.1%
	Renaissance Total				**5975**	**5774**	**96.6%**
1	Van Dijk	2015	Retrospective	SA	487	477	97.9%
2	Devito	2010	Retrospective	SA	646	635	98.3%
3	Schizas	2012	Retrospective	SA	64	61	95.3%
4	Roser	2013	RCT**	SA	72	71	99.0%
5	Ringel	2012	RCT**	SA	146	124	85.0%
6	Schatlo	2014	Retrospective	SA	244	223	91.4%
	SpineAssist Total				**1659**	**1591**	**95.9%**
	Total				**7634**	**7366**	**96.5%**

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4th Generation

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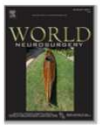
World Neurosurgery

Volume 145, January 2021, Pages 435-442



Technical Note

Mazor X Stealth Robotic Technology: A Technical Note

Timothy E. O'Connor [1, 3]

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https://doi.org/10.1016/j.wneu.2020.10.010

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Achieving Accurate Screw Placement

Up to **100%** screw placement accuracy.[2,7-9]

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Figure 4. A single posterior superior iliac spine Schanz screw can be used to secure the robot to the patient. No additional percutaneous pins are needed to register Stealth imaging to the patient.

placement of the screw heads to assist with subsequent placement of the rod. Another benefit is the ability to view the skin incisions if placing percutaneous screws.

Placement of Instrumentation. Once planning is complete and accuracy is verified, the robotic effector arm is sent to the first screw location. When multiple screws are planned, there is an option to then send the arm to subsequent levels on the ipsilateral side to plan an optimal skin incision. A specialized No. 11 blade scalpel provided by Mazor is placed through the effector arm to make a stab incision. A scalpel can then be used to extend the incision approximately 1–2 cm superiorly and inferiorly through the fascia, for a total incision length of about 3 cm per screw.

Next, a navigated dilator and outer cannula are inserted through the effector arm at the level of interest and into the incision site until bone is felt (**Figure 9**). Of note, the instruments should be lubricated with irrigation before placement through the effector arm. The navigated dilator is removed with the outer cannula left in place. A drill guide is then placed down the outer cannula. An electric navigated drill is then placed down the drill guide and activated (**Figure 10**). The navigated drill has a 3-mm drill bit with 30 mm of a positive stop to prevent overdrilling. Once drilling is complete, the navigated drill is removed and an optional

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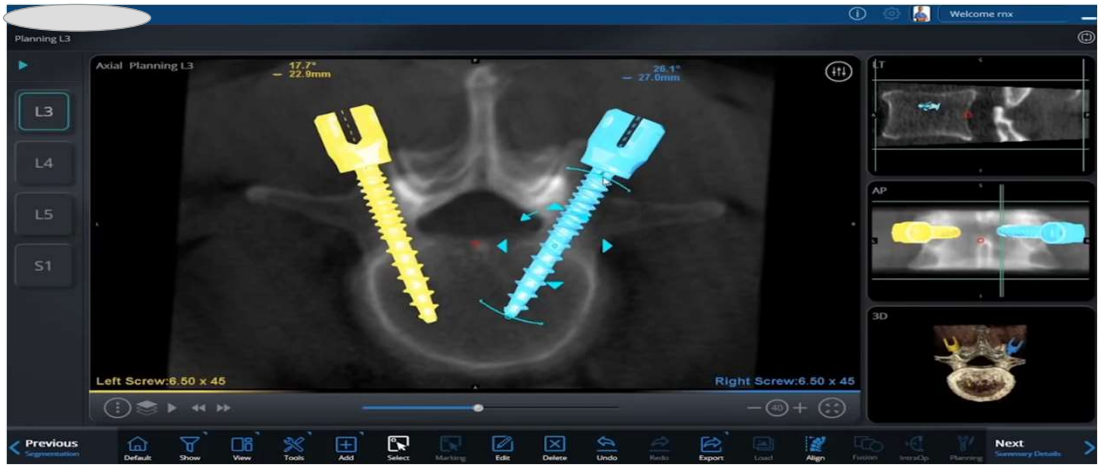
Robotic Technology with 3-Dimensional CT Navigation



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Pre-op Planning and Predictability

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Preoperative Planning and Predictability

- 3D implant and trajectory placement planning
- CT analyzed to recognize anatomical landmarks
- Preop identification of dysplastic features

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Figure 5. Bilateral posterior superior iliac spine screws can be used for additional fixation to secure the robot to the patient.

The planning software has also been integral to aligning our posterior instrumentation to assist in rod placement for multilevel constructs. Our use of this new technology has been encouraging, with

100% grade 1 accuracy

on the Gertzbein-Robbins scale across our first 90 pedicle screws confirmed on postoperative CT with no complications in any case. In our experience, this robotic technology has the potential to improve patient outcomes and is associated with advanced surgical planning compared with more traditional techniques.

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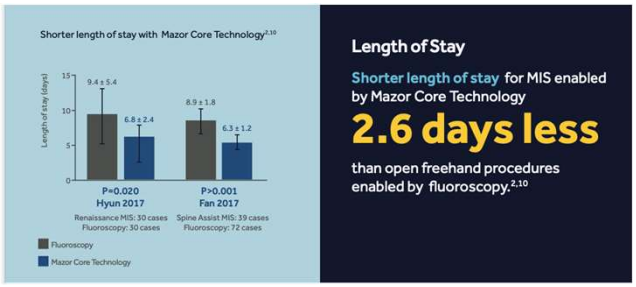
"Average length of stay for our patients was only 1.5 days, with patients discharged home after surgery in less than half the time compared to surgery with more traditional techniques"



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Challenges of Robotic Spine Surgery

- Steep learning curve
- Newer technology requires significantly more training
- Capital Cost of Robotic System
- Not only the surgeon, but the entire team must become proficient in using and understanding robotic technology

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And The Introduction of Artificial Intelligence…

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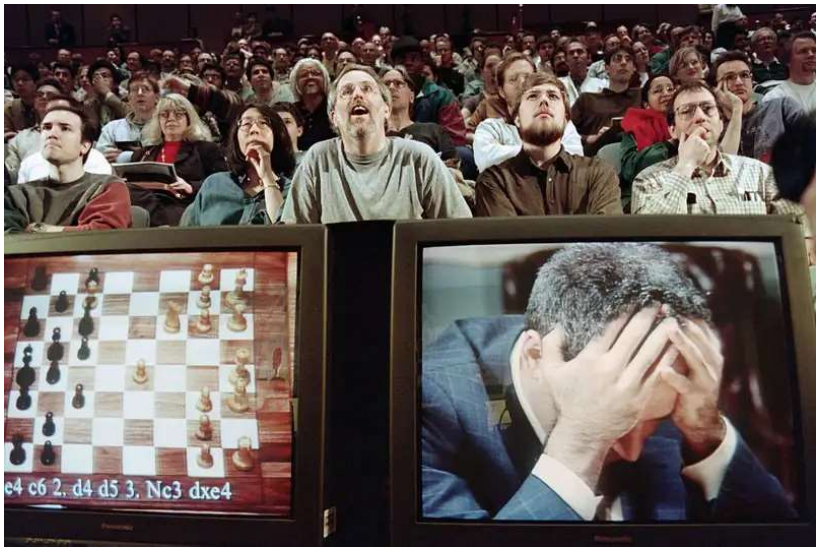
1997: Deep Blue vs Gary Kasparov



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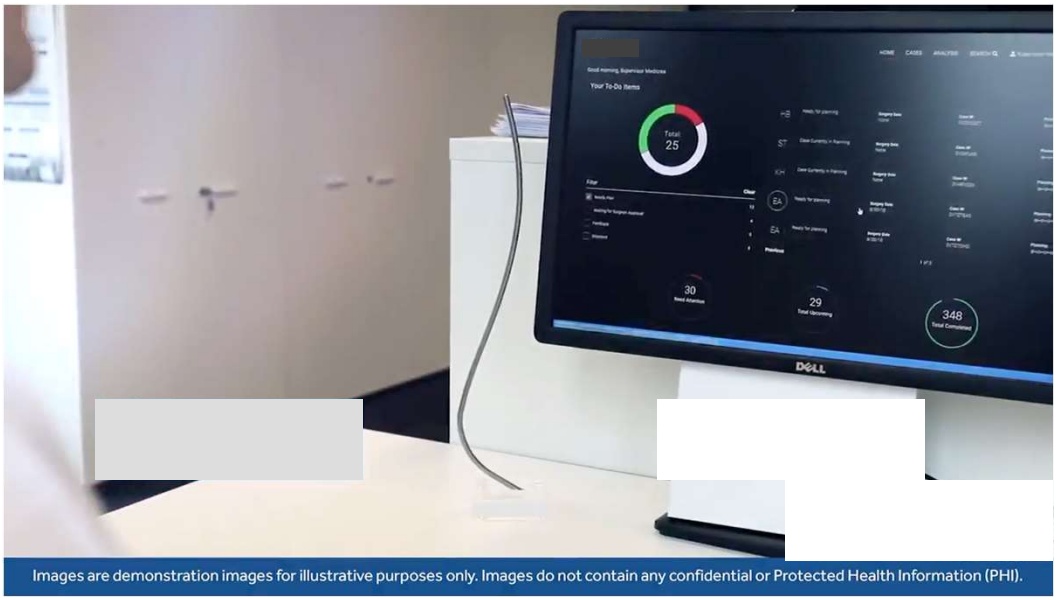

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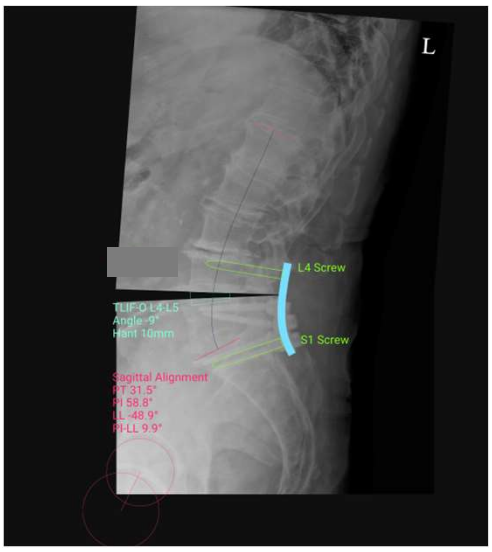
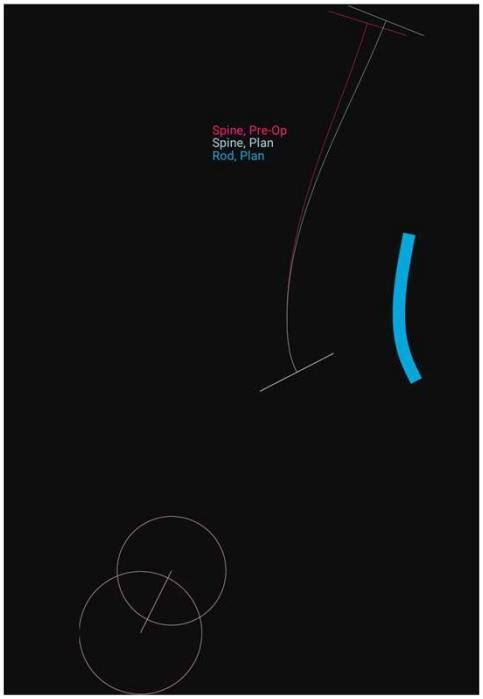
AI for Customized Rod Bending





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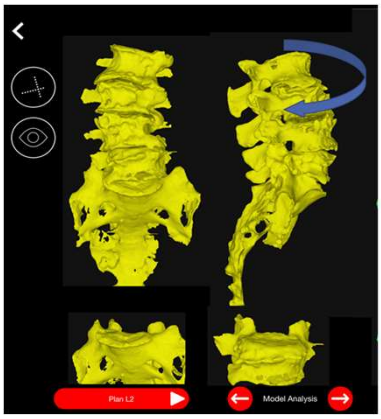
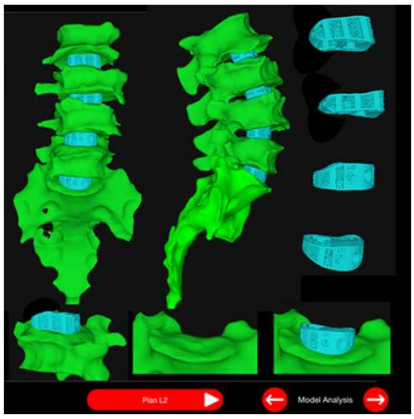
Data Driven Surgery





- uses patient data and digital technologies to create optimal surgical plans and personalized aprevo® spine fusion devices for each patient.
- digital technologies help guide preoperative decisions to align surgeon and patient expectations and increase patient satisfaction.

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Future Directions and Research

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Accuracy of an Augmented Reality Spine Surgery Guidance System with Stereoscopic Targeting Head Mounted Display Compared to Standard Computer Navigation, Robotic Systems, and Existing AR Systems

Timothy O'Connor, MD[1], Ibrahim Hussain, MD[2*], Sudesh K Srivastav, PhD[3], John Pan, MD[4], Thomas Voegeli, MD[5]*

1. Marcus Neuroscience Institute, Florida Atlantic University, Baptist Health, Boca Raton, FL; 2. Dept. of Neurosurgery, Weill Cornell-NewYork-Presbyterian Och Spine, New York, NY; 3. Department of Biostatistics and Data Science, Tulane University, New Orleans, LA; 4. Department of Radiology, Boston University Medical Center, Boston, MA;

Introduction

Augmented Reality (AR) offers the benefit of improved hand-eye coordination by accurately superimposing 3D stereoscopic displays for surgical instruments onto anatomic landmarks.

Objectives

To compare the accuracy of a 4k resolution AR system with novel 3D stereoscopic targeting with existing navigation, robotic and AR systems for implanting thoracic and lumbar pedicle screws.

Methods

120 pedicle screws were implanted using a novel AR system (OnPoint Alm-AR, OnPoint Surgical, Bedford, MA) (thoracic 50, lumbosacral 70; pre-op CT 40, O-arm 80) (Fig. 1).

Heary grading was applied by an independent radiologist assessing the degree of pedicle breaches. 3D measurements of positional error (PE) and angular error (AE) were performed by comparing post-operative CT scans of implanted screws with planned trajectories (Fig. 2). Statistical analyses compared PE and AE for OnPoint AR with the data for other systems using an unequal variance t-test method.

Fig. 1: OnPoint Alm-AR system.

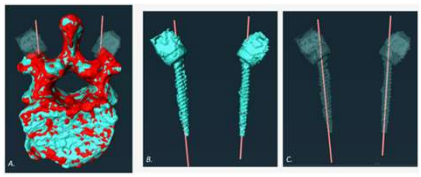

Fig. 2: OnPoint Alm-AR system: A. Registration of intra-operative spin (cyan) with post-operative CT (red). B.&C. Comparison of post-operative screw position (cyan) with intra-operatively planned trajectories (pink); screws are shown with greater transparency in C.

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Accuracy of an Augmented Reality Spine Surgery Guidance System with Stereoscopic Targeting Head Mounted Display Compared to Standard Computer Navigation, Robotic Systems, and Existing AR Systems

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1. Marcus Neuroscience Institute, Florida Atlantic University, Baptist Health, Boca Raton, FL; 2. Dept. of Neurosurgery, Weill Cornell-NewYork-Presbyterian Och Spine, New York, NY; 3. Department of Biostatistics and Data Science, Tulane University, New Orleans, LA; 4. Department of Radiology, Boston University Medical Center, Boston, MA;

Results

113 screws placed demonstrated Heary grade 1 accuracy. 6 screws had a larger diameter than the pedicle and were planned with in-out-in technique with Heary grade 2 accuracy. One screw demonstrated a 1mm lateral breach (grade 2) caused by a loose connection to the screwdriver.

PE and AE (mean ± 1SD) for OnPoint Alm-AR were the following: for intra-operative spin 1.1mm±0.5mm and 1.3°±0.5°; for pre-operative CT 1.9mm±1.2mm and 2.2°±1.3° (Figs. 3&4). Percent increment in PE and AE for Medtronic Stealth Station, Brainlab navigation, Stryker nav3i, Medtronic Mazor X robot, Globus Excelsius robot, Augmedics Xvision, and Novarad VisAR compared to OnPoint AR ranged between 40–80% (Fig. 5), with differences being highly significant for all comparisons (Fig. 5).

Conclusions

PE and AE for placing pedicle screws are statistically significantly smaller for the novel Alm-AR system compared to existing navigation, robotic, and AR systems. A positional error of 1.1mm and angular error of 1.3° makes this technology particularly suited for small pedicles, challenging anatomy and MIS techniques.

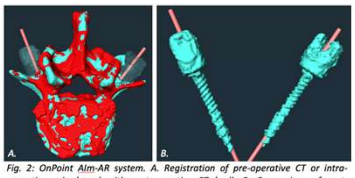

Fig. 2: OnPoint Alm-AR system. A. Registration of pre-operative CT or intra-operative spin (cyan) with post-operative CT (red). B. Comparison of post-operative screw position (cyan) with intra-operatively planned trajectories (pink).

Fig. 5: Percent increment in PE and AE and statistical significance for Medtronic Stealth Station, Brainlab navigation, Stryker nav3i, Medtronic Mazor X robot, Globus Excelsius robot, Augmedics Xvision, and Novarad VisAR compared to OnPoint AR.

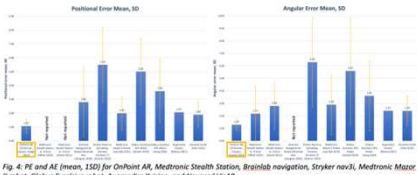

Fig. 4: PE and AE (mean, 1SD) for OnPoint AR, Medtronic Stealth Station, Brainlab navigation, Stryker nav3i, Medtronic Mazor X robot, Globus Excelsius robot, Augmedics Xvision, and Novarad VisAR.

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Augmented Reality Guidance

· Augmented Reality allows the Neurosurgeon to accurately superimpose 3D stereoscopic displays onto anatomic landmarks in real time.

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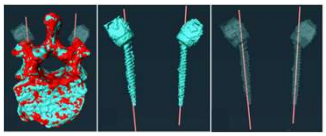
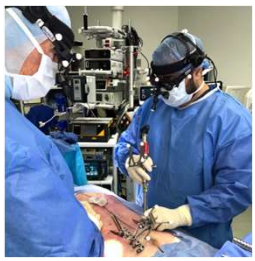
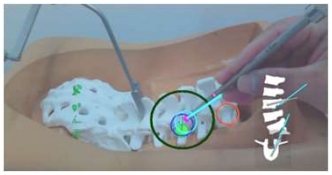
Augmented Reality Guidance

- Offers significantly greater accuracy and precision than other navigation systems
- Allows next generation minimally invasive procedures
- We'll be the first system in Florida to launch this technology







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Take Home Messages for Educational Objectives

- Emerging technologies including robotics, artificial intelligence, and augmented reality are going to revolutionize our treatment for complex spine procedures
- Artificial intelligence can be used for preoperative planning and customized patient implants
- Augmented reality guidance systems can be used to increase intraoperative accuracy, advance minimally invasive surgeries, and improve patient safety

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References:

- Authors: O'Connor, Timothy et al
- Stealth Technology: A Technical Note
- World Neurosurgery. 2021.1.1. Volume 145
- https://www.sciencedirect.com/science/article/abs/pii/S1878875020322026

- Authors: O'Connor Timothy et al
- Accuracy of an Augmented Reality Spine Guidance System with Stereoscopic Targeting Head Mounted Display Compared to Standard Computer Navigation, Robotic Systems, and Existing AR Systems
- Congress of Neurological Surgeons. Oral Presentation. Washington DC, 2023

- Authors: O'Connor Timothy et al
- **Augmented Reality Guidance System for Spine Surgery: Comparison of Screw Placement Accuracy using Preoperative CT vs Intraoperative 3D Spin**
- Congress of Neurological Surgeons. Poster Presentation. Washington DC, 2023

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- O'Connor, T., et al. (2021). Stealth Technology: A Technical Note. World Neurosurgery, 145(1), 1-1. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S1878875020322026
- O'Connor, T., et al. (2023). Accuracy of an Augmented Reality Spine Guidance System with Stereoscopic Targeting Head Mounted Display Compared to Standard Computer Navigation, Robotic Systems, and Existing AR Systems. Oral Presentation presented at the Congress of Neurological Surgeons, Washington DC.
- O'Connor, T., et al. (2023). Augmented Reality Guidance System for Spine Surgery: Comparison of Screw Placement Accuracy using Preoperative CT vs Intraoperative 3D Spin. Poster Presentation presented at the Congress of Neurological Surgeons, Washington DC.

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Thank You.

Baptist Health

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