Computer Navigation in ACL R
A Contemporary Review

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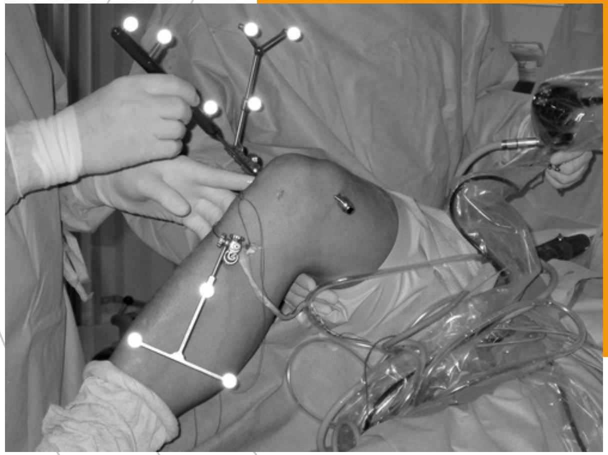



NON-DISCLOSURE
AGREEMENT
is entered into on this

Overview

Understanding CN technology in ACL reconstruction

Current applications in surgical practice

Clinical implications and outcomes

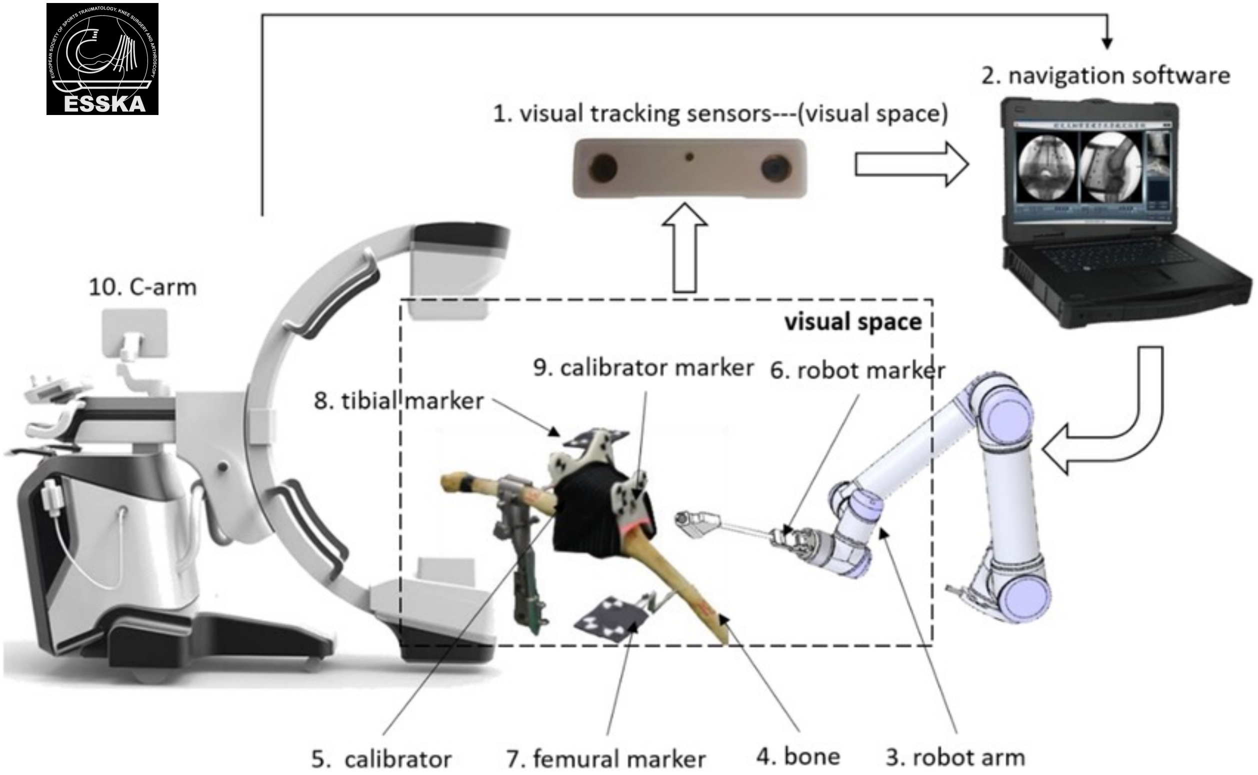
Future directions in the field

What is computer navigation (CN)?

Real-time surgical guidance system using tracking technology

Basic Principles:

- 3D spatial tracking
- Real-time feedback
- Computer-assisted decision making



1. visual tracking sensors---(visual space)
2. navigation software
10. C-arm
visual space
9. calibrator marker
6. robot marker
8. tibial marker
5. calibrator
7. femural marker
4. bone
3. robot arm

The Setup

Study trends for CN ACL surgery up to 2015

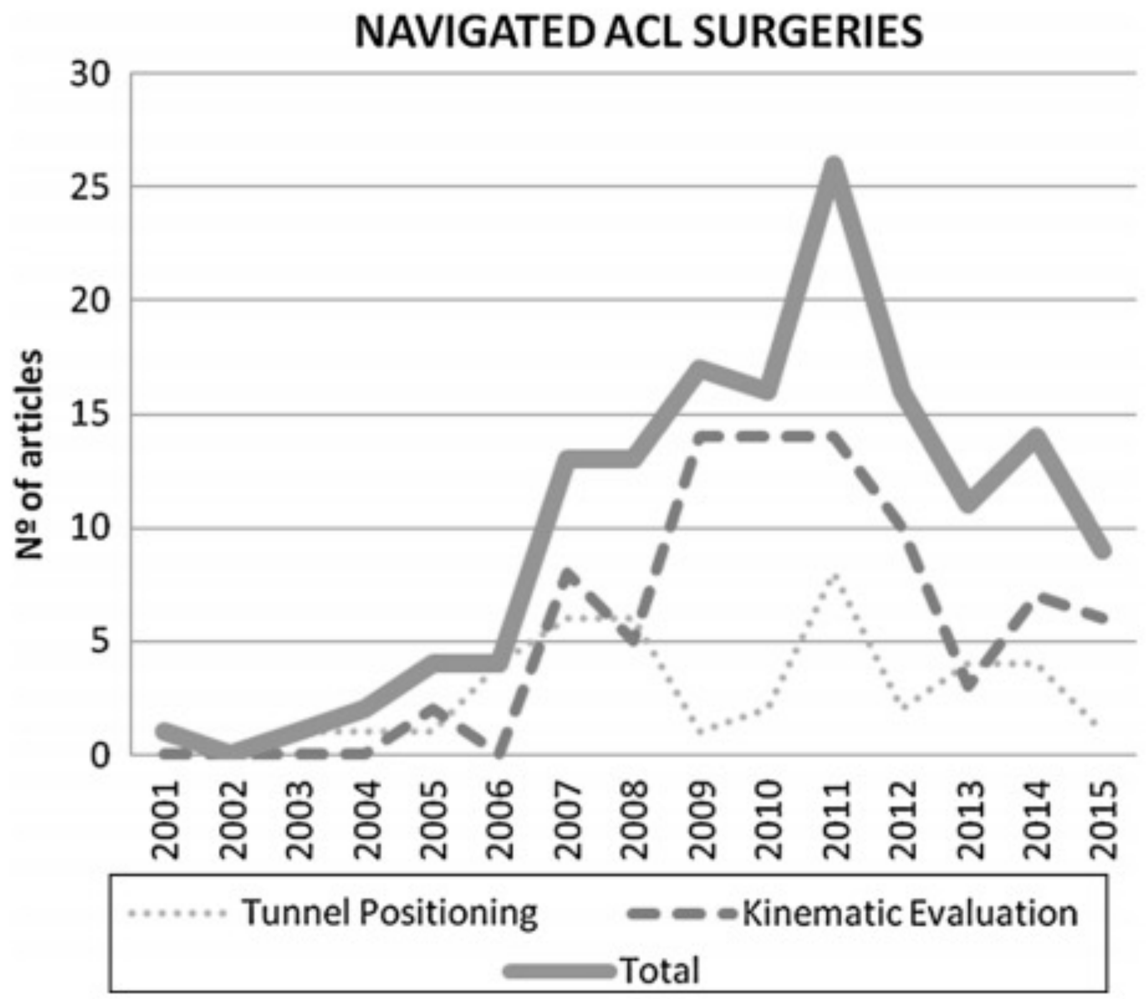


Fig. 2 Trend of publication concerning navigated ACL surgery (*thick line*). During the early years navigation systems were mainly used to improve tunnel positioning (*dotted line*) from 2007 they have been mainly used for kinematics evaluation (*dashed line*)

ESSKA

Studies that have used navigation system for kinematic evaluation in ACL surgery

First author	Year	Set-up	Number of Knees	Evaluated parameters	Analysed structures/technique
Voos et al.	2010	Vitro	12	ATT/IE rot	High versus low femoral tunnel
Bedi et al.	2010	Vitro	N/A	ATT/PST	PST and lateral tibial translation
Bedi et al.	2010	Vitro	20	ATT/PST	ASB versus ADB
Monaco et al.	2010	Vitro	6	ATT/IE rot	ACL and two restraints PLB AMB ALL
Park et al.	2010	Vivo	70	ATT/IE rot	High versus low femoral tunnel
Yamamoto et al.	2010	Vivo	150	ATT/IE rot/PST	Clinical grading versus Kinematic values
Nakamae et al.	2010	Vivo	30	ATT/IE rot	ACL remnants
Musahl et al.	2010	Vitro	12	ATT	Two SB techniques and DB techniques
Miura et al.	2010	Vivo	10	ATT/IE rot	AMB and PLB versus contralateral intact knee
Seon et al.	2009	Vivo	40	ATT/IE rot	ASB versus ADB
Pearl et al.	2009	N/A	N/A	ATT/PST	PST in ACL-deficient knee
Lopomo et al.	2009	Vivo	60	ATT	CAS reliability
Monaco et al.	2009	Vivo	30	ATT	Validation KT 1000
Kanaya et al.	2009	Vivo	26	ATT/IE rot	Oblique ASB versus ADB
Brophy et al.	2009	Vitro	5	ATT/IE rot	Oblique versus central SB
Song et al.	2009	Vivo	85	ATT/IE rot	Stable versus unstable ACL knee
Musahl et al.	2009	Vitro	12	ATT/IE rot	Mechanized pivot-shift
HO et al.	2009	Vitro	16	ATT/IE rot	ASB versus ADB
Song et al.	2009	Vivo	40	ATT/IE rot	ASB versus ADB
Ferreti et al.	2009	Vivo	10	ATT/IE rot	ADB (PL and AM bundle)
Ishibashi et al.	2009	Vivo	90	PST	PST and DB
Steiner et al.	2009	Vitro	20	ATT/IE rot	Independent versus trans-tibial tunnel
Jenny et al.	2009	Vitro	N/A	ATT	CAS versus STRESS RX
Zaffagnini et al.	2008	Vitro	6	ATT/IE rot	Effect of tunnel position
Lane et al.	2008	Vivo	12	ATT/IE rot/ACC/p angle	In vivo analysis of PST
Ishibashi et al.	2008	N/A	N/A	N/A	SB versus DB
Brophy et al.	2008	Vitro	5	ATT/IE rot	Intact ACL versus SB reconstruction
Ishibashi et al.	2008	Vivo	80	N/A	ASB versus ADB
Martelli et al.	2007	Vivo	80	ATT/IE rot/VV	CAS for kinematic assessment
Robinson et al.	2007	Vivo	21	ATT/PST	PL and AM bundles
Steckel et al.	2007	Vitro	5	ATT/IE rot	Intact ACL versus SB/DB reconstruction
Ferreti et al.	2007	Vivo	20	ATT/IE rot	SB versus DB
Monaco et al.	2007	Vivo	20	ATT/IE rot	ACL + LT versus ADB
Martelli et al.	2007	Vivo	79	ATT/IE rot/VV	CAS for kinematic assessment
Kendoff et al.	2007	Vitro	N/A	ATT/IE rot	CAS versus KT1000 and goniometer
Colombet et al.	2007	Vitro	4	ATT/IE rot	Unstable, AMB and PLB
Martelli et al.	2005	Vitro	3	ATT/IE rot/VV	New protocol for kinematic assessment
Ishibashi et al.	2005	Vivo	32	ATT/IE rot	ADB (PLB and AMB)

Studies that have used navigation system for kinematic evaluation in ACL surgery

First author	Year	Set-up	Number of Knees	Evaluated parameters	Analysed structures/technique
Saiegh et al.	2015	Vitro	14	ATT/PST/IE rot	All
Sena et al.	2015	Vitro	6	ATT/PST/IE rot	Mechanized pivot-shift
Bonanzinga et al.	2015	Vitro	7	ATT/IE rot	PLC
Imbert et al.	2015	Vivo	32	ATT/PST/IE rot/VV	ACL + LT
Christino et al.	2015	Vivo	30	ATT/IE rot	ACL paediatric
Usman et al.	2015	Vivo	14	ATT/IE rot	OTT versus SB
Feng et al.	2014	Vitro	7	IE rot	PLC/PMC/ACL & PCL
Porte et al.	2014	Vivo	20	ATT/PST/IE rot	ASB and contralateral intact knee
Kopf et al.	2014	Vivo	15	ATT/PST/IE rot/VV	DB/PLB
Imbert et al.	2014	Vivo	32	ATT/PST/IE rot/VV	ACL-deficient and intact knees
Monaco et al.	2014	Vivo	20	ATT/PST/IE rot	ACL + LT
Zaffagnini et al.	2014	Vivo	26	ATT/PST/IE rot	ADB versus NADB
Lopomo et al.	2014	Vivo	40	ATT/ACC	Pre-op and post-op status
Komzák et al.	2013	Vitro	30	ATT/IE rot	PLB and AMB
Signorelli et al.	2013	Vivo	100	ATT/PST/IE rot/VV	Pre-op and post-op status
Sena et Al	2013	Vitro	6	ATT/IE rot vel.	ITB versus TT versus AE
Verhelt et al.	2012	N/A	N/A	ATT/IE rot	SB versus DB
Lim et al.	2012	Vitro	7	ATT/IE rot	ASB versus NASB
Nakase et al.	2012	Vivo	50	ATT/IE rot	ACL remnants
Komzák et al.	2012	Vivo	60	ATT/IE rot	ASB and ADB (PL and AM)
Ettinger et al.	2012	Vitro	10	ATT/IE rot	DB
Dawson et al.	2012	Vitro	26	ATT	Pivot versus Lachman test
Lee et al.	2012	Vivo	42	ATT/IE rot	Kin evaluation of tunnel placement
Van der Brachtet al.	2012	Vitro	5	ATT/IE rot	Lateral tibial tunnel in Rev. ACL
Lee et al.	2012	Vivo	42	ATT/IE rot	ASB versus ADB
Ohkawa et al.	2012	Vivo	125	ATT/IE rot	CAS and clinical outcomes
Voos et al.	2011	Vitro	11	ATT/PST	Effect of Tibial Slope
Koga et al.	2011	Vitro	11	ATT/IE rot	Effect of graft angles fixation
Citak et al.	2011	Vitro	6	ATT/IE rot	Valgus force in the PST
Cross et al.	2011	Vitro	12	ATT/PST	AM SB versus CTR SB
Plaweski et al.	2011	Vivo	46	ATT/IE rot/PST	ASB versus ADB
Monaco et al.	2011	Vitro	10	ATT/IE rot	ACL + LT
Maeda et al.	2011	Vivo	83	ATT/IE rot	ACL remnants
Zaffagnini et al.	2011	Vivo	35	ATT/PST/IE rot/VV	ACL + LT versus ADB
Petrigliano et al.	2011	Vitro	10	PST	ACL and menisectomy
Seon et al.	2011	Vivo	62	ATT/IE rot	High versus low femoral tunnel
Musahl et al.	2011	Vitro	5	ATT/PST	ASB versus ADB with meniscal lesion
Plaweski et al.	2011	Vivo	63	ATT/IE rot/PST	ASB versus ADB
Colombet et al.	2011	Vivo	20	ATT/IE rot/PST	ACL + LT
Bedi et al.	2011	Vitro	20	ATT/PST	Effect of tunnel position
Plaweski et al.	2011	Vivo	63	ATT/IE rot/PST	ASB versus ADB
Colombet et al.	2011	Vivo	20	ATT/IE rot/PST	ACL + LT
Bignozzi et al.	2010	Vivo	18	ATT/PST	ADB
Lopomo et al.	2010	Vivo	18	ATT/PST	PST decomposition
Hofbauer et al.	2010	Vivo	55	ATT/IE rot	ASB versus ADB
Musahl et al.	2010	Vitro	16	ATT/PST	ACL and menisectomy
Lombach et al.	2010	Vitro	20	IE rot	PL and AM bundles

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Navigation system types

(a) (b)

1. **Optical tracking systems**. This system uses infrared cameras and transmitters with reflective markers attached to the femur and tibia to register the precise location of the instruments in three-dimensional (3D) space.
   - Infrared camera technology
   - Reflective marker tracking

2. **Image-based systems.** Require anatomical reference data obtained from **preop CT/MRI** or **intraoperative fluoroscopy** imaging. **Image-free** systems require no preoperative data, as they are able to acquire anatomical landmark and knee kinematics information

Key Applications

- Tunnel Positioning
- Kinematic Evaluation

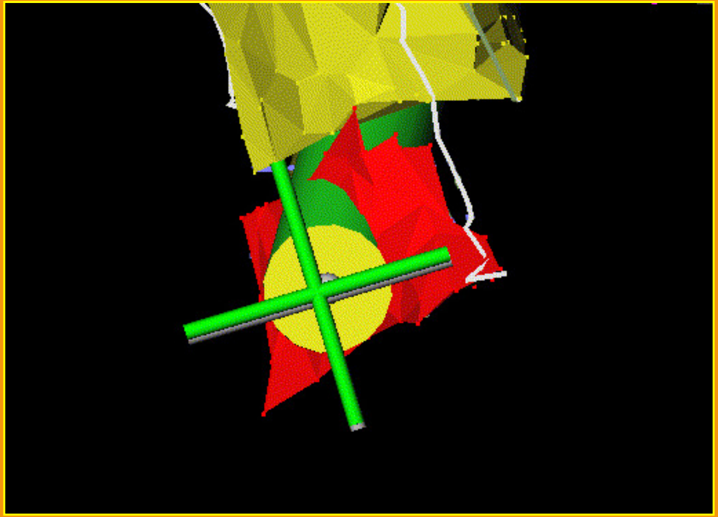
Anatomical Accuracy:

- Precise tunnel placement within **1mm**
- 3D visualization of optimal positions
- Real-time angle verification

Clinical Benefits:

- 82% improvement in tunnel placement accuracy
- Reduced risk of tunnel misplacement
- Better outcomes in complex cases

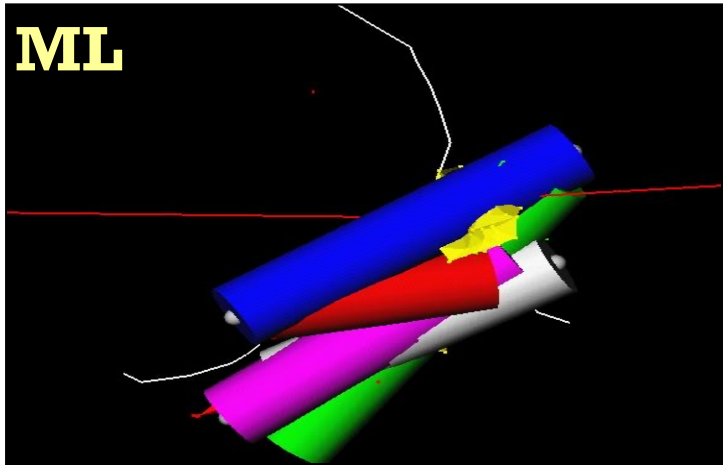
Tunnel Positioning

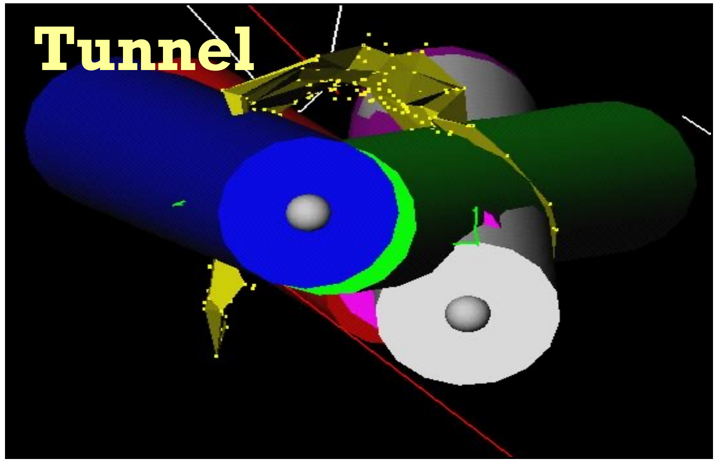


Tunnel Positioning

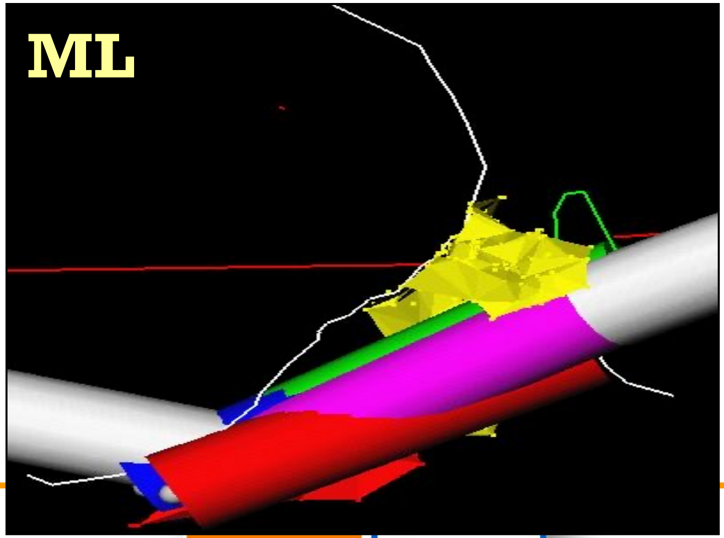
Sati et al., *Operat Tech Orthop 2000*

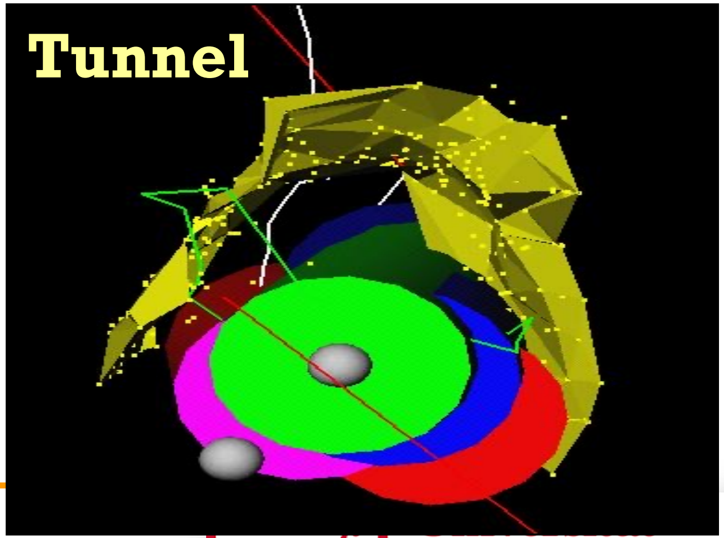
<u>**Without CN**</u>
6 surgeons
great variation





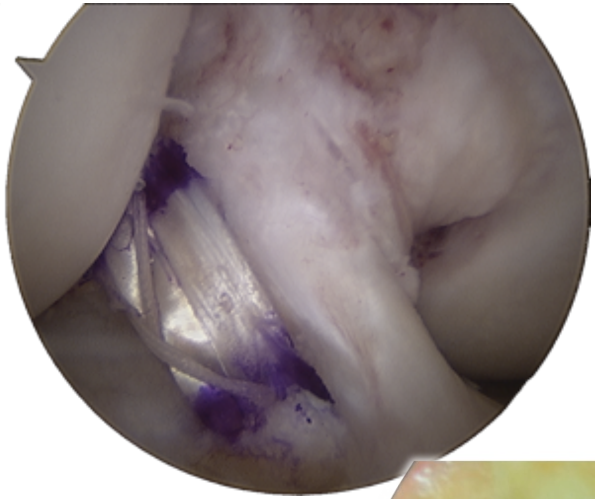
<u>**With CN**</u>
same surgeons
less variation





Clinical applications

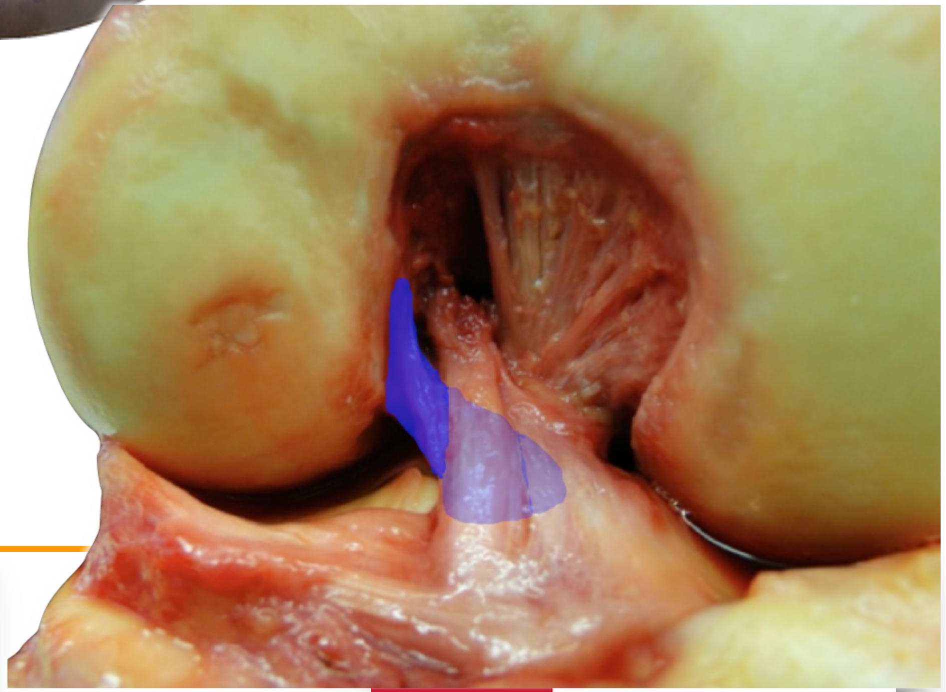
Tunnel Positioning



<u>Selective ACL R</u>

Preserving remnants ➔ challenging situation

- Femoral side
- Graft inside the footprint
- Dimensions of the graft / notch



Tunnel Positioning

Revision ACL R

Finding the right spot ➔ challenging situation

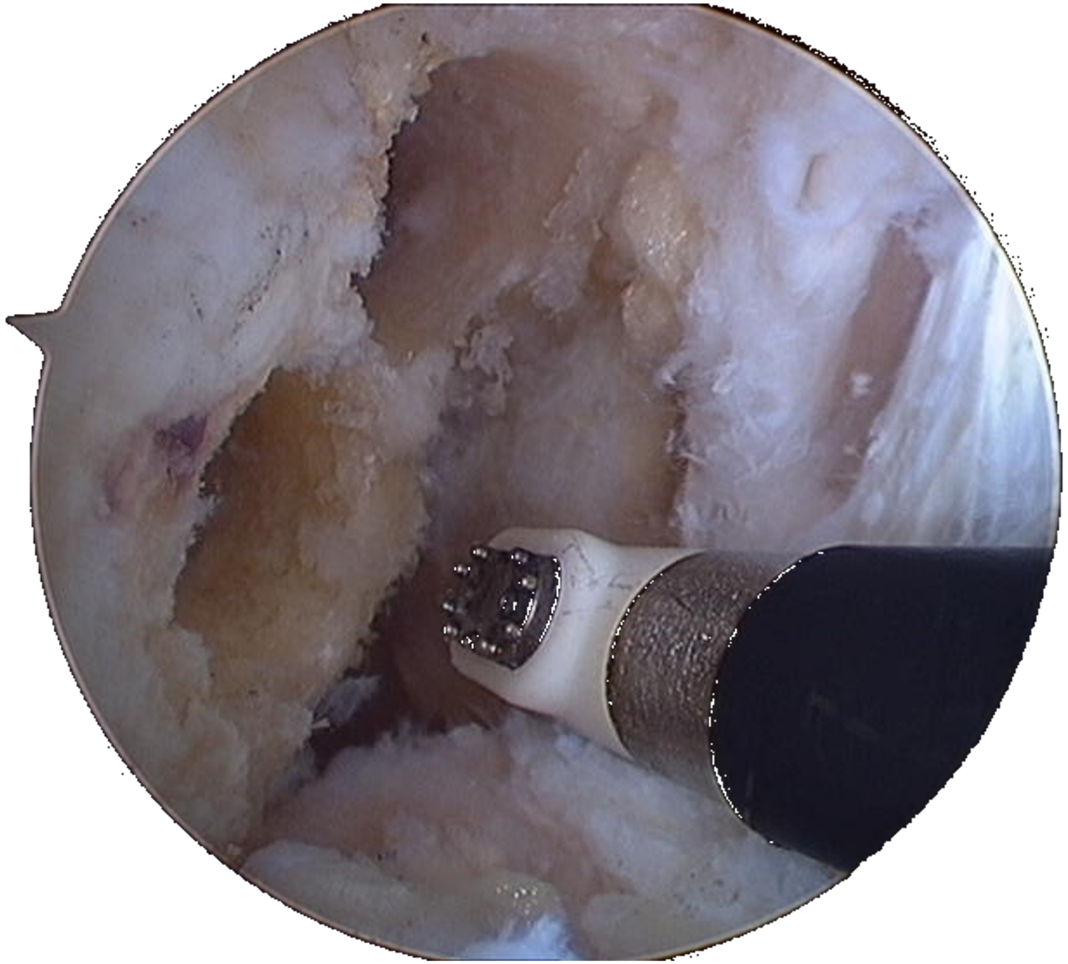
- Bone defects
- Primary tunnel malposition

Tunnel Positioning

Double bundle ACL R

Finding the right spot ➔ challenging situation

- Accuracy when drilling two tunnels is key



Intraoperative Assessment

- Real-time laxity measurement
- Multi-planar stability testing
- Quantitative data collection

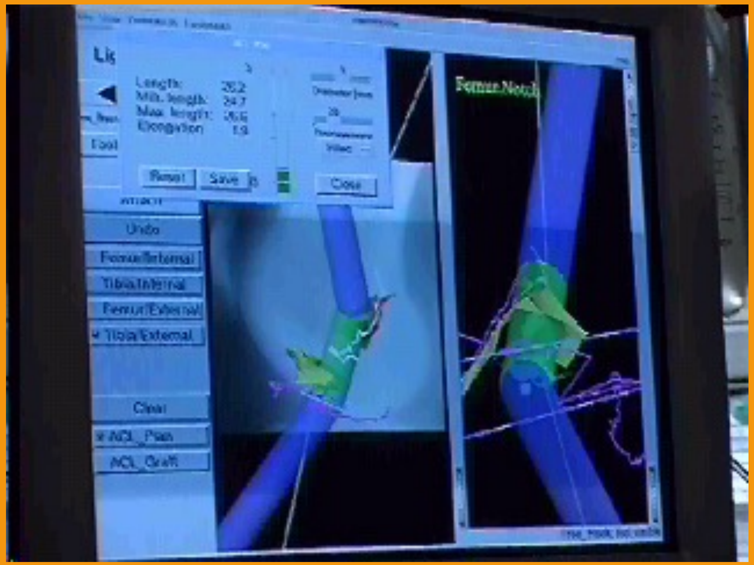
Measurement Capabilities

- Anterior-posterior translation
- Rotational stability
- Varus-valgus alignment

Clinical Applications in the scientific field

- Surgical technique comparison
- Immediate outcome verification
- Research protocol standardization

Kinematic Evaluation



Clinical applications

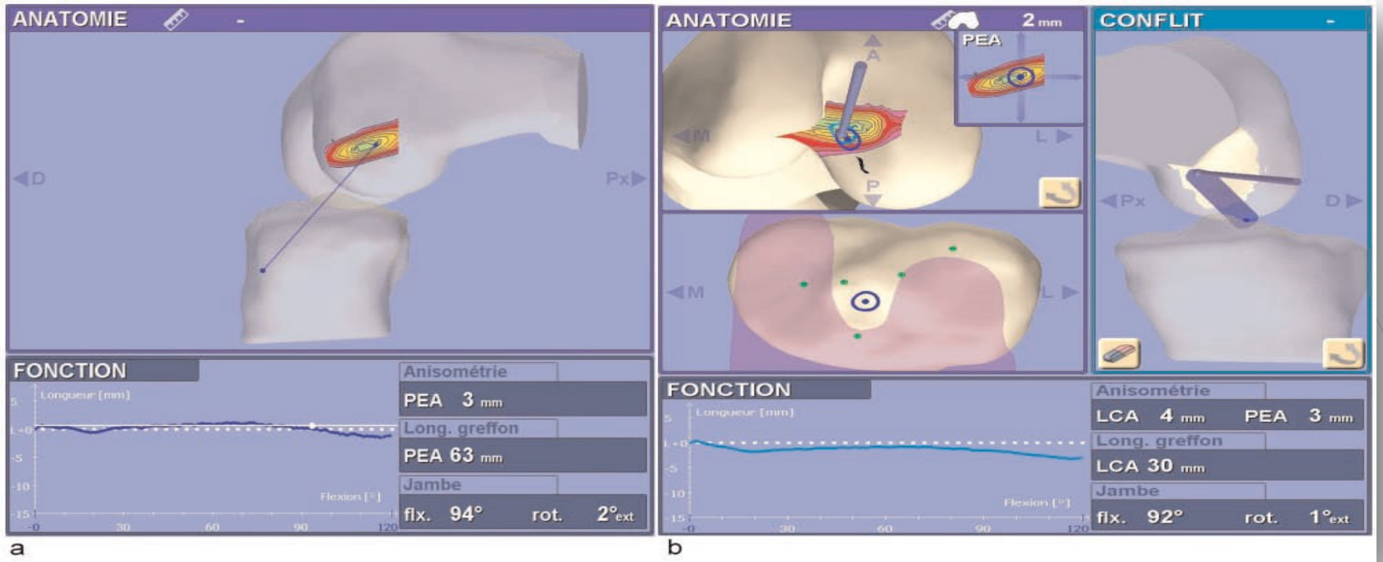
Surgical Technique Comparison

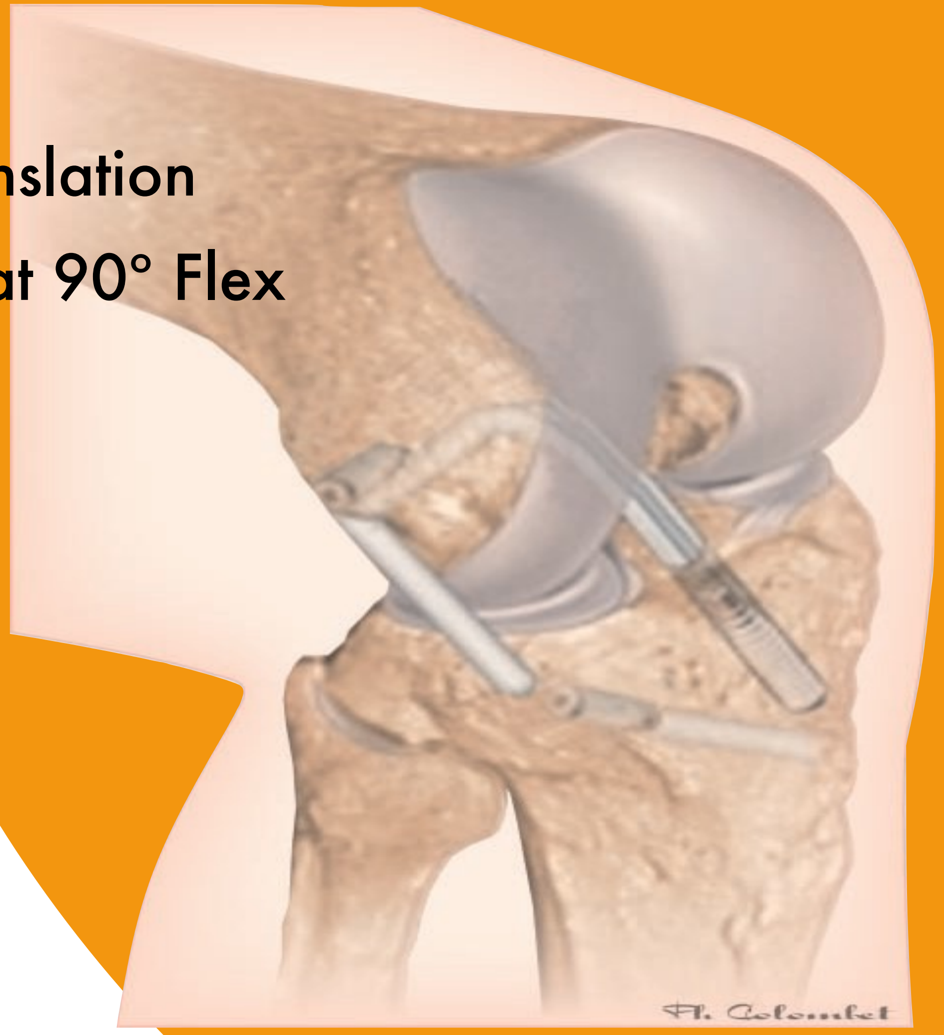
ACL R +/- LET

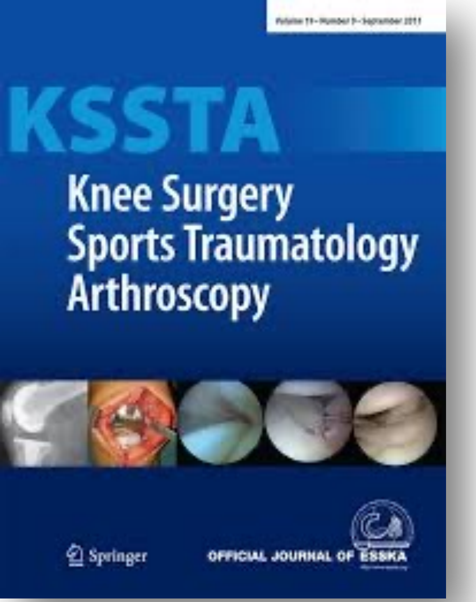
Colombet P et al. Knee laxity control in ACL Rev...
AJSM 2011;39:1248-54

- ✓ 20 failures of ACL R
- ✓ Navigated Hamstring ACLR Revision
- ✓ Addition or not of LET

- Similar anterior tibial translation
- < internal tibial rotation at 90° Flex







Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-016-4356-y

KNEE

Current use of navigation system in ACL surgery: a historical review

S. Zaffagnini[1,2,3,4] · F. Urrizola[5] · C. Signorelli[1] · A. Grassi[1,3,4] · T. Roberti Di Sarsina[1,3] · G. A. Lucidi[1] · G. M. Marcheggiani Muccioli[1,2,3,4] · T. Bonanzinga[1,2,3] · M. Marcacci[1,2,3]

"Currently, NS are considered the **gold standard for laxity quantification & validation** of new non-invasive devices for clinical practice."

"Also useful for the **measurement of knee laxity and kinematics** of pre- and post-operative surgery, thus allowing a precise comparison of different techniques."

Limitations

- **Increased expense** of ACLR
- **Additional surgical time**

→ NOT MITIGATED BY BETTER CLINICAL OUTCOMES

**These factors have limited the use of navigation systems to research-related cases*

State of the Art Review

Navigation in anterior cruciate ligament reconstruction: State of the art

Francisco Figueroa [a,b,*], David Figueroa [a], Rodrigo Guiloff [a,b], Sven Putnis [c], Brett Fritsch [d], Minerva Itriago [a]

[a] Clinica Alemana-Universidad del Desarrollo, Av Vitacura 5951, Vitacura, Santiago, 7650568, Chile
[b] Hospital Sotero del Rio, Avenida Concha y Toro 3459, Puente Alto, Santiago, 8207257, Chile
[c] Southmead Hospital, Southmead Rd, Bristol, BS10 5NB, UK
[d] Sydney Orthopaedic Research Institute, The Gallery, Level 1/445 Victoria Ave, Chatswood, NSW, 2067, Australia

Hardware Challenges

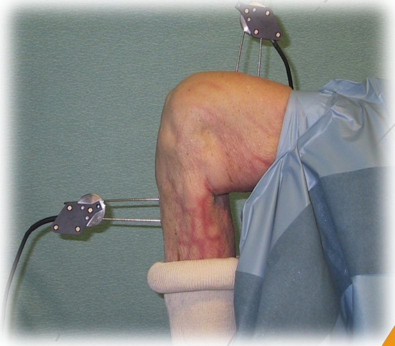
- Additional incision requirements
- Reference frame placement
- Line-of-sight issues

Radiation Considerations

- Exposure levels in image-based systems
- Protection protocols

Technical Complexity

- Multiple step verification
- System calibration requirements
- Potential error sources



Technical Limitations

Practical Limitations

Time and Efficiency

- Setup time: **15-20 minutes** additional
- **Learning curve**: 20-30 cases

Cost Analysis

- Initial investment: **USD 100,000-150,000**
- **Per-case costs**
- **Maintenance** requirements

Clinical Evidence

- Current research findings
- Outcome comparisons
- **Cost-benefit analysis**

Rehabilitation Applications

- Objective progress tracking
- Customized protocol development
- Patient-specific modifications

Return-to-Sports Assessment

- Quantitative benchmarks
- Risk assessment tools
- Performance metrics

Prevention Strategies

- Movement pattern analysis
- Risk factor identification
- Predictive modeling

Clinical Future Perspectives

Technological Future Perspectives

Emerging Technologies

- Artificial Intelligence integration
- Machine learning algorithms
- Augmented reality applications

System Improvements

- Miniaturization of hardware
- Wireless technology integration
- Enhanced user interfaces

Integration Possibilities

- EMR connectivity
- Remote monitoring capabilities
- Patient engagement tools

Current Status:

Proven benefits in accuracy

Remaining challenges

Cost-effectiveness considerations

Future Outlook:

Technology trends

Clinical application expansion

Research directions

Key Takeaways:

Role in modern ACL surgery

Best practice recommendations

Implementation strategies

Conclusion

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