Variable Sound-Fields of Electro-Hydraulic Extracorporeal Shockwave Applicators

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Disclosures & Acknowledgements

- There are no financial conflicts of interest to report
- Collaborators:
  - Paul Slezak
  - Julia Böhm
  - Kyle Hutchings
  - David Hercher
  - Roland Rose
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  - TRT Tissue Regeneration Technologies
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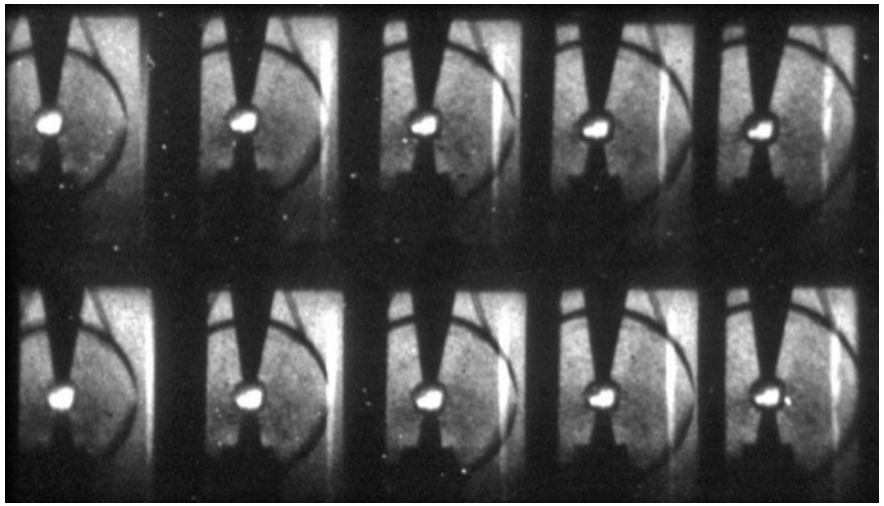
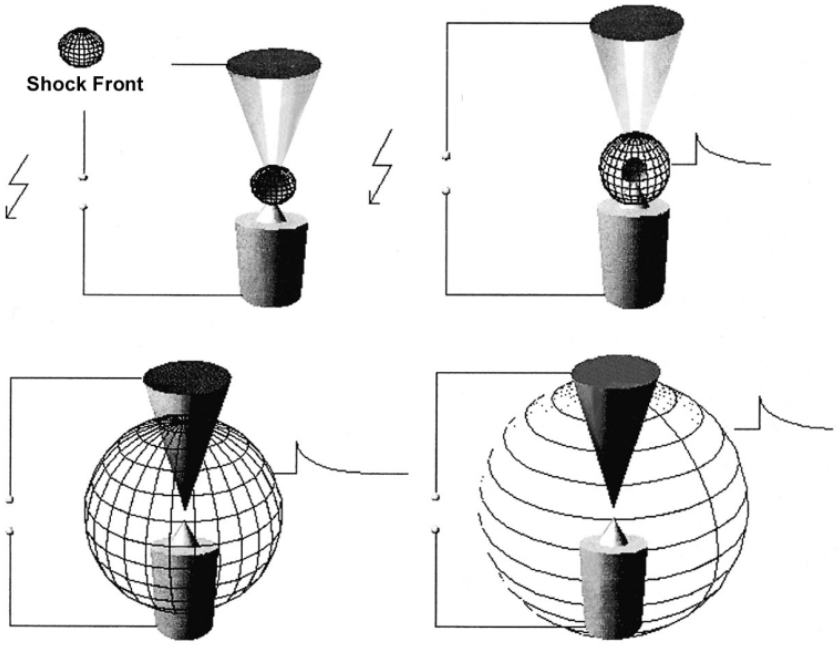
  - Austrian Cluster for Tissue Regeneration
  - THE UNIVERSITY OF UTAH CHPC

Therapy Measurements

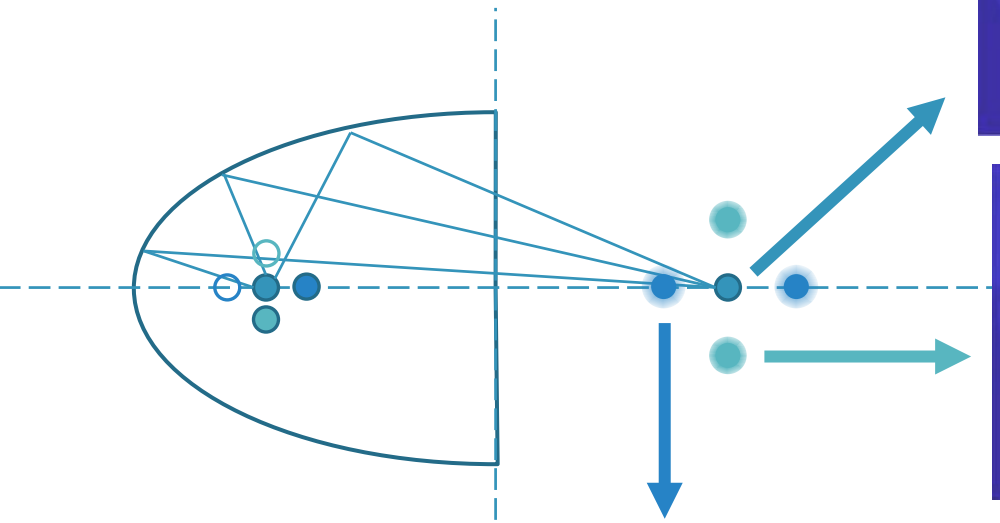
Electro-Hydraulic Sock-Wave Generation

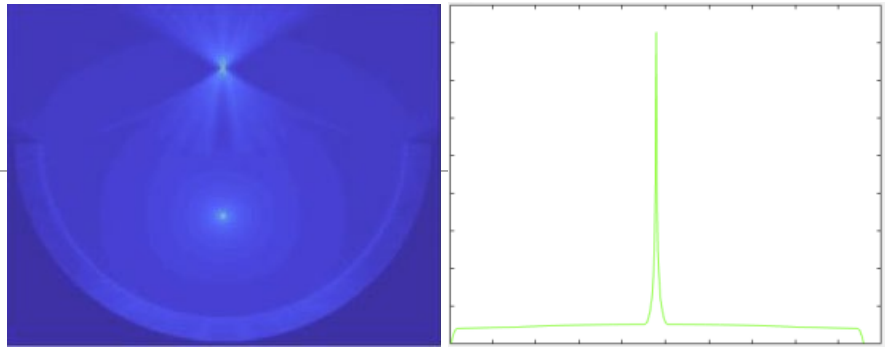


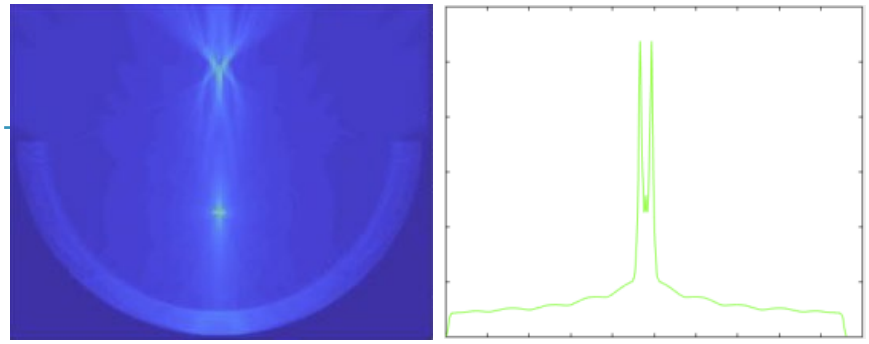


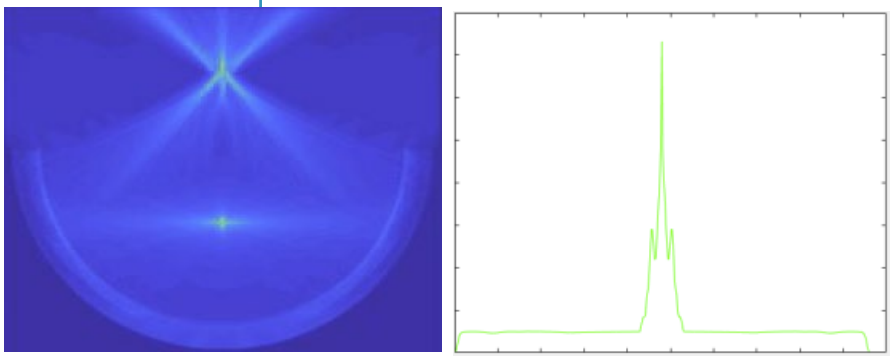
O. Wess. Physikalische Grundlagen der extrakorporalen Stoßwellentherapie. Journal für Mineralstoffwechsel 11(4):7–18, 2004

Source Variability



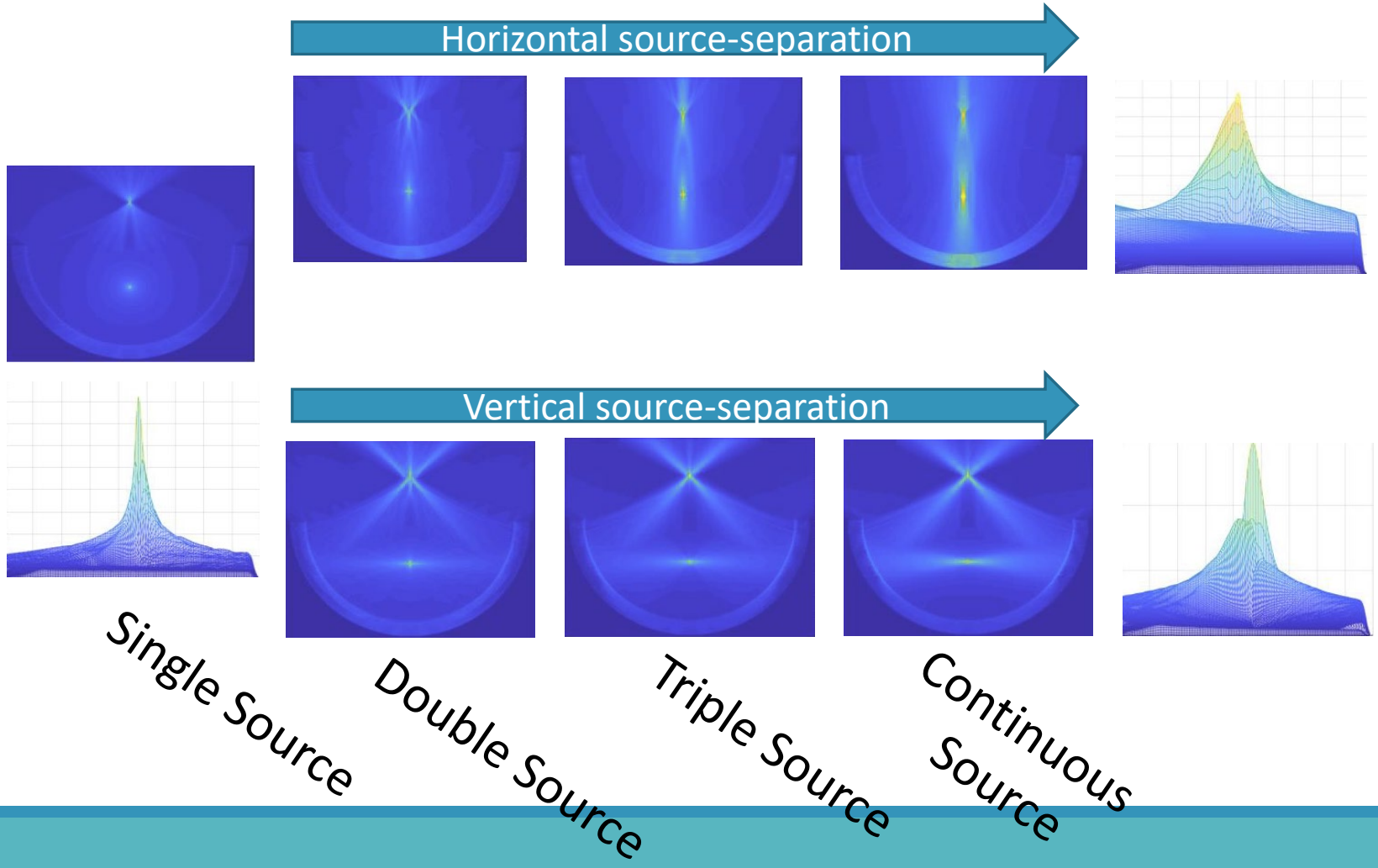




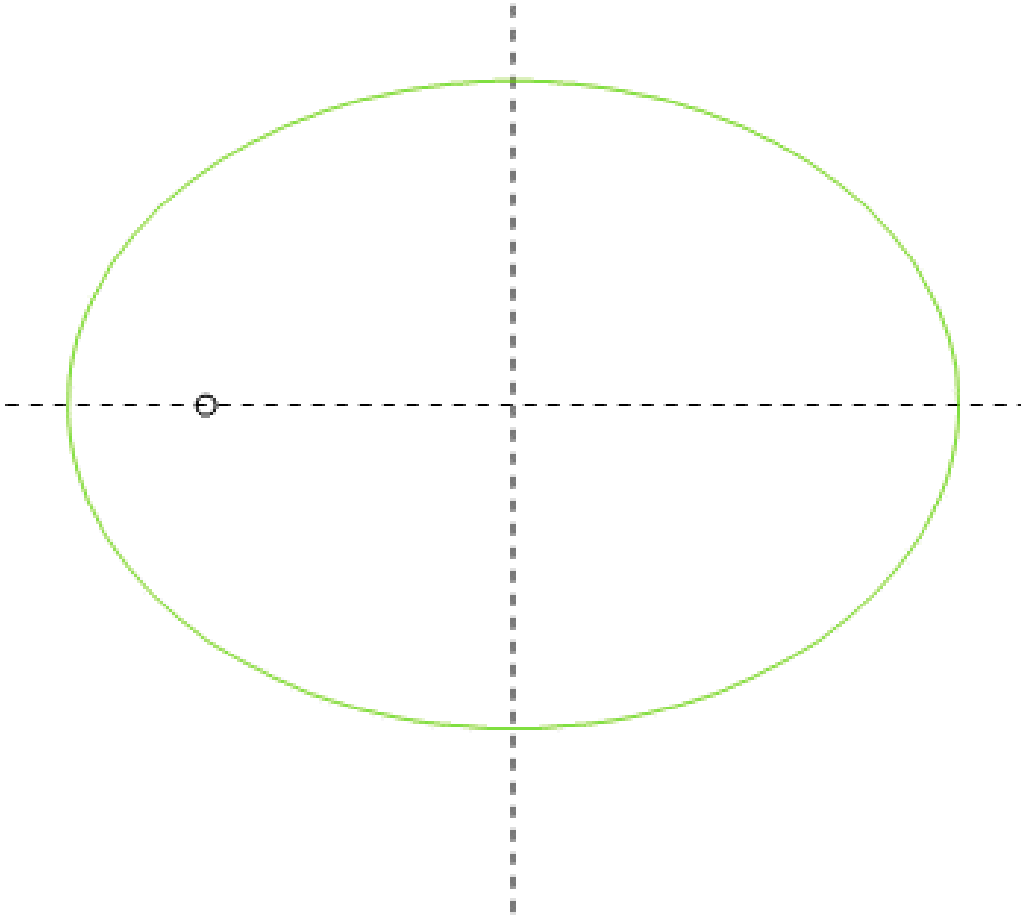


Beyond Point-Source

Continuous-Spark Discharge

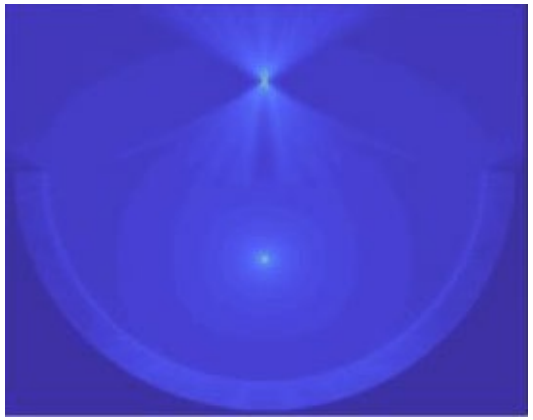
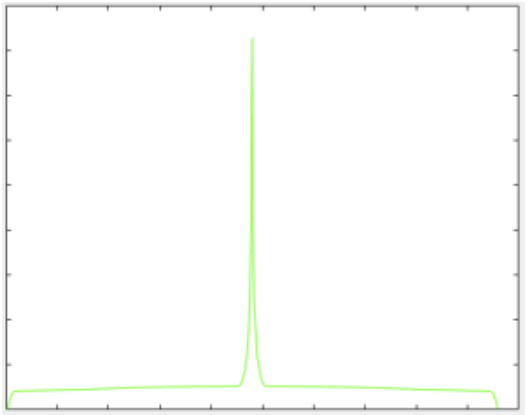
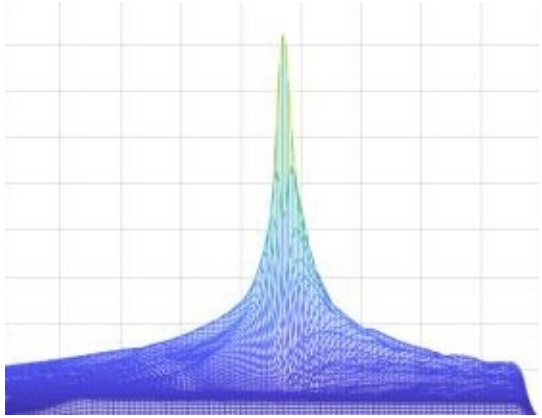
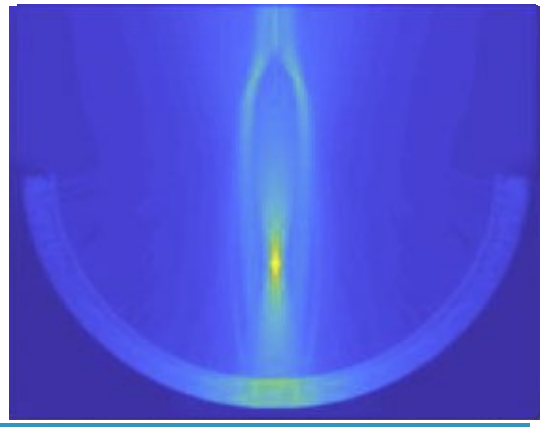
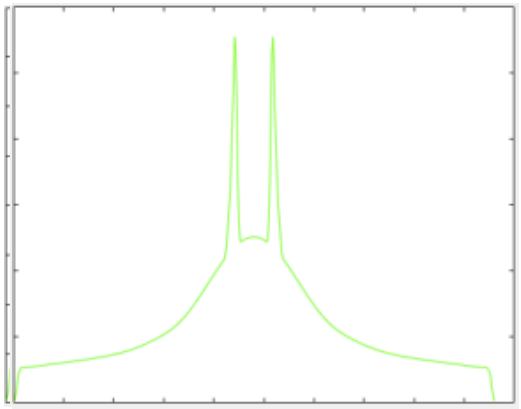
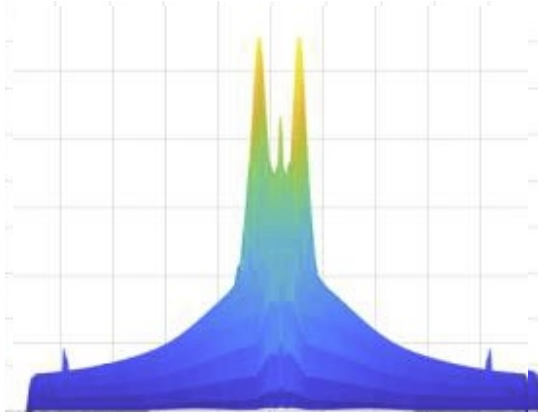


Reflector Geometry



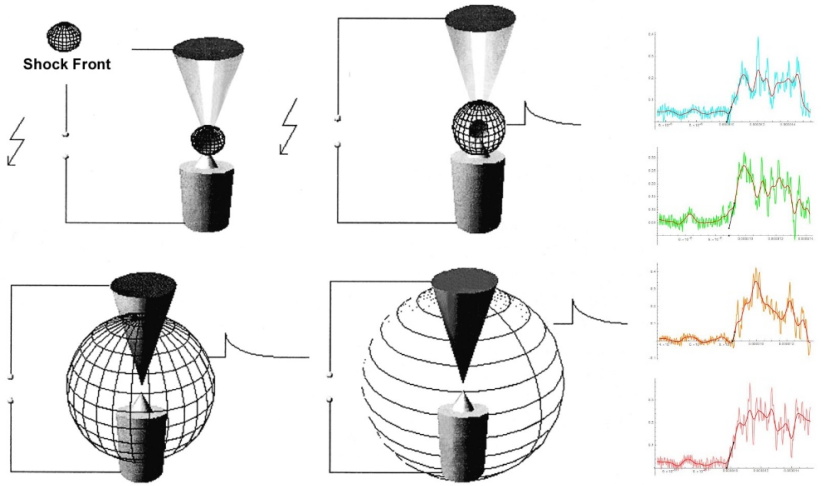
HEART REGENERATION TECHNOLOGIES

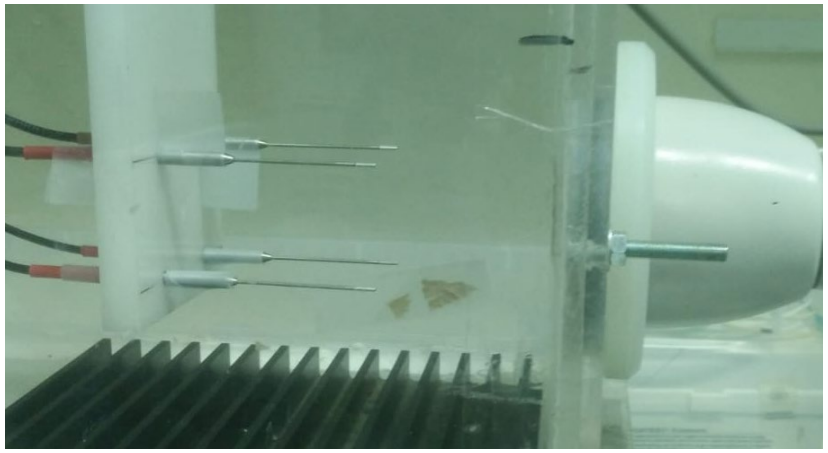
Image-Location & Acoustical Focus Stability

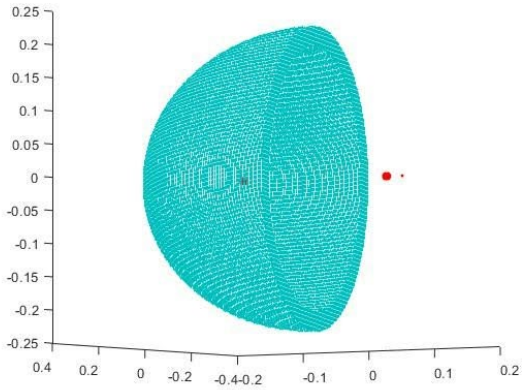







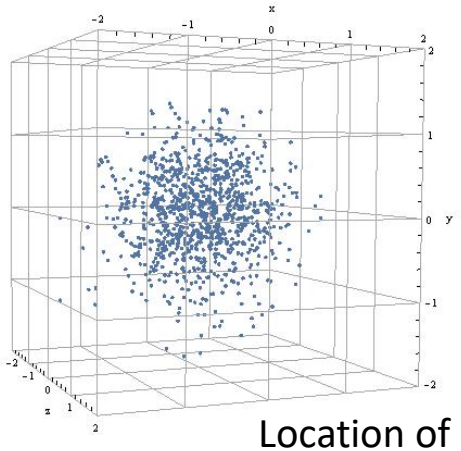
Continuous Source

Time-Difference of Arrival



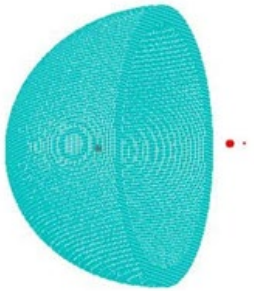


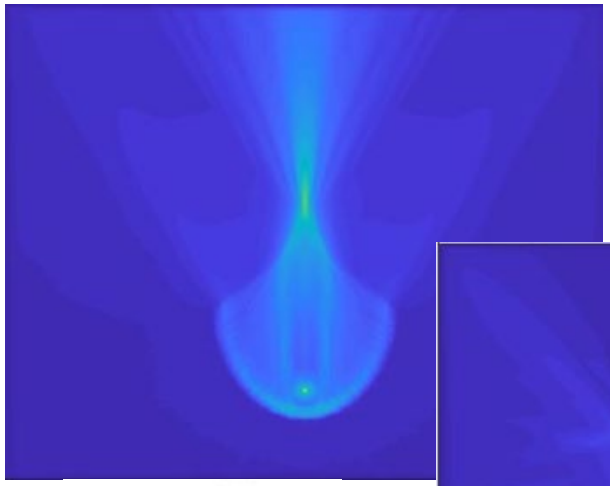




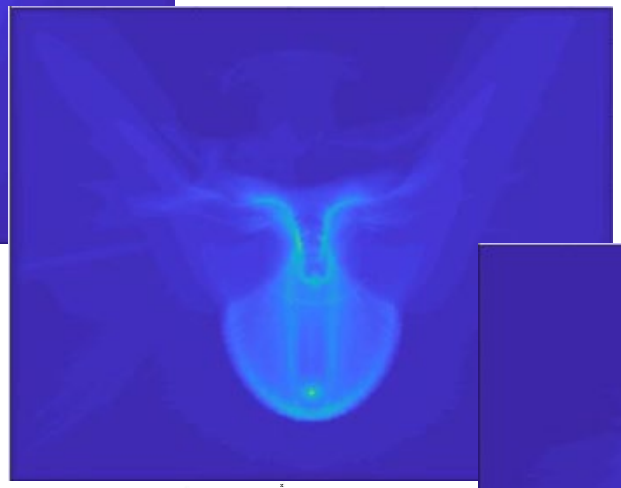
Location of highest intensity

A Pathway to In-Silico Therapy

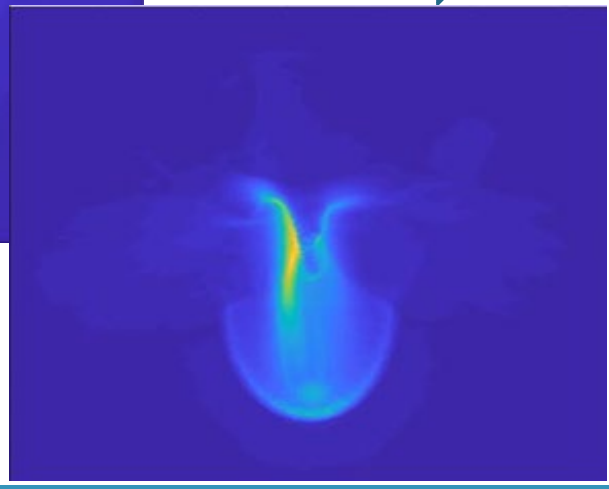




Sound Field



Therapy Field



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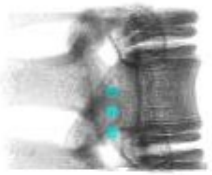
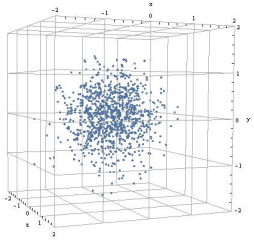
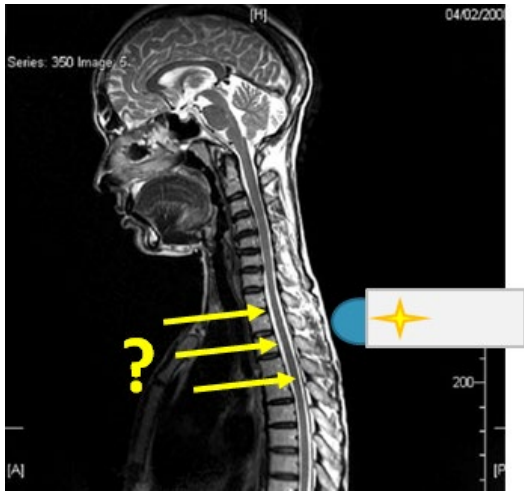


Experimental Applicator Data

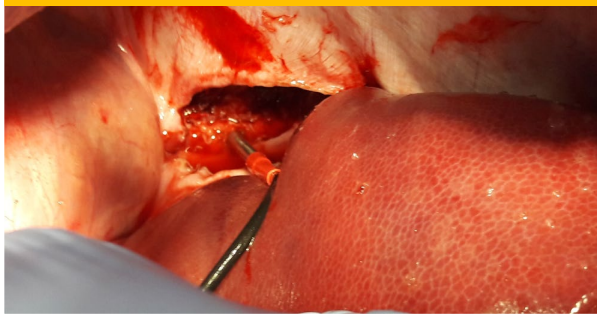


Nerve Regeneration & Spinal Cord Trauma

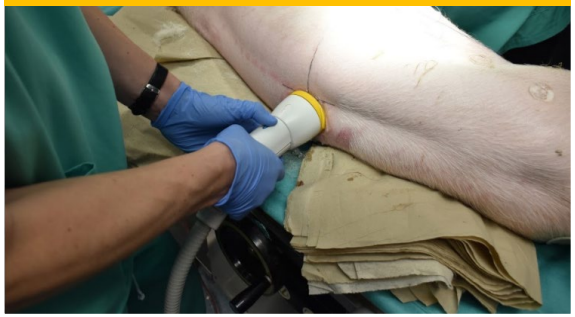


Holfeld et.al.

Place hydrophone in spinal cord

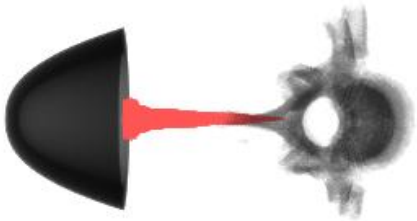
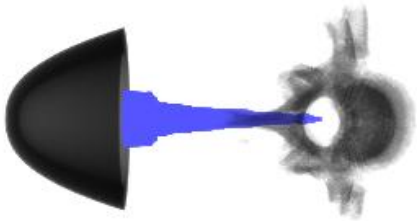
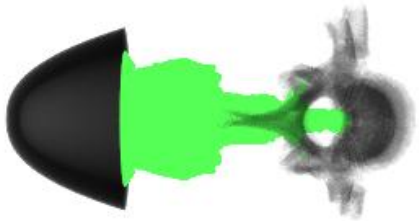
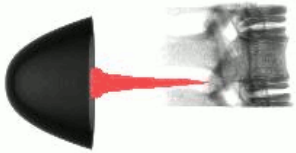
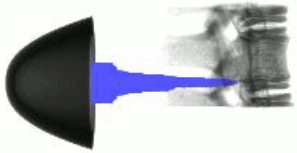
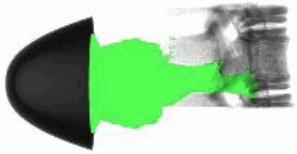


In-situ energy measurement

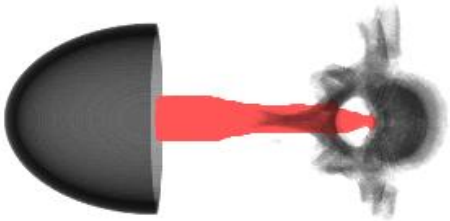
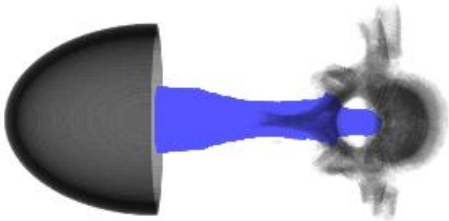
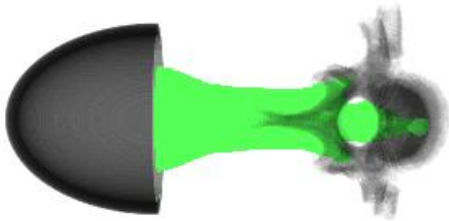
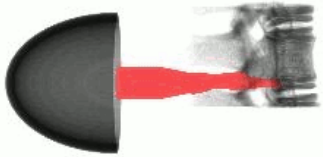
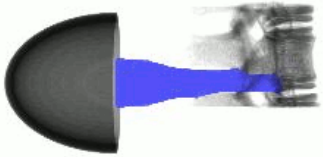
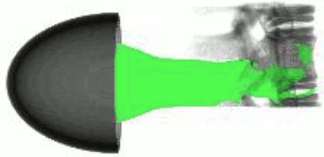


Therapeutic-application evaluation

Defocused Reflector

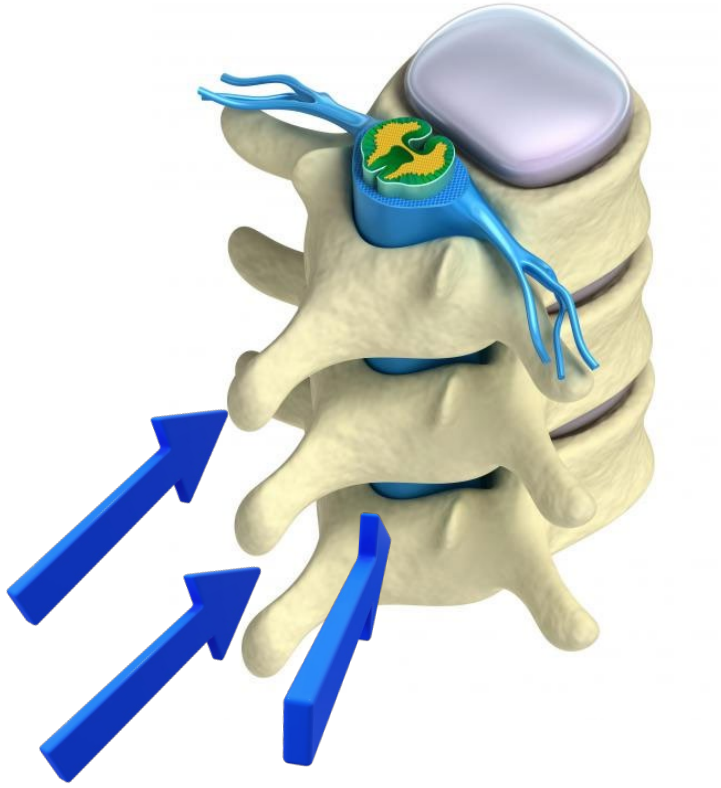
	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

Focused Reflector

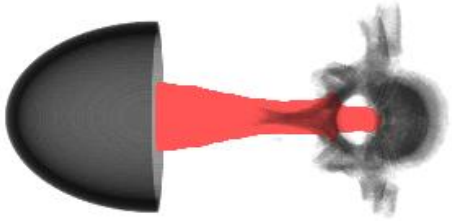
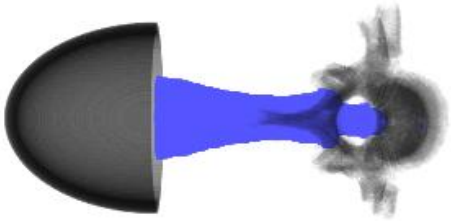
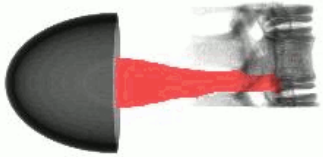
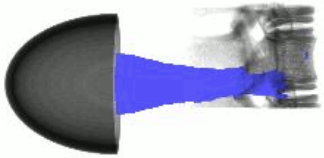
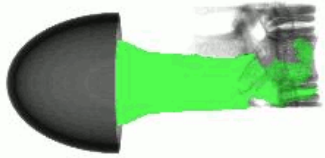
	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

Acoustic Windows & Anatomical Entry

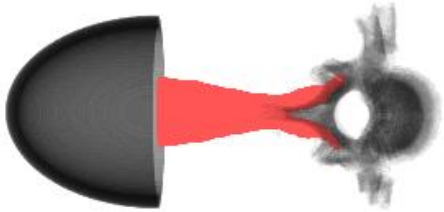
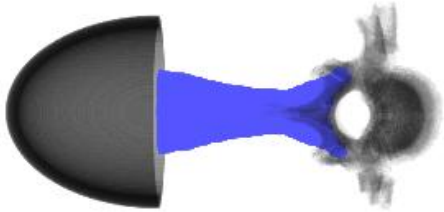
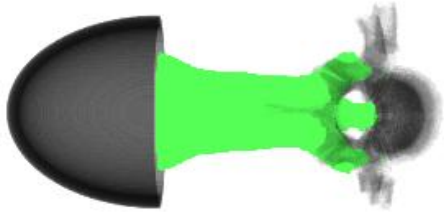
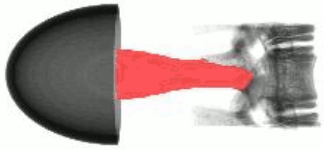
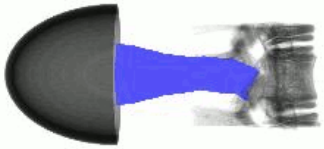
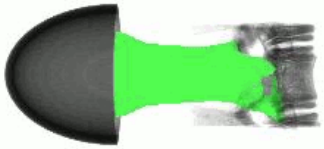
- Focusing Reflector (elliptical)
- Continuous Source (spark)
- Entry Angle
  - Between Spinous Processes
  - Through Spinous Processes
  - Lateral to Spinous Processes
  - Laminectomy
- Spark Variability



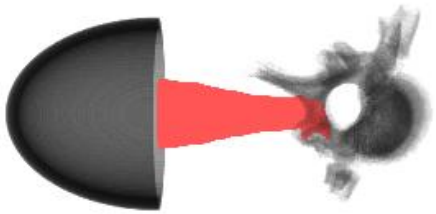
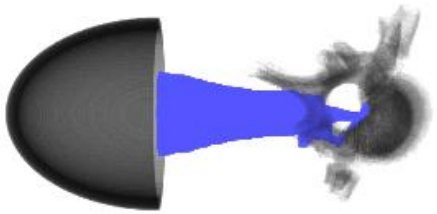
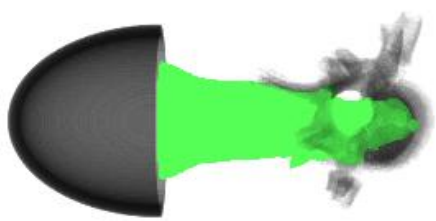
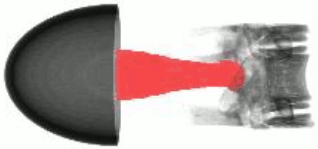
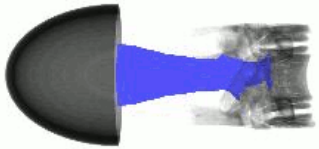
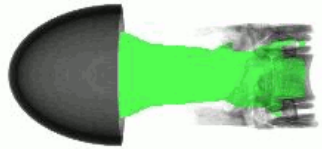
Between Spinous Processes

	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

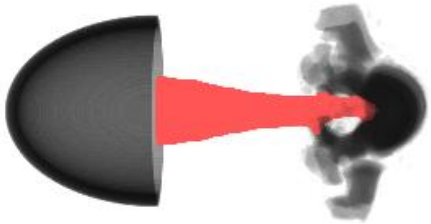
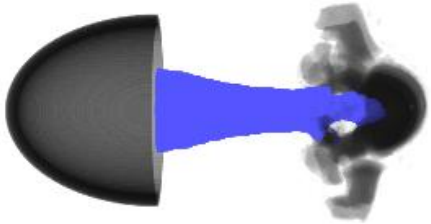
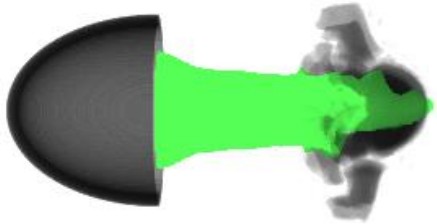
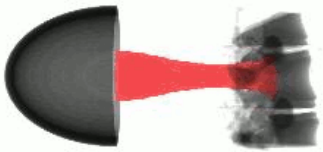
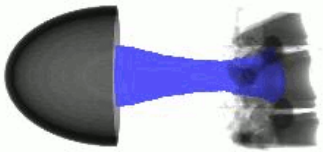
Through Spinous Process

	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

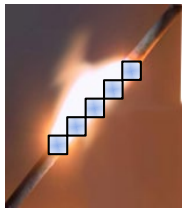
Lateral to Spinous Process

	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

Laminectomy

	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

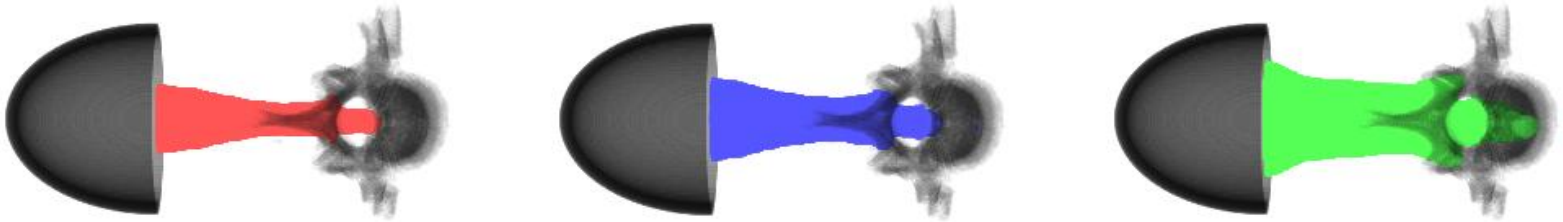
Straight Spark



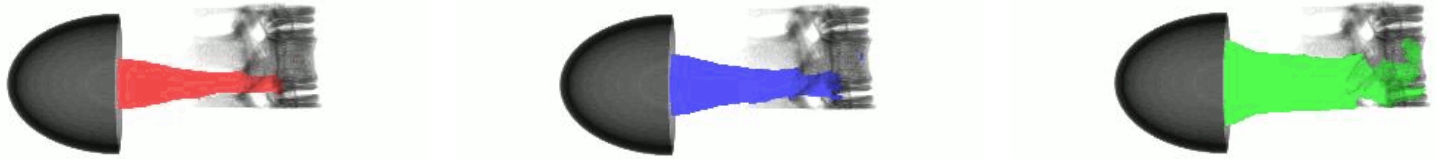
Between Spinous Processes

15 MPa zone | 10 MPa zone | 5 MPa zone

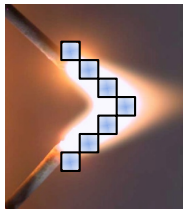
Top view:



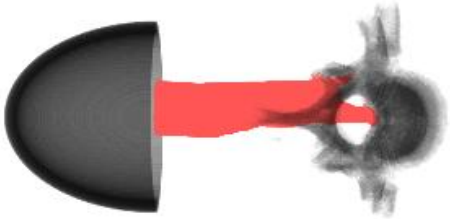
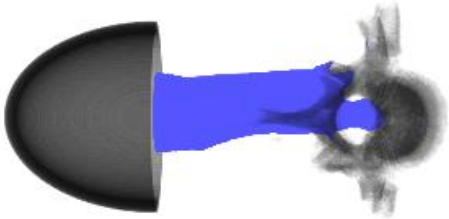
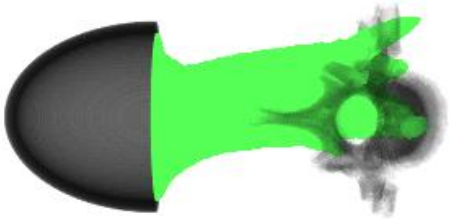
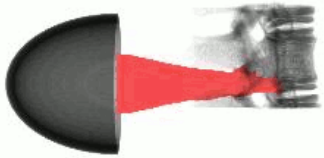
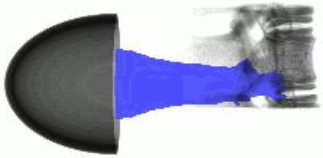
Side view:



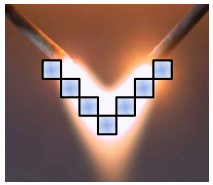
Sideway Spark



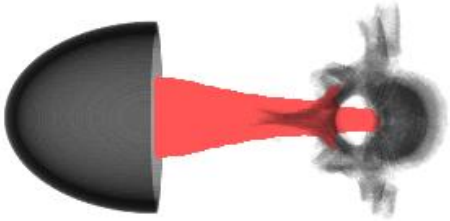
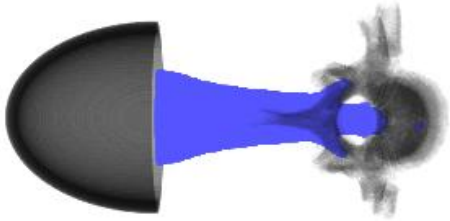
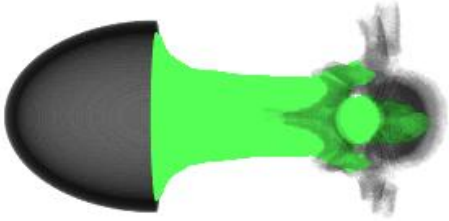
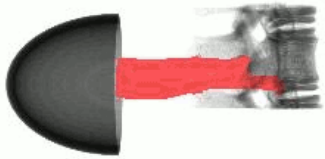
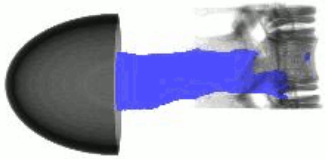
Between Spinous Processes

	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

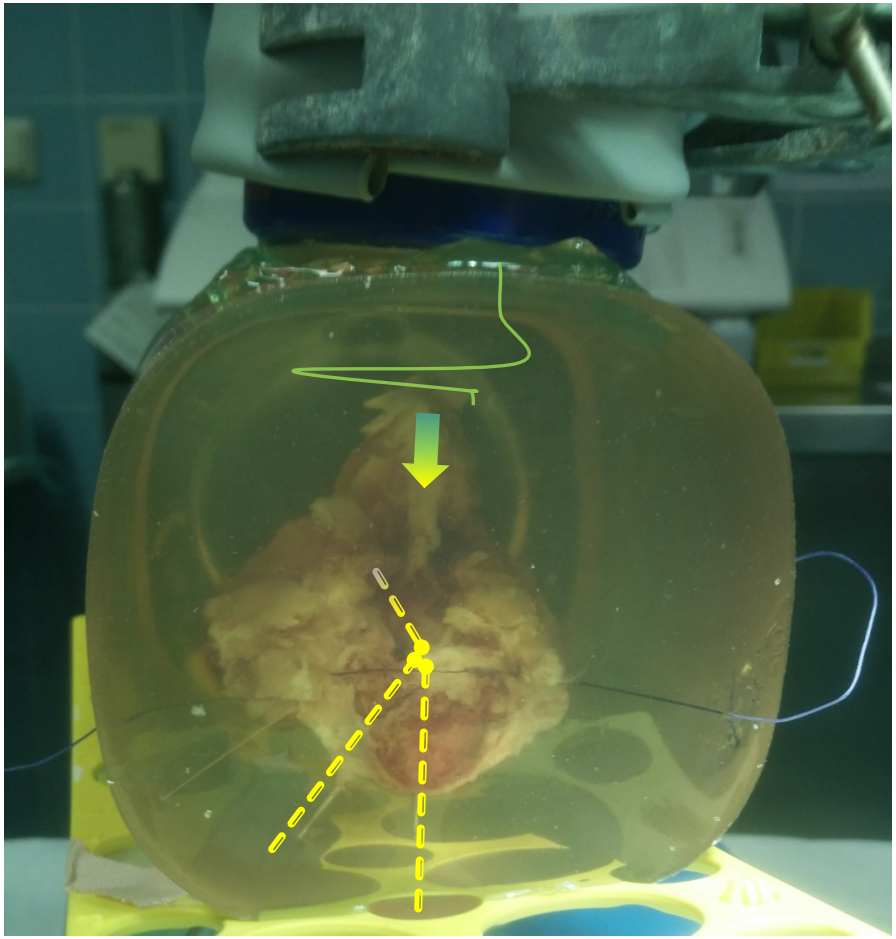
Downward Spark

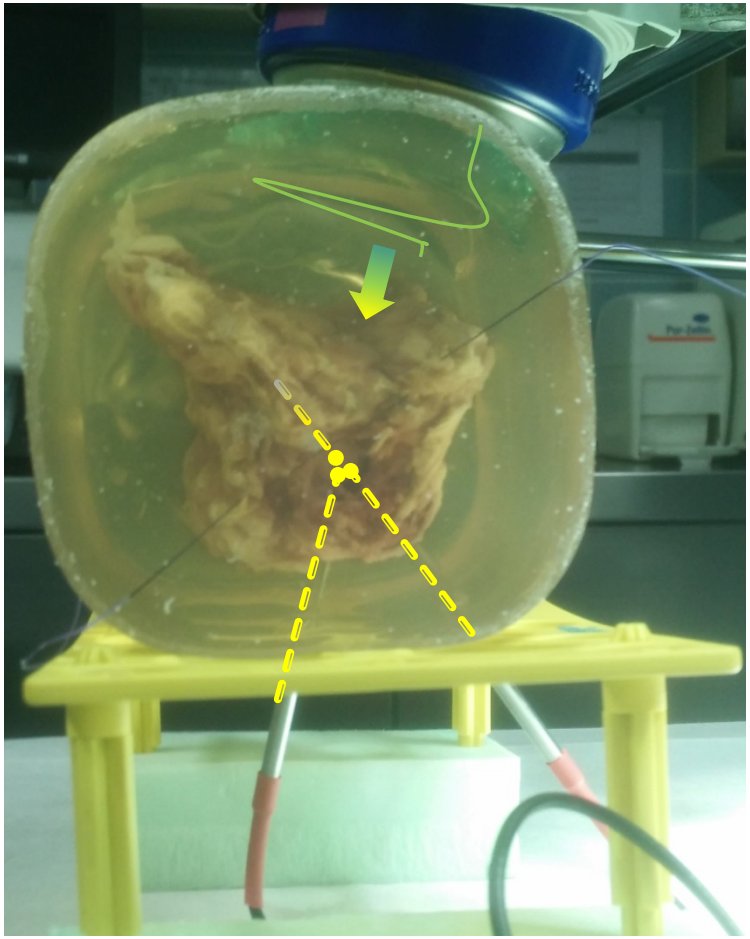


Between Spinous Processes

	15 MPa zone	10 MPa zone	5 MPa zone
Top view:			
Side view:			

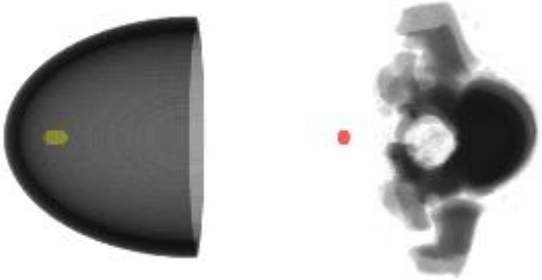
Phantom Reference-Measurements



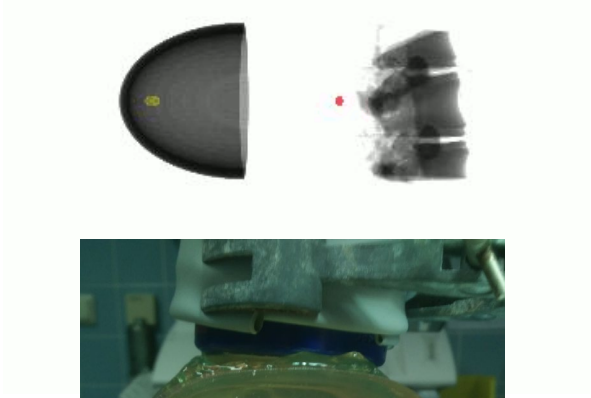


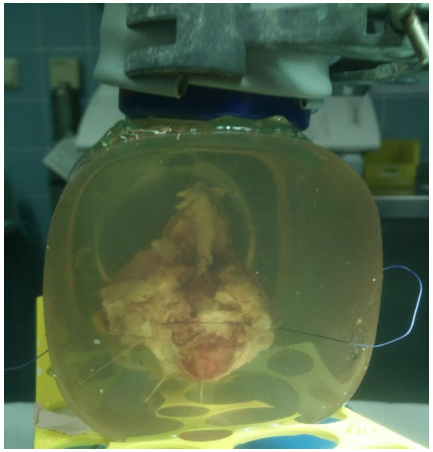
In-Silico Approach: Viability for Laminectomy

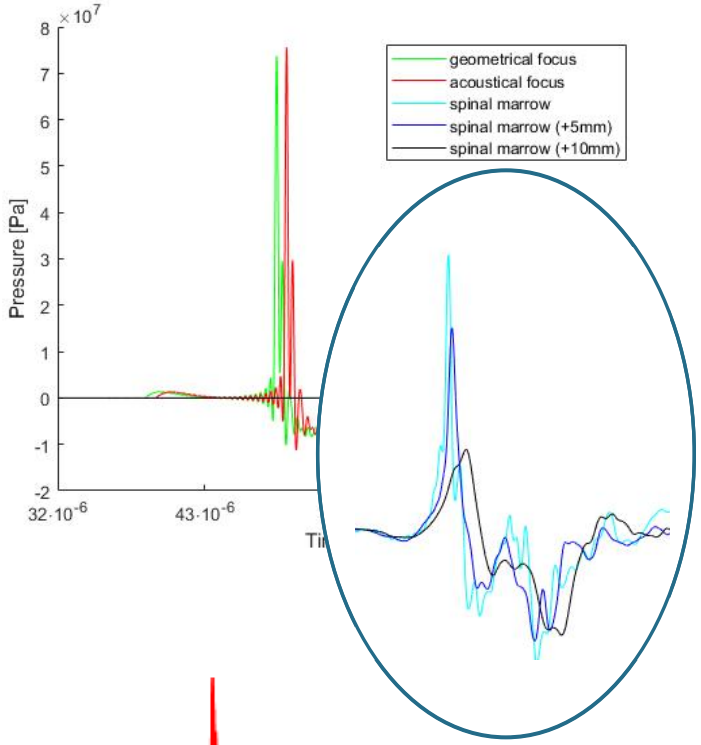
Top view:

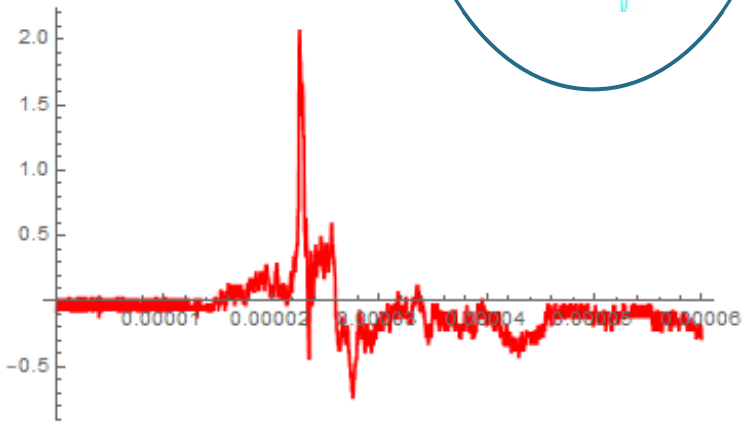


Side view:









Computational Expense

CHPC – Center for High Performance Computing

THE UNIVERSITY OF UTAH

2D Simulation

maximum input pressure: 100 MPa

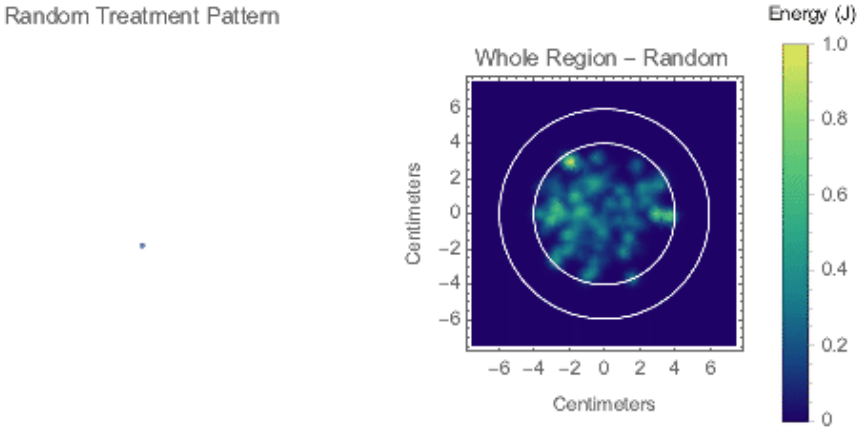
grid spacing [m]	grid size	displacement of acoustical from geometrical focus [mm]	maximum pressure	computing time GPU[1]	memory GPU
0.125*1e-3	384 x 324 = 124 416	0 0.1250	158 MPa	23 sec	1.52 GB
0.1*1e-3	480 x 400 = 192 000	0 0.3000	162 MPa	33 sec	1.54 GB
1/11*1e-3	512 x 450 = 230 400	0 0.2727	165 MPa	35 sec	1.54 GB
1/13*1e-3	625 x 512 = 320 000	0 0.2308	170 MPa	51 sec	1.56 GB
0.0625*1e-3	750 x 625 = 468 750	0 0.2500	174 MPa	1 min 4 sec	1.59 GB
0.05*1e-3	945 x 768 = 725 760	0 0.2000	180 MPa	1 min 40 sec	1.60 GB
0.04*1e-3	1176 x 1024 = 1 204 224	0 0.2000	188 MPa	3 min 30 sec	1.65 GB
0.01*1e-3	4608 x 3600 = 16 588 800	0 0.1200	230 MPa	2 h 12 min	3.49 GB

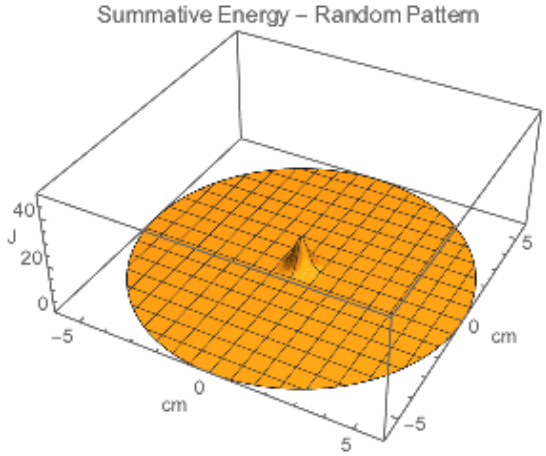
3D Simulation

maximum input pressure: 150 MPa

grid spacing [m]	grid size	compiling time input.h5	size input.h5	size input.h5 compressed	displacement of acoustical from geometrical focus [mm]	maximum pressure	computing time lonepeak	memory lonepeak
0.125*1e-3	384 x 324 x 384 = 47 775 744	20 sec	1.24 GB	2.36 MB	0 -3.7500 0	70 MPa	2 h 40 min	4.86 GB
0.1*1e-3	480 x 400 x 480 = 92 160 000	45 sec	2.40 GB	4.07 MB	0 -3.5000 0	70 MPa	6 h 23 min	9.35 GB
1/11*1e-3	512 x 450 x 512 = 117 964 800	1 min	3.07 GB	5.11 MB	0 -3.5455 0	70 MPa	8 h 36 min	11.96 GB
1/13*1e-3	625 x 512 x 625 = 200 000 000	2 min	5.21 GB	8 MB	0 -3.6923 0	72 MPa	25 h 26 min	20.25 GB
0.0625*1e-3	750 x 625 x 750 = 351 562 500	8 min	9.16 GB	13.5 MB	0 -3.5625 0	72 MPa	48 h 19 min	35.59 GB

Computational modeling of treatment sessions

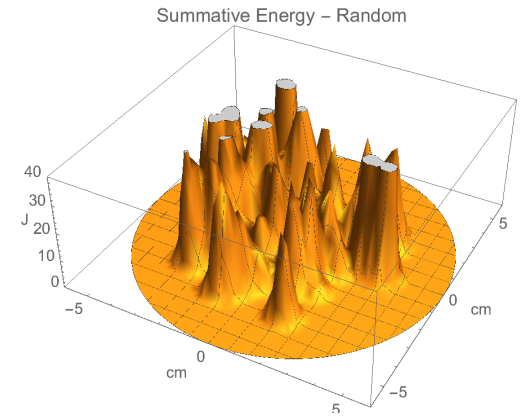


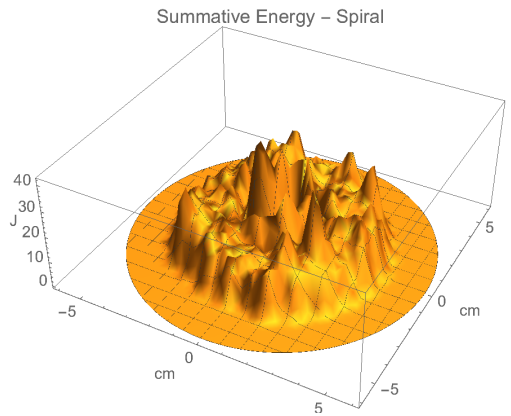


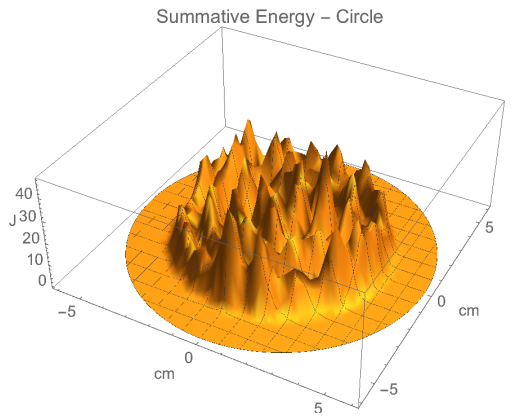
- Non-Deterministic Outcomes
- Probabilistic Modeling
- Random walk and treatment patterns comparison

Computational modeling of treatment sessions

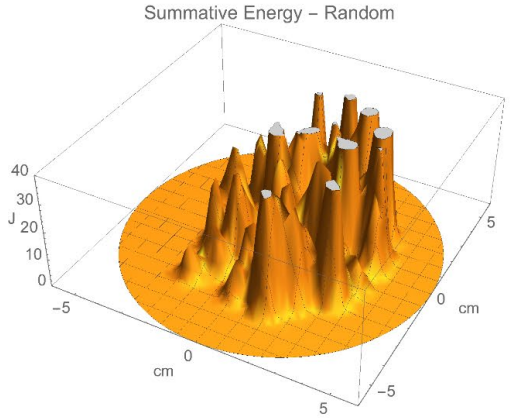
Electro-Hydraulic

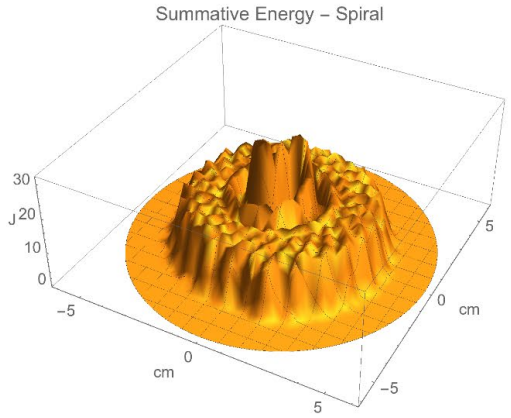


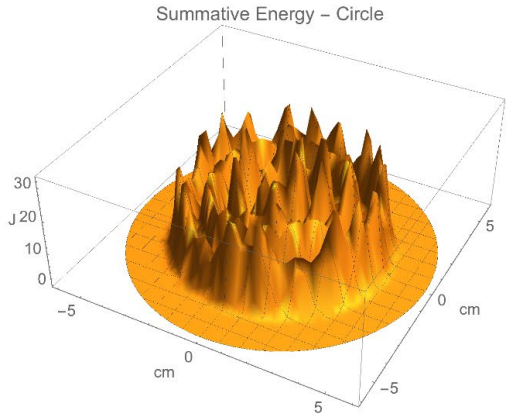




Electro-Magnetic







300 Shots
4cm penetration depth

Summary

- Spark-variations modulate sound field
- In-Silico treatment estimations correlate with reference measurements
- Simulations are currently the only way to explore treatment options and devise therapy plans