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Investigating the variabilities in the spinal cord injury in pig models using benchtop test model and ultrasound analyses

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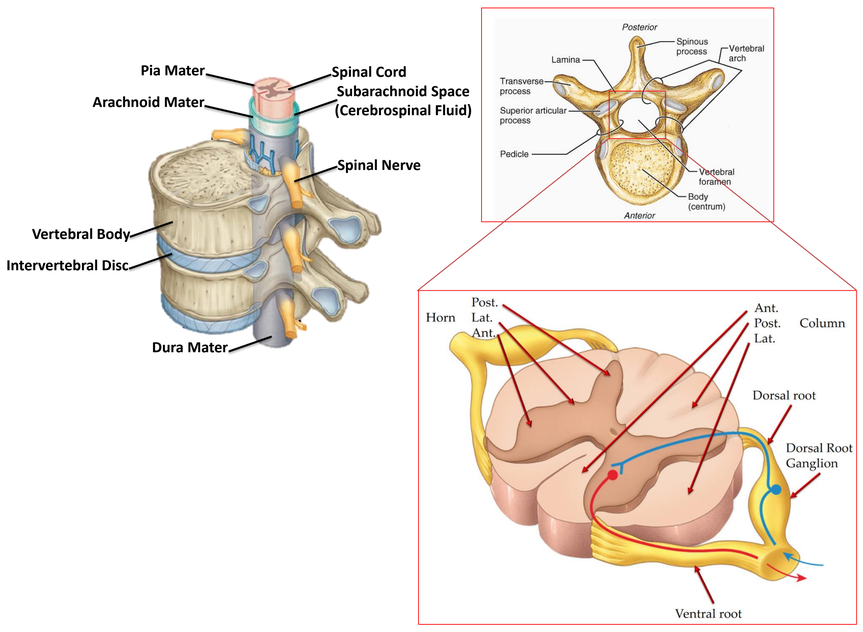
Spinal Cord Injury (SCI)

Spinal Cord Injury (SCI) frequently results in long-term neurological impairment.

The annual incidence of SCI per million people varies from 8.0 to 246.0 cases worldwide. *(1)*

In Canada, a person with a traumatic spinal cord injury is expected to have a lifetime economic cost of **1.5 to 3 million dollars.** *(2)*

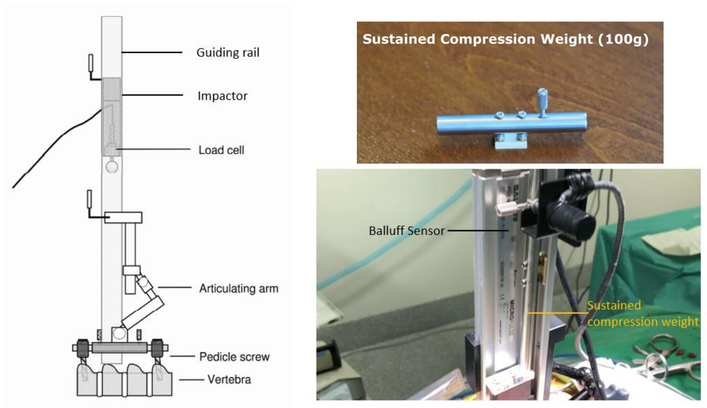
Spinal cord and vertebrae anatomy



In-vivo SCI Models

- The goal of SCI models is to mimic as closely as possible the characteristics of human SCI.
- The greatest biofidelic modeling of the human spinal cord, dura, and CSF response to mechanical trauma is currently provided by in vivo pig animal models. *(3)*
- Weight-drop method is selected as an injury mechanism because it closely resembles burst fractures and fracture-dislocations, which are common in SCIs. *(4)*

Schematic of the impactor (left) showing the Balluff sensor measuring compression displacement and impact velocity. After impact, a sustained compression weight is applied for 5 minutes to simulate post-SCI cord compression (right).



Mechanical parameters like impact velocity, maximum displacement or load, rate of displacement or load, or impulse could characterize an experimental contusion SCI.

Impulse(J)=Force(F)×Time(t)=Mass(m)·Change in Velocity(Δv)

Problem

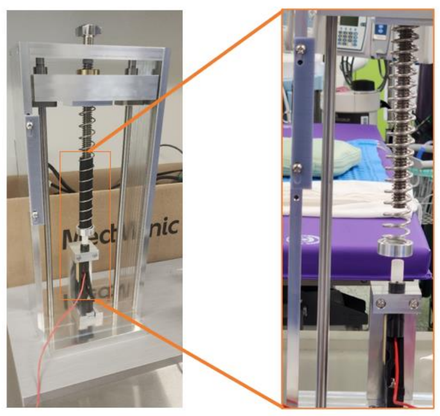
The results were less consistent than desired in terms of force, displacement, and velocity, which impacted the interpretation and post-test analysis of the data.

Objective

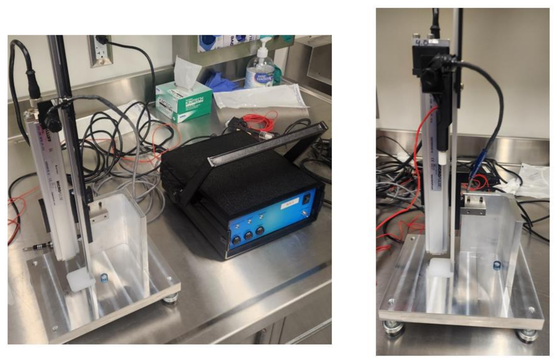
We are dedicated to minimizing variability by refining the impactor design and utilizing ultrasound to examine stress risers on the ventral surface of the spinal canal.

Updating the impactor device and benchtop model

a. Balluff sensor adjustments
b. Load cell calibration jig and repairment



c. Development of a new benchtop test model



After conducting an extensive number of tests (214 tests), we established recommendable acceptable ranges (cut-off value) for load, impulse, displacement, and velocity, which we provided to the surgical team.

Suggested acceptable ranges of mechanical parameters

	Suggested acceptable range of variables (cut off value)							
	Box3_4.1_16.73cm		Box3_4.0_16.73cm		Box3_4.1_20cm		Box3_4.0_20cm	
Mechanical Parameters	Min	Max	Min	Max	Min	Max	Min	Max
Impulse (kdynes*s)	12.87	15.22	13.66	16.00	14.32	15.51	14.85	16.50
Vcontact(mm/s)	1647.14	1752.45	1595.52	1769.27	1778.76	1875.84	1726.67	1854.73
Change in Height (mm)	3.98	4.44	3.92	4.46	4.36	4.67	4.24	4.65
Δheight/Vcontact (s)	0.00237	0.00258	0.00240	0.00257	0.00243	0.00251	0.002429	0.002534
Zeroed force (kdyne)	3015.24	3344.29	3046.28	3527.68	3336.86	3637.51	3353.15	3715.15

The experimental design included 8 setups, distinguished by two electronic conditioning boxes (box 2 and box 3), two weight drop impactors (4.0 and 4.1), and two rail heights for different drop tests studies (16.73cm and 20cm). Box 2 is excluded here. 1 Kdyne = 0.01 N.

In these tests, the coefficient of variation (CV) was **less than 3%, demonstrating high consistency in the impactor's results.**

Mechanical parameters results for the new benchtop test device

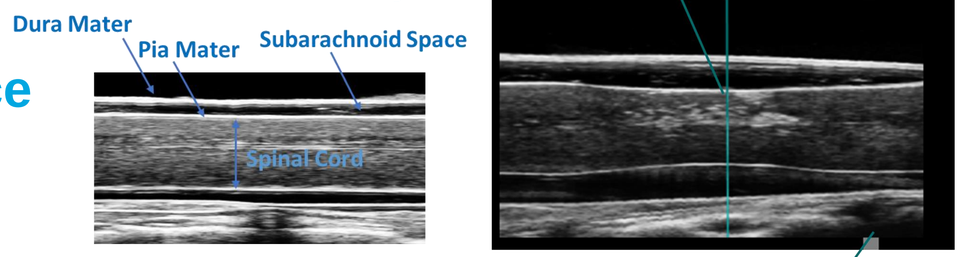
	Different impactor set-ups (benchtop model)											
	Box3_4.1_16.73cm			Box3_4.0_16.73cm			Box3_4.1_20cm			Box3_4.0_20cm		
Mechanical Parameters	Average	SD	CV (%)	Average	SD	CV (%)	Average	SD	CV (%)	Average	SD	CV (%)
Impulse (kdynes*s)	14.05	0.39	2.78	14.83	0.39	2.62	14.91	0.20	1.33	15.67	0.28	1.7582
Vcontact(mm/s)	1699.79	17.55	1.03	1682.39	28.96	1.72	1827.30	16.18	0.89	1790.70	21.34	1.1919
Change in Height (mm)	4.21	0.08	1.84	4.19	0.09	2.17	4.51	0.05	1.12	4.44	0.07	1.5497
Δheight/Vcontact (s)	0.002478	0.000035	1.42	0.002489	0.000028	1.14	0.00247	0.0000148	0.60	0.00248	0.000018	0.7100
Zeroed Force (kdyne)	3179.77	54.84	1.72	3286.98	80.23	2.44	3487.19	50.11	1.44	3534.15	60.33	1.7071

Box 2 is excluded here. 1 Kdyne = 0.01 N.

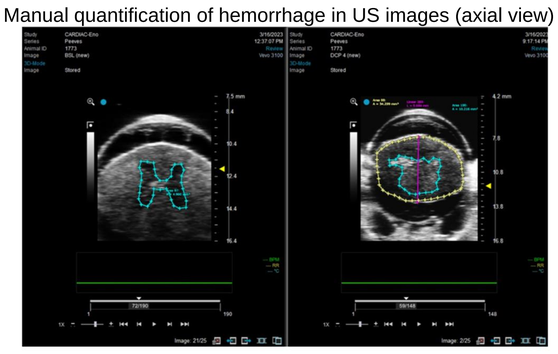
Ultrasound Analysis

Ultrasound images were used to study the effect of distance between the injury epicenter and intervertebral disc.

➢ Manual analyses



Manual quantification of hemorrhage in US images (axial view)

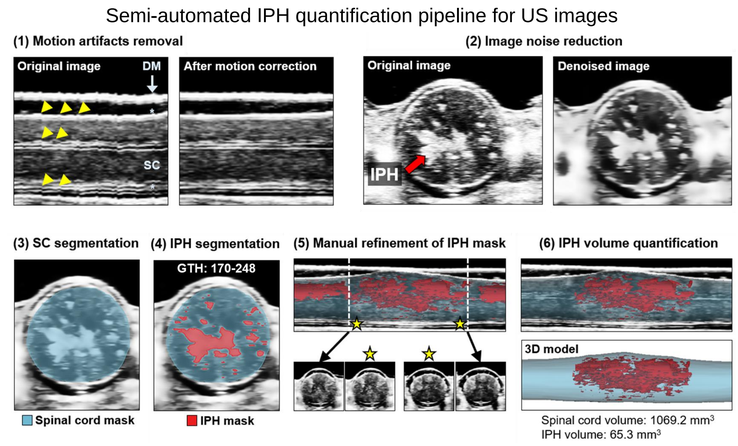


Intact spinal cord | Spinal cord after contusion injury

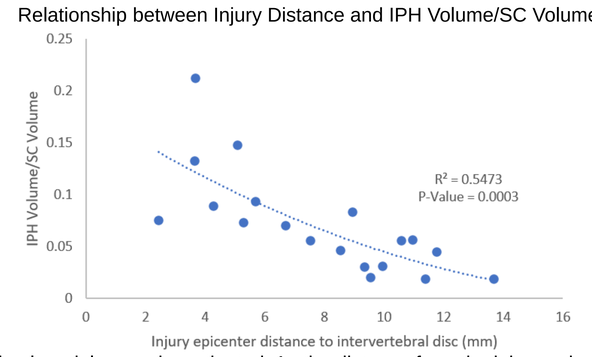
➢ Semi-automated US analysis

After issues with the manual approach, a semi-automated intraparenchymal hemorrhage (IPH) quantification pipeline for ultrasound images has recently been developed. *(5)*

Semi-automated IPH quantification pipeline for US images



Relationship between Injury Distance and IPH Volume/SC Volume



19 animal models were investigated. As the distance from the injury epicenter to the intervertebral disc increases, the IPH volume relative to the SC volume decreases. This suggests **that injuries closer to the intervertebral disc result in larger IPH volumes.**

Discussion & Conclusion

- ✓ Enhanced Consistency in Mechanical Parameters
- ✓ Improved Ultrasound Analysis
- ✓ Significant Relationship Between Injury Distance and IPH Volume
- ✓ Advancements contributing to better translational outcomes in clinical settings.

Reference / Bibliography

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