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Heat generation from high power holmium laser lithotripsy: In-vivo assessment in a porcine model

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Disclosure

Unrelated to this presentation

- I am an inventor on patents licensed to HistoSonics.
- I hold stock in HistoSonics.

Further information:

http://www.engin.umich.edu/admin/adaa/disclosure
http://histosonics.com/
David Bloom, MD Chairman of Urology UM

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Background

- Kidney/ureteral stones increasing in frequency
- URS with LL now dominant modality for most stones
- Expanded laser parameter set with newer high power (120 W) holmium lasers.

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Laser Power

- Definition: rate at which energy is transferred
- SI unit is the Watt = 1 Joule/sec
- Laser power = pulse energy x frequency

  Actual peak power is ~3 kilowatts for 1 J pulse

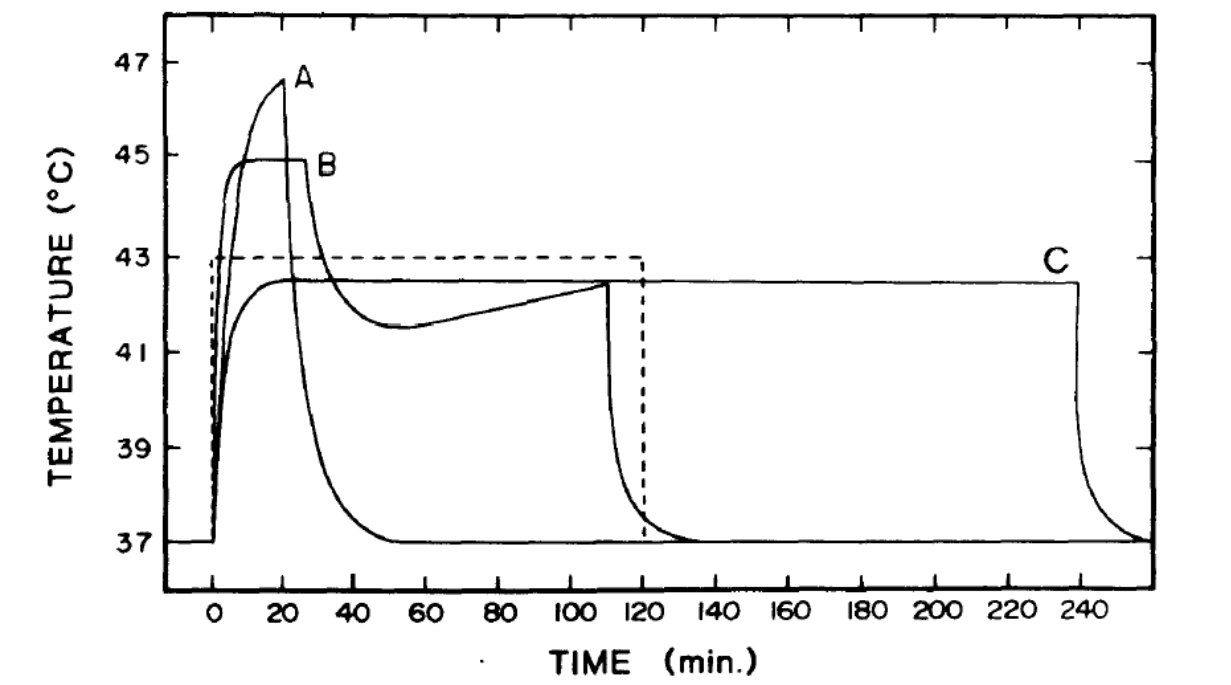
- Thermal effects are result of the **time-averaged power**
- i.e. 0.5J x 20Hz = 0.2J x 50 Hz = 10 W

Typical laser settings

- Fragmentation 0.8J at 10 Hz 8 W
- Dusting 0.3-0.5 J at 50 Hz 15-25 W
- Pop-dusting 0.5 J at 80 Hz 40 W

Thermal dose

- For in-vivo and in-vitro systems an exponential relationship exists between temperature and exposure time.



Sapareto and Dewey Int J Rad Onc Biol Phys 1984

Thermal dose

- Cell death occurs when tissue is maintained at 43 C for 120 minutes.
- t_{43} equivalent minutes is a concept developed by Dewey and Sapareto.

$$t_{43} = \sum_{t=0}^{t=final} R^{(43-\bar{T})} \Delta t$$

- t_{43} > 120 minutes = cell death

Thermal dose

Threshold for tissue damage is 43 C for 120 min.

- Equivalent to 50 C for 56 sec
- Equivalent to 56 C for 0.9 sec
- In each of these cases the t_{43} = 120 minutes

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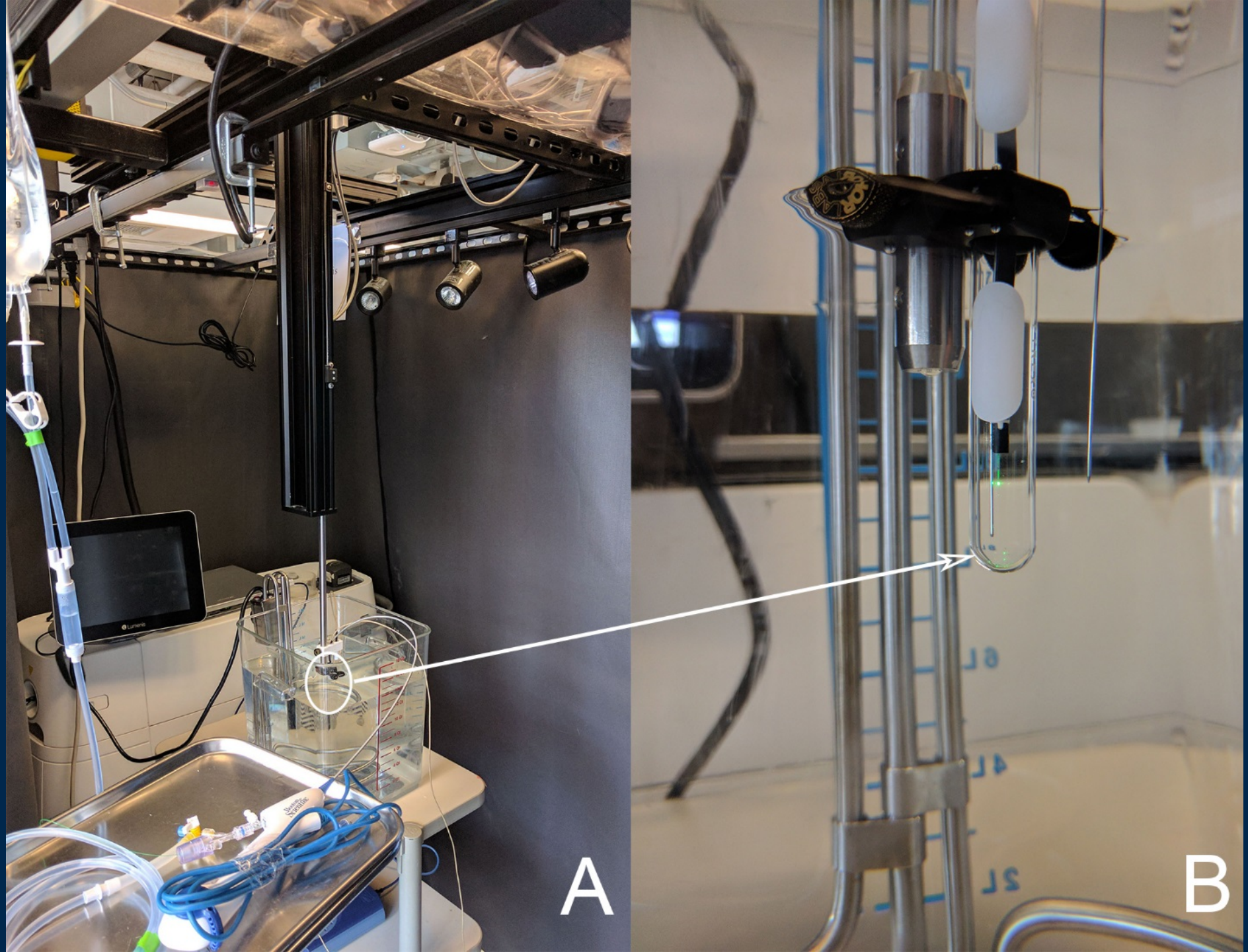
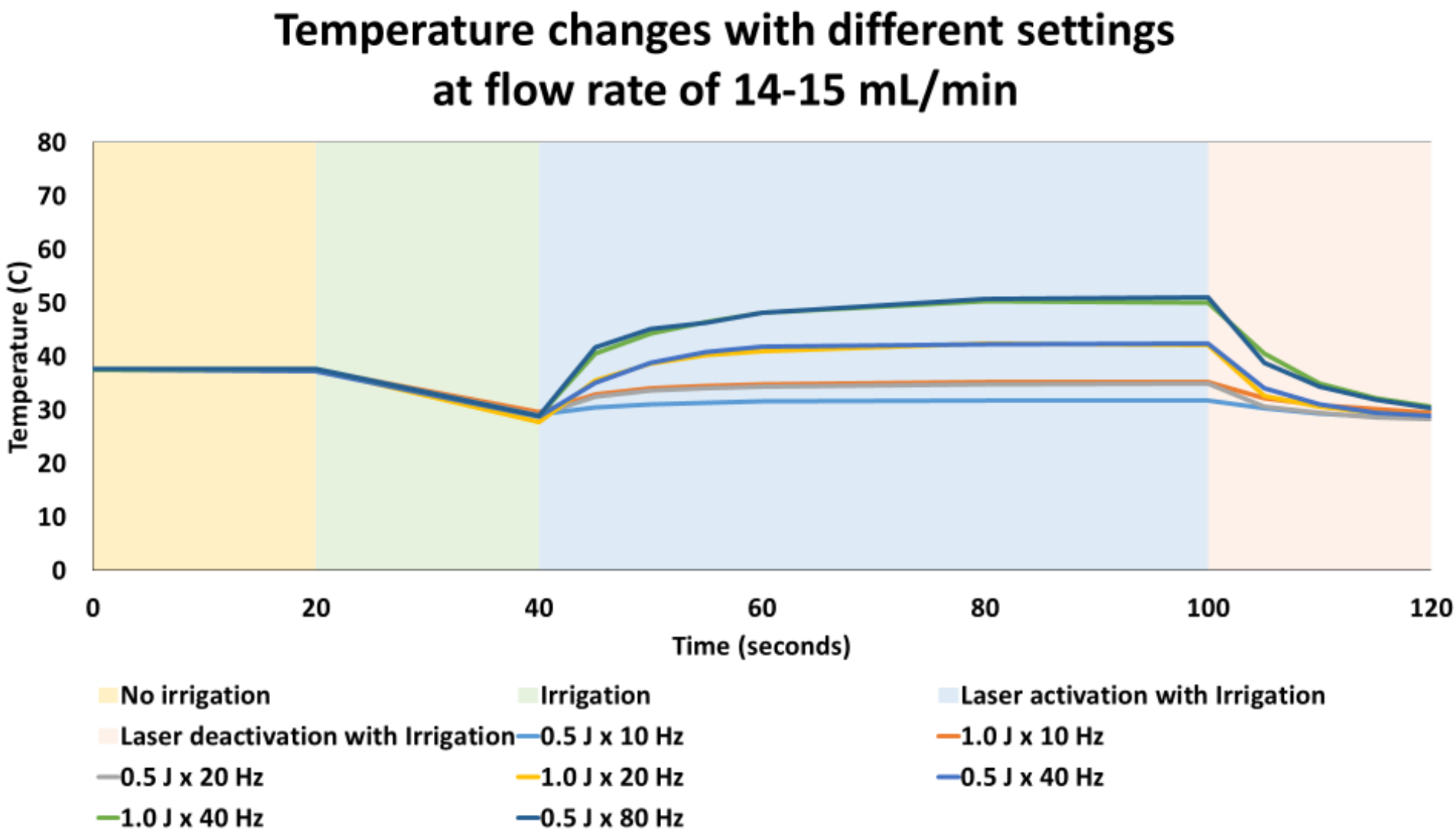
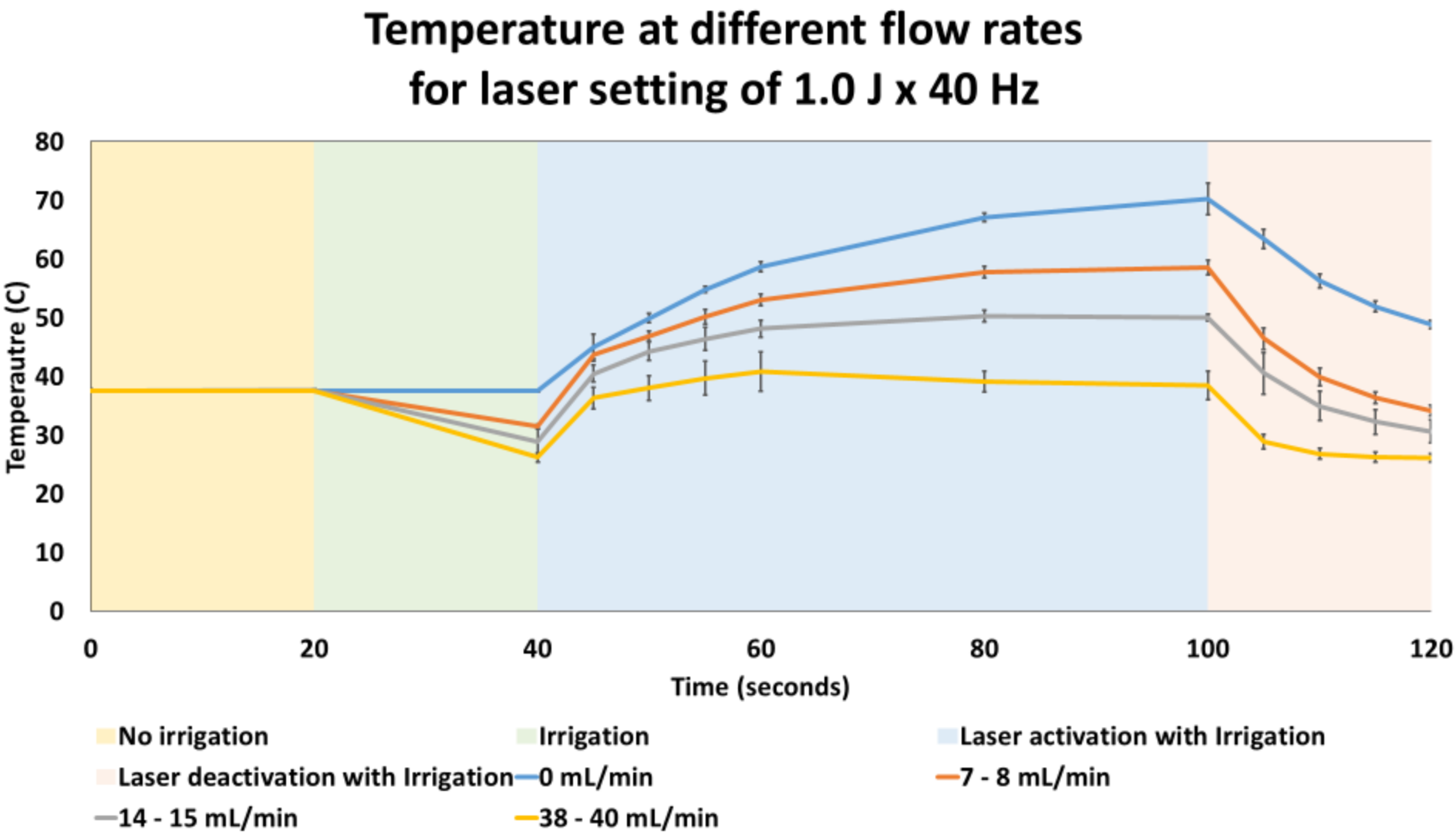
In vitro studies

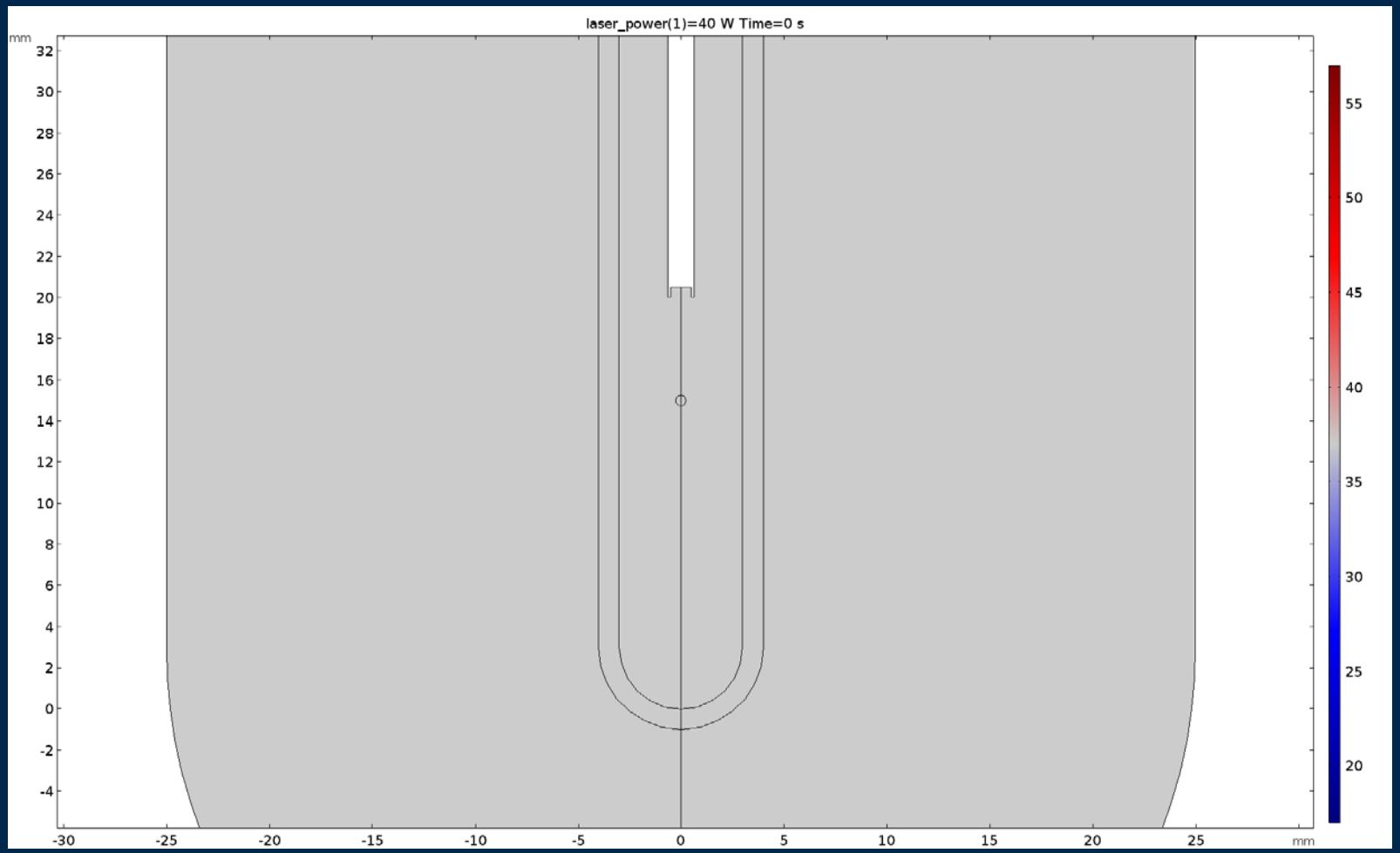
Molina…Kim et al J Endo 2015
Buttice…Traxer et al J Endo 2016
Sourial…Knudsen et al abstract EUS 2017
Aldoukhi…Roberts et al J Endo 2017
Wollin…Lipkin et al J Endo 2018


A
B

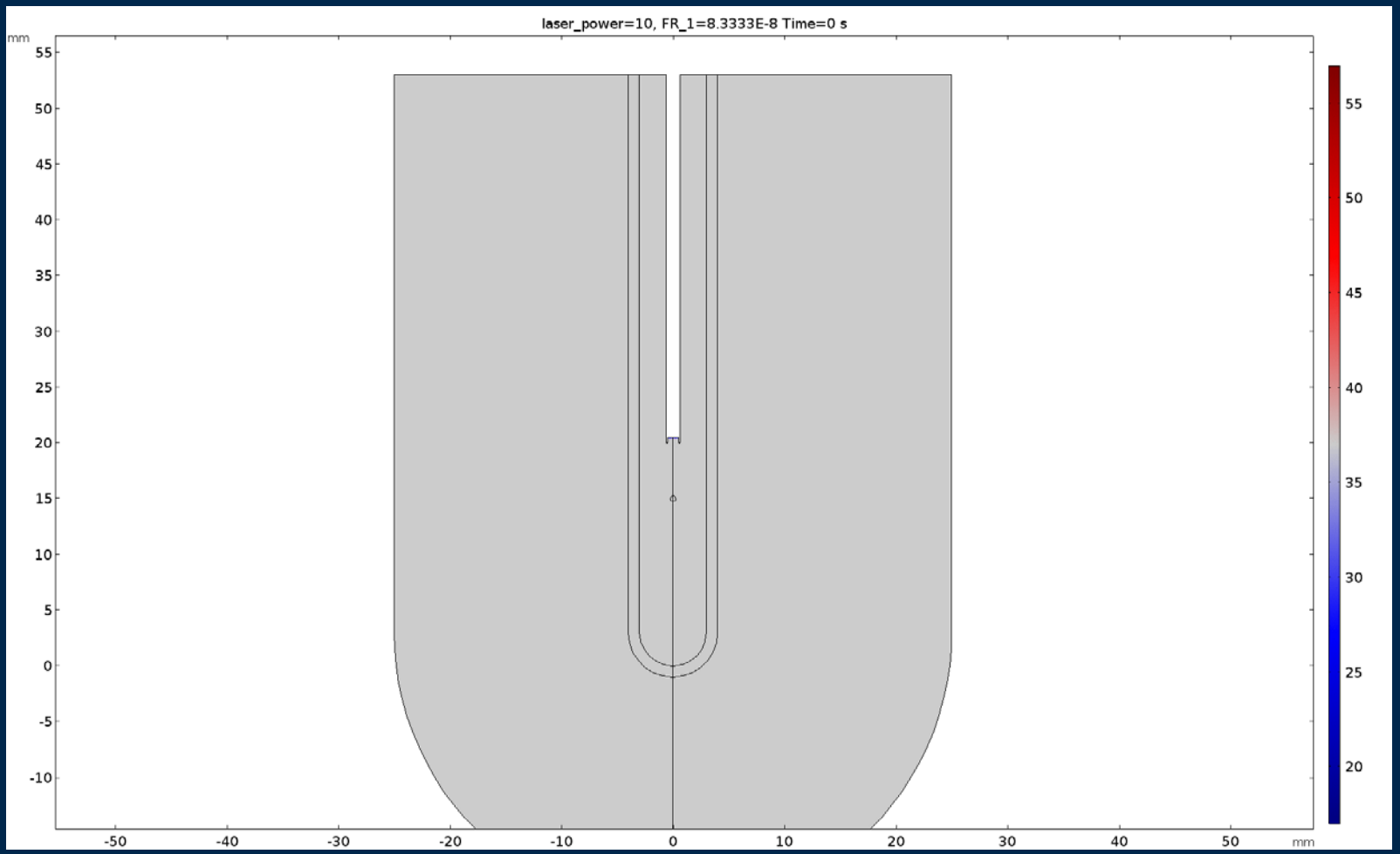

Temperature changes with different settings
at flow rate of 14-15 mL/min
Temperature (C)
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
Time (seconds)
No irrigation
Irrigation
Laser activation with Irrigation
Laser deactivation with Irrigation
0.5 J x 10 Hz
1.0 J x 10 Hz
0.5 J x 20 Hz
1.0 J x 20 Hz
0.5 J x 40 Hz
1.0 J x 40 Hz
0.5 J x 80 Hz


Temperature at different flow rates
for laser setting of 1.0 J x 40 Hz
Temperautre (C)
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
Time (seconds)
No irrigation
Irrigation
Laser activation with Irrigation
Laser deactivation with Irrigation
0 mL/min
7 - 8 mL/min
14 - 15 mL/min
38 - 40 mL/min

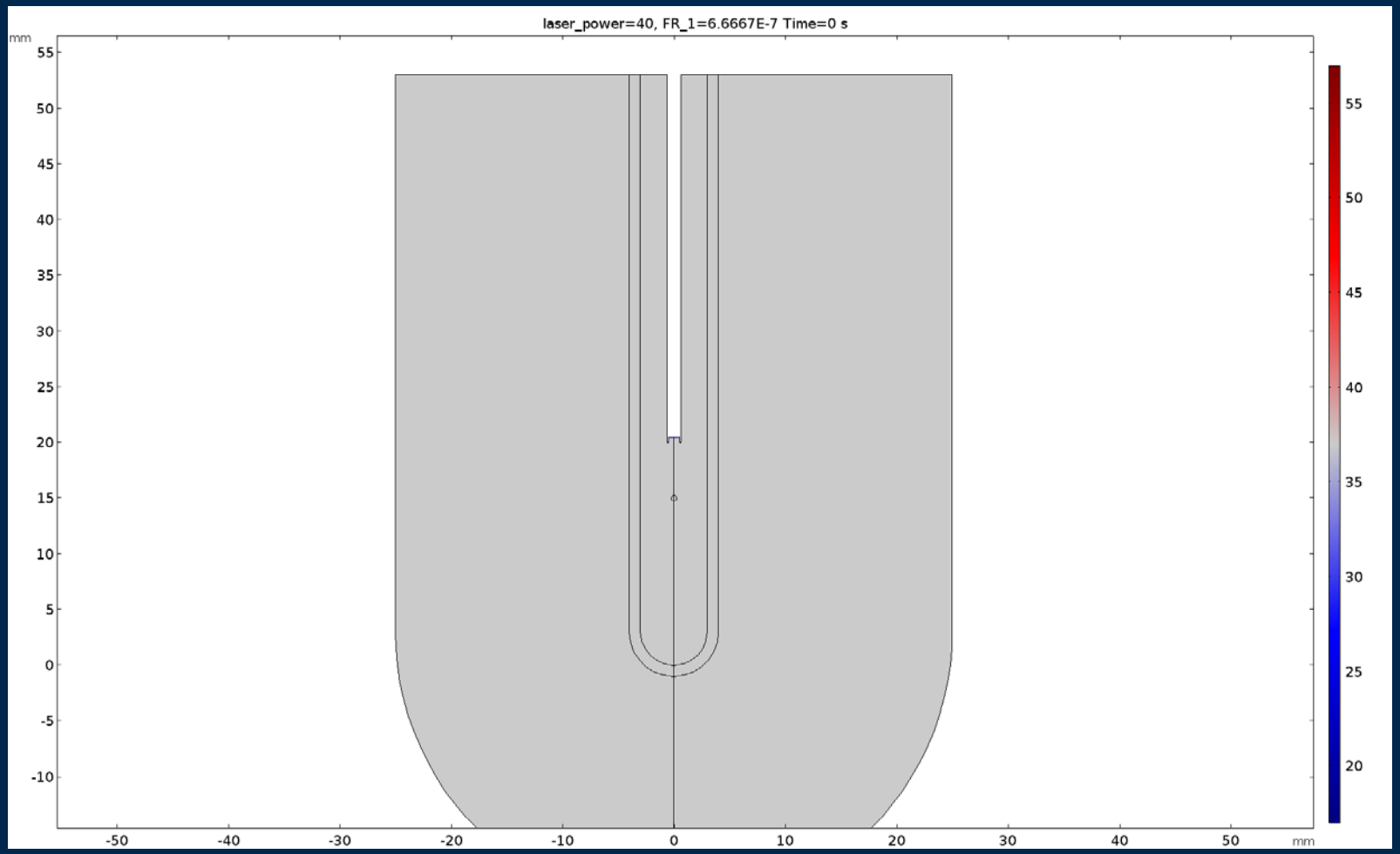
Simulation 40 W, 0 ml

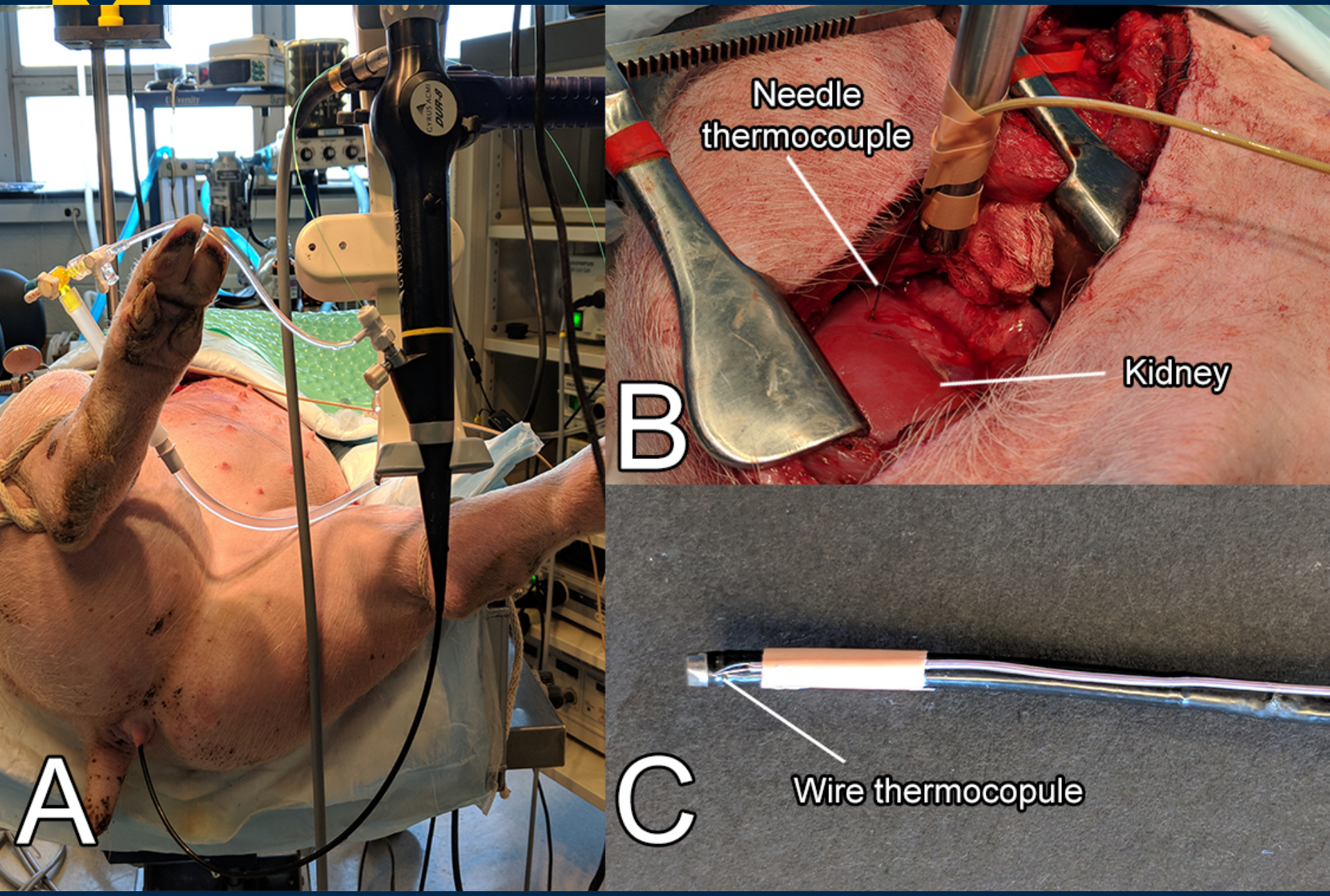


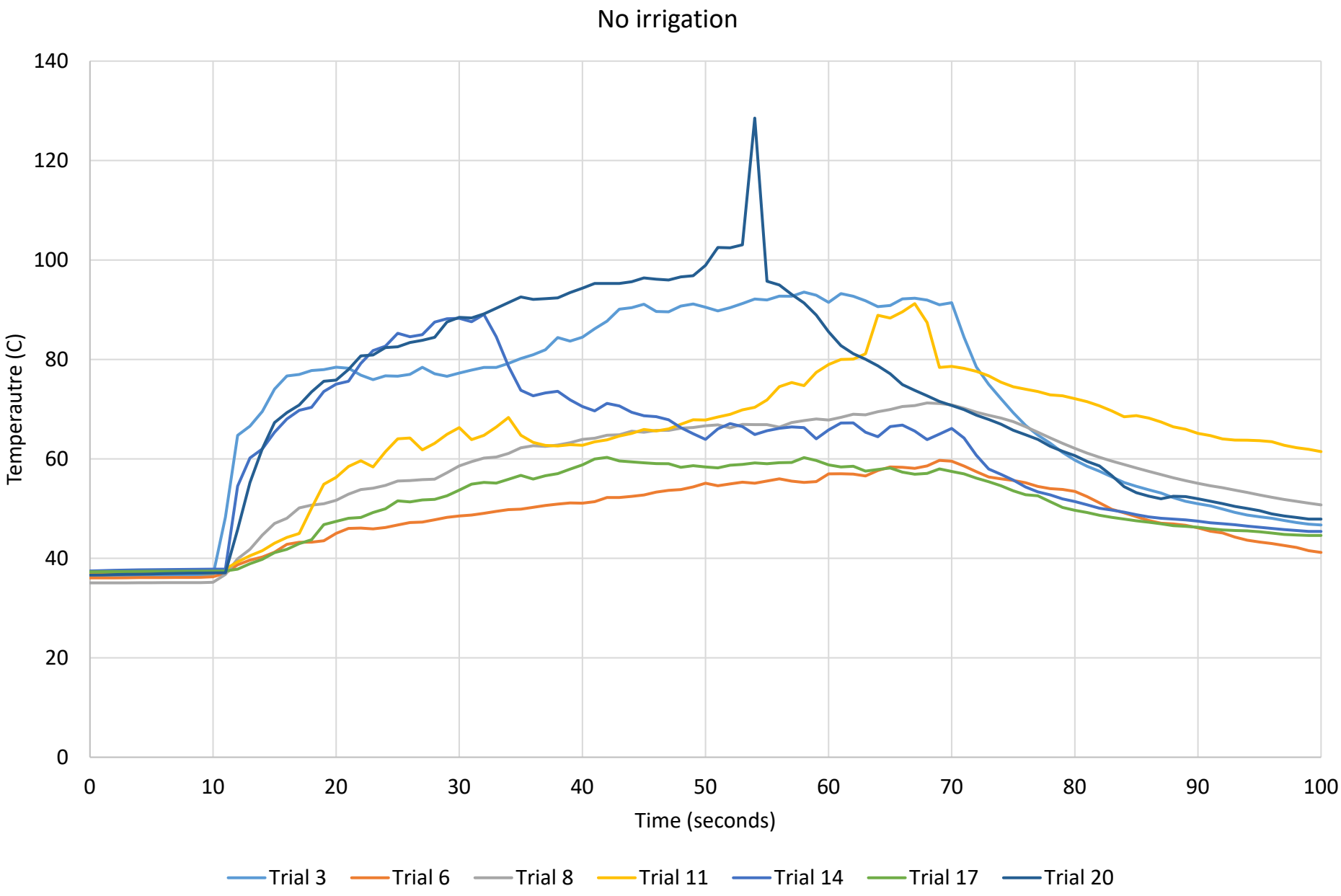
Simulation 10W 5 ml

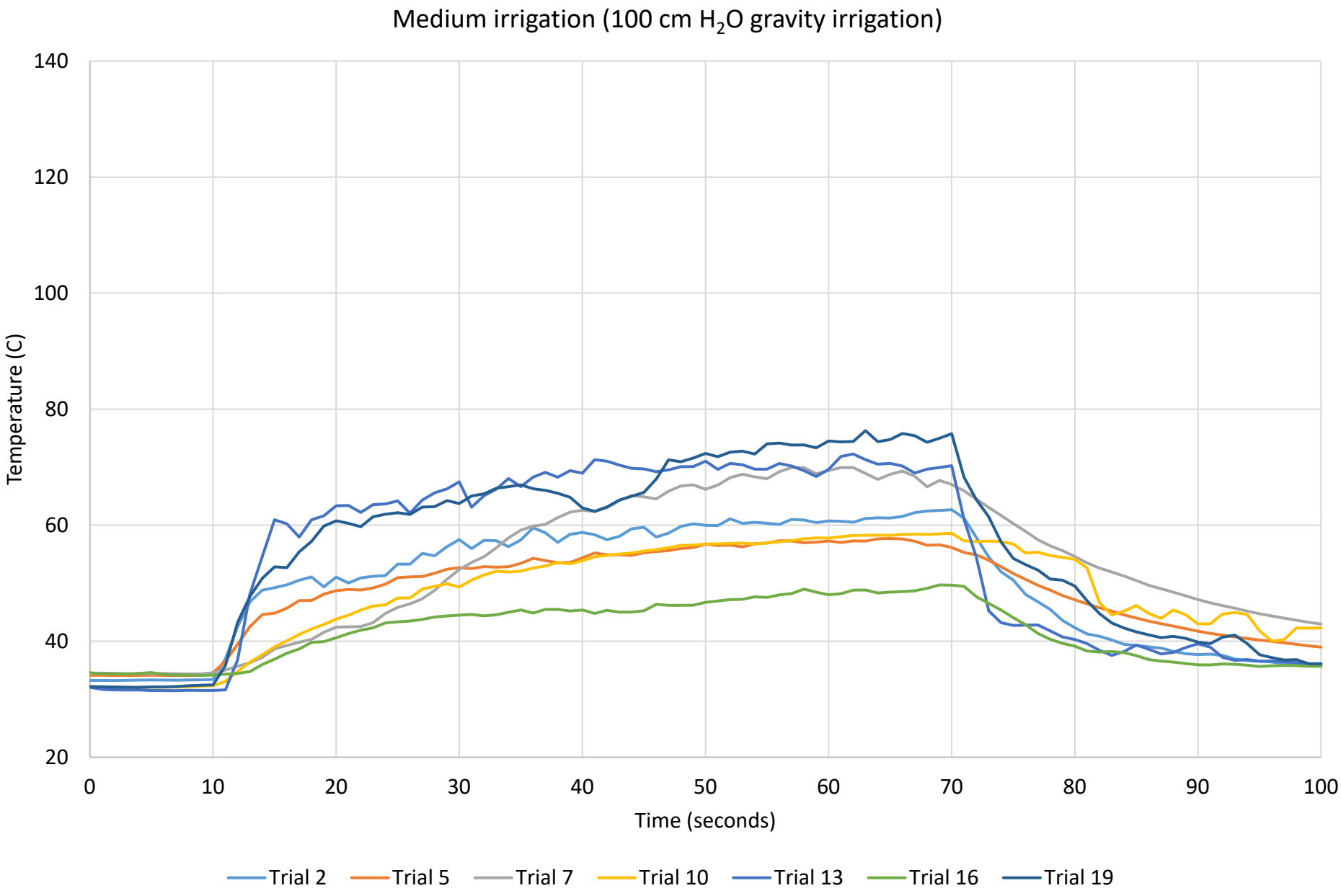


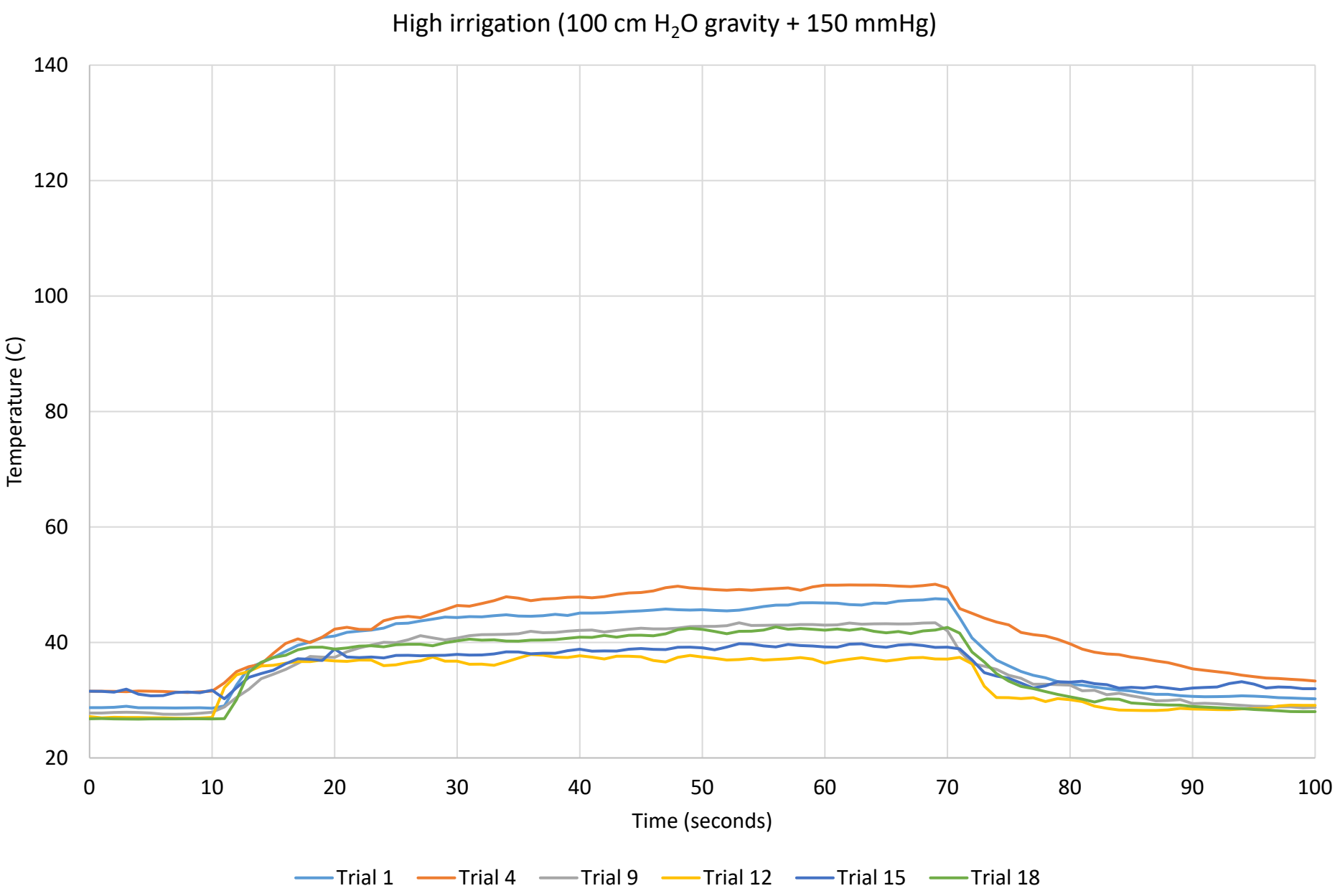
Simulation 40 W, 40 ml

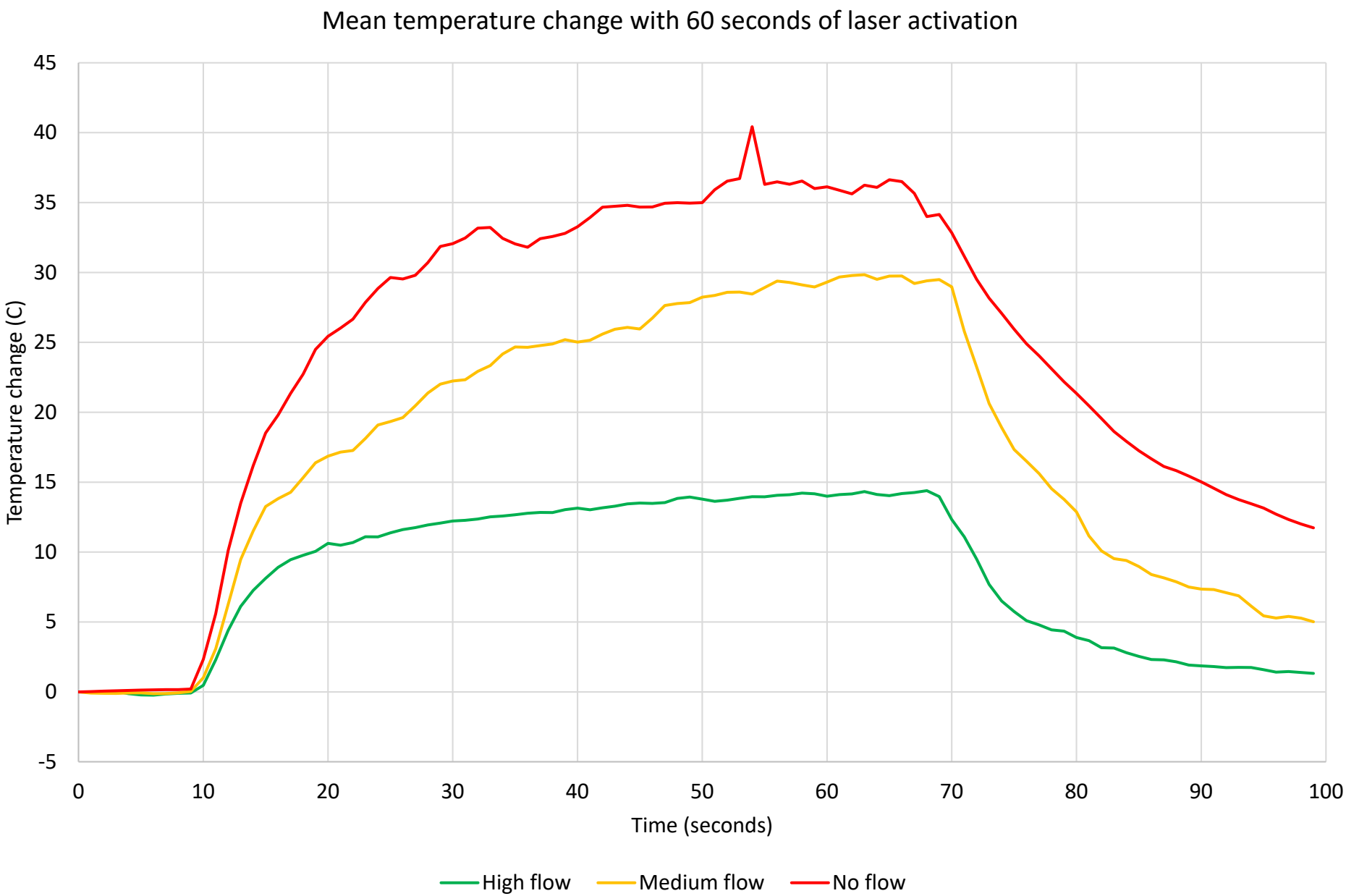



A
B
Needle
thermocouple
Kidney
C
Wire thermocopule


No irrigation
Temperautre (C)
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
Time (seconds)
Trial 3
Trial 6
Trial 8
Trial 11
Trial 14
Trial 17
Trial 20


Medium irrigation (100 cm H_2O gravity irrigation)
Temperature (C)
140
120
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
100
Time (seconds)
Trial 2
Trial 5
Trial 7
Trial 10
Trial 13
Trial 16
Trial 19


High irrigation (100 cm H_2O gravity + 150 mmHg)
Temperature (C)
140
120
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
100
Time (seconds)
Trial 1
Trial 4
Trial 9
Trial 12
Trial 15
Trial 18


Mean temperature change with 60 seconds of laser activation
Temperature change (C)
45
40
35
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
60
70
80
90
100
Time (seconds)
High flow
Medium flow
No flow

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Trial	Irrigation rate	Thermocouple type	Temperature after 10 seconds (C)	Time to T43 120 min. (sec)	Peak temp (C)	T43 equivalent minutes
3	No	Needle	78.44	2	93.54	$>10^{13}$
6	No	Needle	45.03	37	59.7	$>10^{3}$
8	No	Needle	51.68	14	71.26	$>10^{6}$
11	No	Needle	56.29	10	91.23	$>10^{11}$
14	No	Needle	75.04	3	89.04	$>10^{11}$
17	No	Wire	47.44	21	60.31	$>10^{3}$
20	No	Wire	75.84	2	128.53	$>10^{22}$
2	Medium	Needle	51.06	17	62.67	$>10^{4}$
5	Medium	Needle	48.71	25	57.72	$>10^{3}$
7	Medium	Needle	42.43	23	69.95	$>10^{6}$
10	Medium	Needle	43.8	30	58.61	$>10^{3}$
13	Medium	Needle	63.35	5	72.27	$>10^{6}$
16	Medium	Wire	40.59	NA	49.71	19.6
19	Medium	Wire	60.75	7	76.3	$>10^{8}$
1	High	Needle	41.11	N/A	47.57	6.2
4	High	Needle	42.3	N/A	50.09	47.5
9	High	Needle	37.42	N/A	43.41	<0.01
12	High	Needle	36.8	N/A	37.92	<0.01
15	High	Wire	38.86	N/A	39.78	<0.01
18	High	Wire	38.84	N/A	42.69	0.14

INCHES
1
2
LABORATORY APPARATUS. FURNITU
SCIENTIFIC INSTRUMENTS & CHEMIC
1
2
3
4
5

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Conclusions

- High power laser lithotripsy expands the options and strategies for laser lithotripsy and increases treatment efficiency.
- High power laser settings, prolonged laser activation, and low irrigation can produce a thermal dose that is injurious to adjacent tissue.
- Further work to define the safety envelope within the laser lithotripsy parameter space is ongoing.
- Strategies and techniques are being studied to control and mitigate thermal effects during Holmium laser lithotripsy.

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Thank you!

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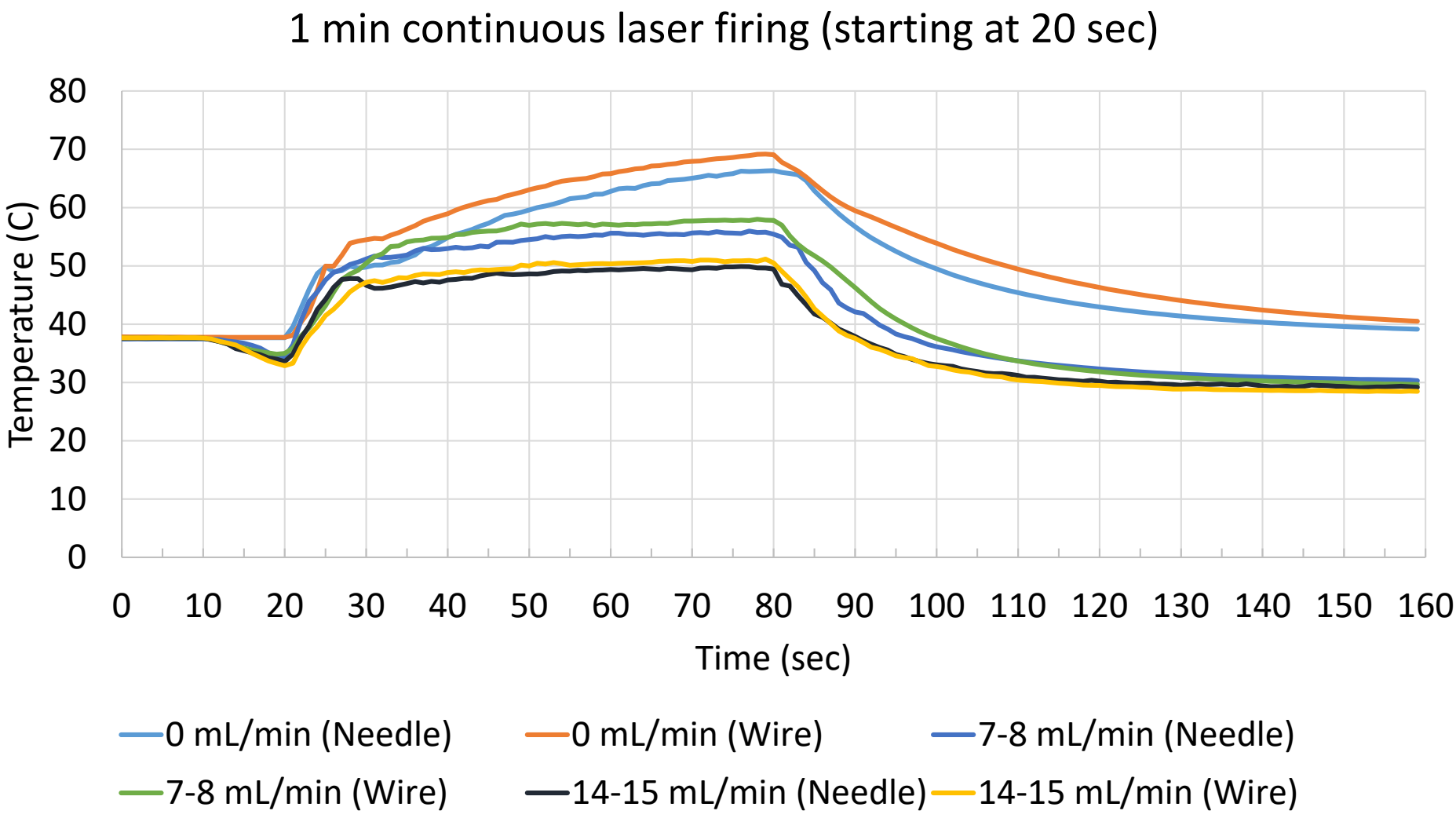
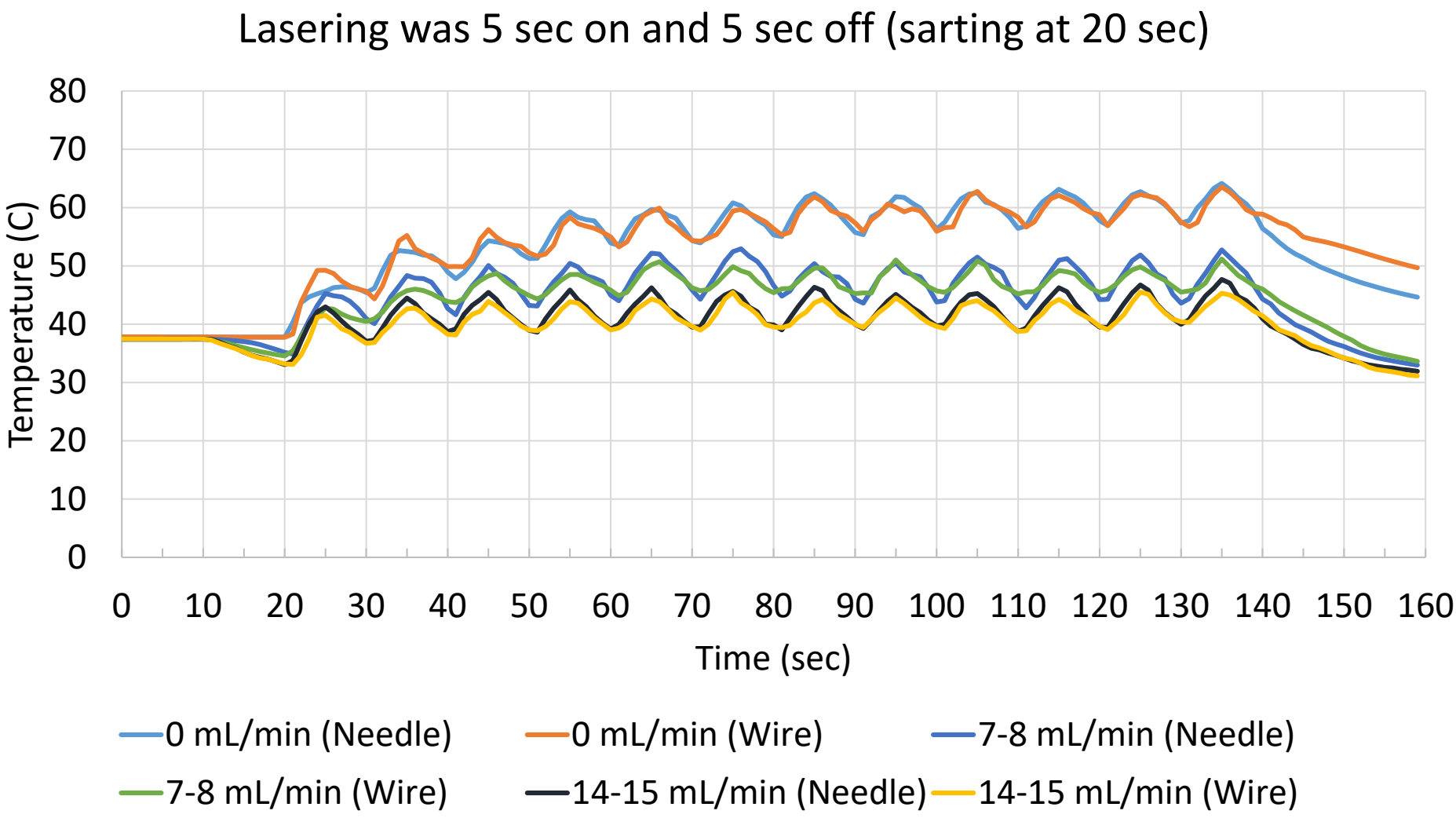
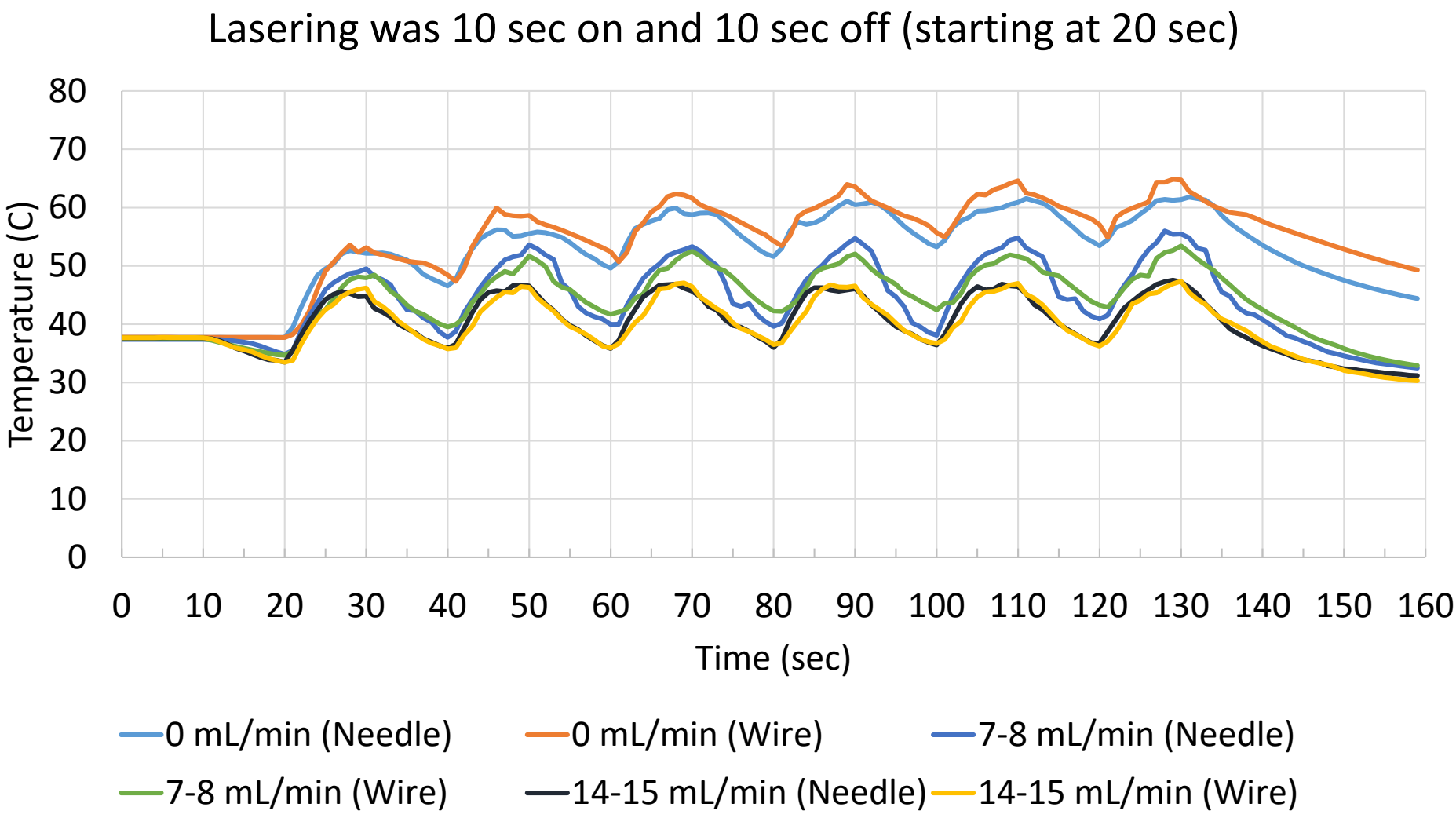
- Operator Duty Cycle


1 min continuous laser firing (starting at 20 sec)
Temperature (C)
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Time (sec)
0 mL/min (Needle)
0 mL/min (Wire)
7-8 mL/min (Needle)
7-8 mL/min (Wire)
14-15 mL/min (Needle)
14-15 mL/min (Wire)


Lasering was 5 sec on and 5 sec off (sarting at 20 sec)
Temperature (C)
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Time (sec)
0 mL/min (Needle)
0 mL/min (Wire)
7-8 mL/min (Needle)
7-8 mL/min (Wire)
14-15 mL/min (Needle)
14-15 mL/min (Wire)


Lasering was 10 sec on and 10 sec off (starting at 20 sec)
Temperature (C)
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Time (sec)
0 mL/min (Needle)
0 mL/min (Wire)
7-8 mL/min (Needle)
7-8 mL/min (Wire)
14-15 mL/min (Needle)
14-15 mL/min (Wire)

T43

- It was calculated for the whole curve.

Flow rate (thermocouple type)	1 min	5 on 5 off	10 on 10 off
0 mL/min (Needle)	2,328,827.32	672,635.80	515,716.33
0 mL/min (Wire)	14,587,782.00	294,156.48	1,512,717.17
7-8 mL/min (Needle)	5,942.97	302.75	1,978.30
7-8 mL/min (Wire)	25,901.07	93.01	288.17
14-15 mL/min (Needle)	61.87	4.76	8.34
14-15 mL/min (Wire)	137.83	1.64	6.39