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## Introduction

Non-thermal plasma is now being widely used for various medical application like skin sterilization, blood coagulation, cancer treatment etc. So far no studies have been carried out to analyze the toxicity of non-thermal plasma treatment of living tissue. **This work analyzes the toxicity of non-thermal plasma treatment of intact and wounded tissue in vivo using a porcine model.**

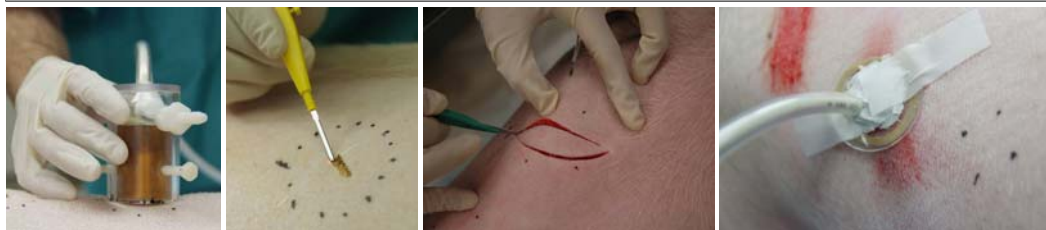


15 seconds of FE-DBD clots the blood and seals the vessel **without damaging tissue, preventing additional bleeding.**

Original Concentration	5 sec of FE-DBD	10 sec of FE-DBD	15 sec of FE-DBD	5 seconds of direct plasma:		
10 <sup>9</sup> cfu	850 ± 183	9 ± 3	4 ± 4	850	22	2
10 <sup>8</sup> cfu	22 ± 5	5 ± 5	0 ± 0	Original concentration (10 <sup>9</sup> cfu)	10x dilution (10 <sup>8</sup> cfu)	100x dilution (10 <sup>7</sup> cfu)
10 <sup>7</sup> cfu	6 ± 6	0 ± 0	0 ± 0			

**DBD Plasma: ~7-log reduction in 5 seconds**  
 Microorganisms: *Streptococci, Staphylococci, Yeast* on agar

## Non-Thermal Plasma Treatment of Pigs



Plasma treatment of intact skin

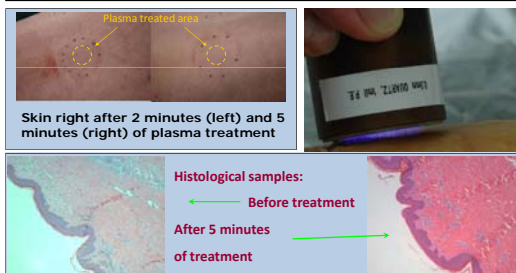
Positive Control "Bovie"

Harvesting a intact skin section for histology

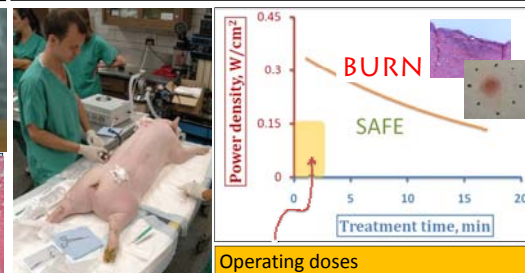
Plasma treatment of shallow wounds using a special electrode

## Toxicity of Non-Thermal Plasma Treatment of Intact Skin

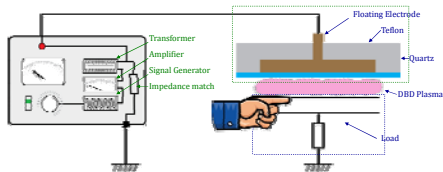
### Safety of intact skin DBD plasma treatment on pig model



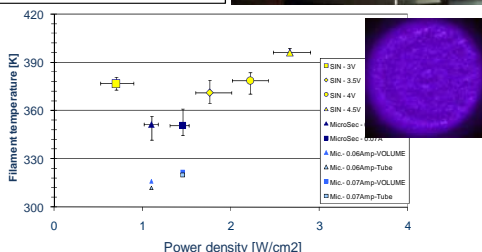
### Toxic DBD plasma dose for intact pig skin



## Floating Electrode DBD



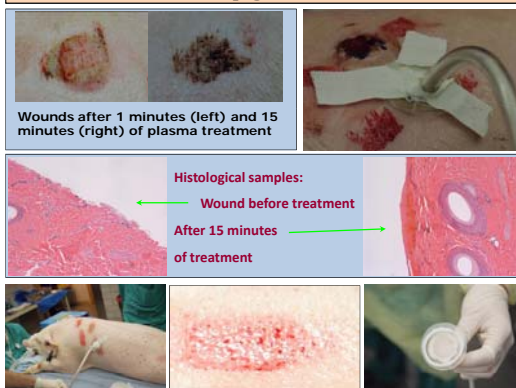
Voltage: 20 kV  
 Frequency: 0.7 - 2 kHz  
 Rise time: ~5 V / nsec  
 Pulse duration: ~2 µsec  
 Power density: 0.2 - 0.5 W/cm<sup>2</sup>  
 Filament temperature: 320-420K



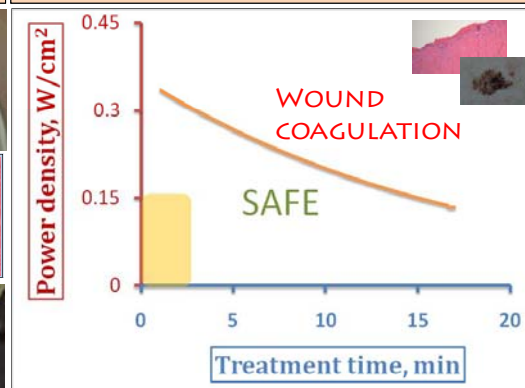
Plasma treatment at normal operating parameters does not cause tissue damage: Plasma doses up to 10 times longer than required for complete sterilization are safe: We see a burn formation only after 10 mins of continuous application of high power plasma dose

## Toxicity of Non-thermal Plasma Treatment of Shallow Wounds

### Safety of wounded tissue DBD plasma treatment on pig model



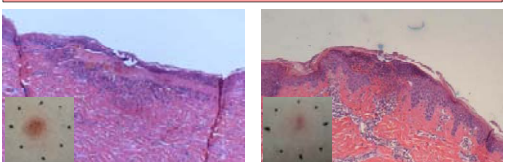
### Toxic DBD plasma dose for wounds



Plasma treatment at normal operating parameters does not cause tissue damage in wounds: Non-thermal Plasma starts coagulating an open wound after 30 seconds which protects the underlying wound from further damage by the plasma. We mostly see coagulated wounds after higher doses

## Toxicity Analysis

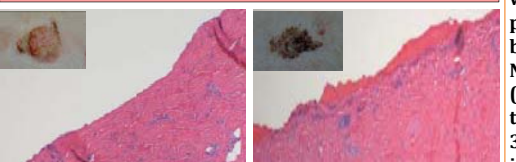
### Intact Tissue



2<sup>nd</sup> degree burn seen on skin after treatment at 0.6 W/cm<sup>2</sup> for 3 mins. Inset (treatment area and visible burn)

Mild reddishness seen on skin after treatment at 0.2 W/cm<sup>2</sup> for 15 mins. Inset (treatment area and mild erythema)

### Wounded Tissue



No burn seen on wound treated for 1 min at low power 0.2 W/cm<sup>2</sup>. Blood coagulation observed. Inset (treated wound)

No burn formation even on wound treated for 15 min at high power 0.6 W/cm<sup>2</sup>. Complete blood clotting observed. Inset (treated wound)

## Conclusions

Non-thermal plasma is non-toxic to intact skin and wounded tissue at doses (1 min at low power) where plasma completely coagulates blood or effectively kills bacteria. Non-Thermal plasma treatment up to 15 min at low doses (0.2 W/cm<sup>2</sup>) is non-toxic to intact skin and even wounded tissue. 3 min treatment at high doses leads to a 2<sup>nd</sup> degree burn in intact skin. 15 min treatment at high doses (0.6 W/cm<sup>2</sup>) leads to formation of a blot clot on the wound which protects it from damage.