A CONVECTION-BASED SYSTEM MAY IMPROVE INTRA-ARTICULAR COOLING FOR REHABILITATION PURPOSES

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INTRODUCTION

Cryotherapy **is an essential modality for rehabilitation in outpatient clinics and for sport injuries. Due to limitation on treatment time and the risk of cutaneous frostbite, the cooling effect may reach superficial structures. Application of such modality is commonly performed by applying ice or gel packs to the treatment segment. This method applies conduction based heat transfer. Such method uses direct contact between the heating/cooling source and the application site. Intraarticular target tissues such as the ACL, meniscus and other structures are restricted with therapeutic treatment using *conduction method (CDM).* There is a need for a cooling system that can target the Intraarticular structures within the allotted treatment time. Using *convection heat transfer (CVM)* allows heat transfer from high to low energy gradient without causing harm to the skin or subcutaneous tissue.**

THE CONCEPT OF CONVECTION VERSUS CONDUCTION HEAT TRANSFER

Instead of applying cold *onto* the affected area creating surface contact; convection cooling method actively *pulls heat out*. Early studies have shown that this method can cool the synovial space of a cadaver pig knee joint by 160% and in less (20% of the) time, when tested against the leading competitor in the space.

PURPOSE OF THE STUDY

- To discuss the concept and method of intra-articular cooling.
- To present data that validate the effectiveness of the method/system in cooling intra-articular structures in cadaver pig leg.
- To compare the data & results of convection and conduction based systems.

METHODS

The CVM system consists of an engine for cooling & heating air, with attachments constructed for the desired airflow pattern that circulate in a disposable cuff.
The cooling system was tested on a swine cadaver leg targeting the knee joint for a period of 60 min using the following parameters,

- full wrap cuff with two inch inlet and outlet, 4 mil polybag 12" tall and 16.5" wide,
- silicone bands to hold it on, steady 35 degree F air flow, flow rate 9.6 CFM.

The swine leg was tested during normal vertical position.

- The temperature gradient was measured for the intra articular structure progressing to subcutaneous tissues to the skin using thermocouples.
- Test was repeated 3 times to ensure consistency and data reliability.
- Test was repeated using CDM system for comparison.

THE TEST BENCH

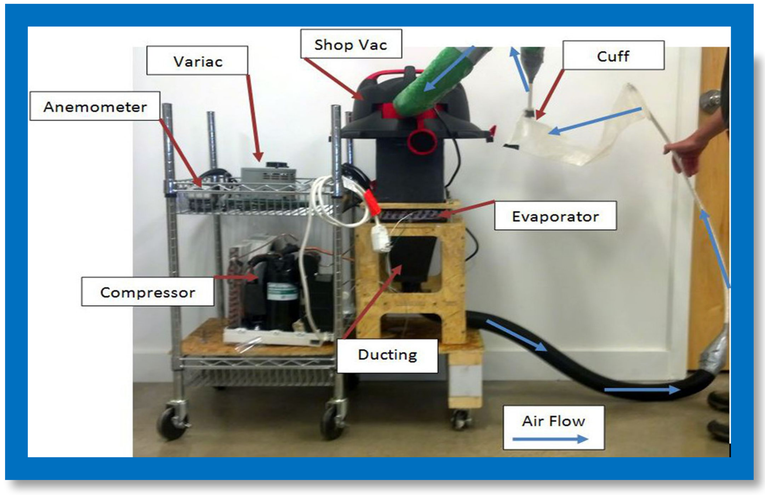

Fig. 1: Test Bench

EXPERIMENTAL PROCEDURES

TEST PROCEDURE:

- Warm cadaver pig leg in a hot water bath
- Prop leg on the stand
- Install Thermocouples
- Hook up cooling device
- Record and analyze data

. TC PROBE LOCATIONS;

- Just under the skin
- Behind the knee cap
- In the muscle

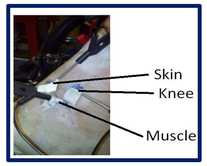

Fig. 3: Placement of probes

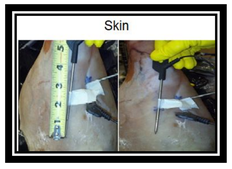

Fig. 4: Skin probe inserted sub-dermal 1.75 inch

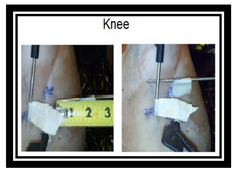

Fig. 5: Knee probe inserted in intra-articular space behind patella 1.25 inches

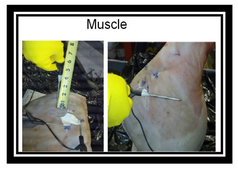

Fig. 6: Muscle probe inserted intra-musclar 3,5 inch

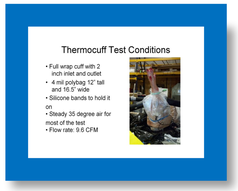

Fig. 7: Thermocuff test conditions

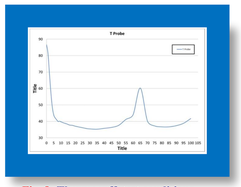

Fig. 8: Thermocuff test conditions

Fig 9: Cadaver pig leg

DATA

TEMP. Fahrenheit	KNEE	SKIN	MUSCLE
SOOTHE AWAY 1	83.3	108.5	76.2
SOOTHE AWAY 2	99.3	96.0	92.3
TC	98.9	95.7	85.2
AMBIENT	93.0	105.4	88.5

Table 1: The initial temperature values of three methods for the knee, skin and muscles

Temp. Diff. F	Knee		Temp. diff.	Skin		Temp. Diff.
	Initial	20 min		Initial	20 min	
SA	99	92	7	96	81	15
TC	99	81	18	96	69	27
Ambient						

Table 2: Temperature changes (before and 20 min) in the knee and skin during SA and TC testing;

RESULTS-CMV

Results from CVM shows a temperature change from 99 to 81 degrees at 20 min for the intraarticular space compared to 99 to 92 for CDM. CVM causes skin temperature changes from 95 to 69 whereas CDM showed a change from 96 to 81 degrees F. None of the cooling options dropped muscle temperature significantly.

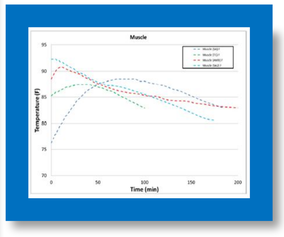

Fig. 10: Comparison of intramuscular temperature with TC(green), SA (blue) and ambient (red). Muscle temperature decreased faster than other methods during the ambient test.

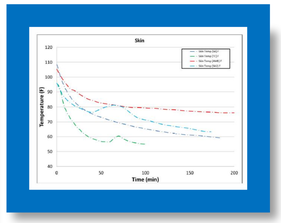

Fig. 11 : Comparison of skin temperature with TC(green), SA (blue) and ambient (red). Skin temperature decreased faster than other methods.

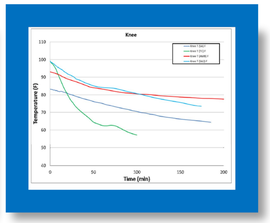

Fig 12 : Comparison of knee temperature with TC (green), SA (blue) and ambient (red). Knee temperature decreased faster than other methods during TC test .

RESULTS-SWINE LEG TEST

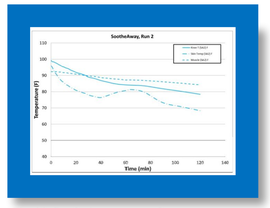

Fig. 14: SootheAway test results

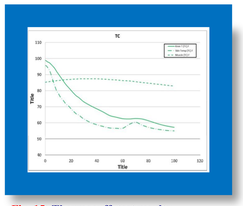

Fig. 15: Thermocuff test results

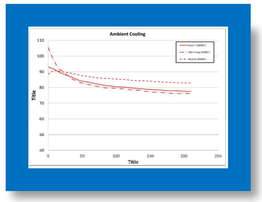

Fig. 16: Ambient cooling test results

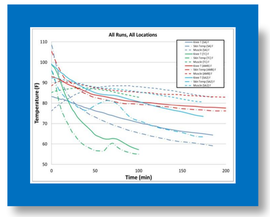

Fig. 17: Cumulative test results

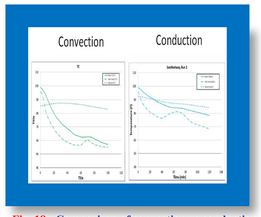

Fig. 18 : Comparison of convection vs conduction cooling methods.

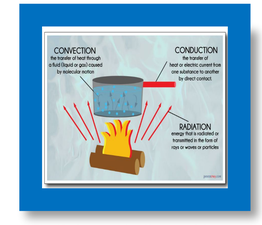

Fig. 19: Comparative diagram of the heat/energy transfer.

Results from the swine leg study shows;

- A temperature gradient of the intra articular structures supporting the validity of the CVM system.
- CVM was better cooling system than CDM.
- This cooling system may be applied on internal injuries for other joints in sport injuries.
- **Convection method** is more effective for cooling tissue when compared to Conduction & requires less time.
- Convection was effective at dropping the knee and skin temperatures, and slightly better at dropping muscle temperatures.
- Convection method reduces the intra-articular temperature faster than conduction cooling method.
- None of the cooling options dropped muscle temperature significantly.
- The similarity between pig and human knee structure suggest suitability of the system for application in human studies and treatment. This needs to be completed before application on patients with knee injuries.
- Conduction unit most likely kept heat in with its neoprene pad, and does not have enough flow to cool quickly or deeply.
- Conduction requires direct surface contact. May lead to uneven distribution of heat and/or hot spots.

OBSERVATIONS

- ✔ Thermocuff in its current configuration is as good or better than the SootheAway for cooling tissue.
- ✔ Thermocuff was effective at dropping the knee &skin temperatures, and slightly better at dropping muscle temp.
- ✔ None of the cooling options dropped muscle temperature significantly.
- ✔ SootheAway cuff most likely kept heat in with its neoprene pad, and does not have enough flow to cool quickly or deeply.

Fig. 20: Thermocuff unit

CLINIC RELEVANCE

The internal operation of convection units relies less on the radiant heating patterns, and more on the even flow of air. With fewer hot and cold spots, the internal temperature is easier to precisely control, and particular temperature settings yield more consistent and repeatable results for further research.

DISCUSSION & CONCLUSION

The more efficient reduction of intraarticular temperature with TC (convection-based system) is due to directional suction of heat from the joint out as compared to SA (conduction based system)
The faster heat transfer induced by CV based than Conduction based system is probably due to the inherent mechanism of the proposed system.

REFERENCES

W.Sabbahi, T. Phillpott. Thermocuff case study; Charlotte, N.C. 2014

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