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ORIGINAL ARTICLE OPEN ACCESS

Evaluation of Force Degradation of the Niti Open Coil Spring After Exposure to High and Low Temperatures, in Vitro Study

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ABSTRACT

Open coil springs are designed to provide expansion force, as indicated in the opening spaces. The super elasticity of Niti arch wires and springs allows the orthodontist to apply almost continuous light force with larger activations, resulting in reduced tissue trauma. However, indirect factors like high or low temperature should be monitored as an essential part of applying any force using open coil springs. These temperature differences may influence the springiness, corrosion, and efficacy of Niti coil springs over time. The aim of this study was to evaluate the force rate of NITI open coil springs compressed from 15.0 mm to 8.5 mm after exposure to high (45 ± 3 °C) and low temperature (10 ± 3°C). Forty-five samples of 15.0 mm long Niti springs were divided into 3 groups (n = 15). Group A was immersed in artificial saliva at 37° C for 21 days. Group B was immersed in hot water (45± 3 °C). Group C was immersed in cold water (10± 3 °C). The springs were then subjected to a compression test using a Manual Digital Force Gauge at 43% of the initial size (pre-stretched). Subsequently, the springs were compressed from 15.0 mm to 8.5 mm, and the data were recorded at Day 0, 1, 10, and 21. The analysis of variance revealed p-values below 0.05 for the four-time frames: initial test (0.046), after 24 hours (0.007), after 10 days (0.082), and after 21 days (0.038), indicating significant differences in the force rate of Niti open coil springs when immersed in different temperatures. Additionally, significant differences were found among the different pairings of the three tested groups. The force rates of open coil springs with low temperature were statistically different across different time frames. However, high temperature affected the coil springs more significantly than low temperature. There were significant differences in the force rate of Niti open coil springs when immersed in different temperatures.

Keywords: Niti open coil spring, Degradation force, Open coil spring

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Introduction

In orthodontic treatment, there is an indication for opening spaces caused by impacted or strongly crowded teeth, as well as for molar distalization [1], which require certain loads of strength that vary from one case to another. Open springs are designed to provide expansion force, as indicated in the opening spaces. There are different mechanics for opening spaces, such as friction and frictionless mechanics. Open NITI and stainless-steel coil springs are included in the friction sector [2].

Although several studies have explored effective and ideal methods to open spaces, the majority provide a consensus, with early studies suggesting that Niti coil springs are the 'best method' as they provide a significantly greater and more consistent rate of gaining space compared to alternative forms of mechanotherapy [3].

These Niti springs produce continuous, light forces over a range of activation. Conventional coil springs (stainless steel, titanium) display a decent force with deflection rate; whereas super elastic Niti springs show a typical force level over time [4]. The stress-strain curve for a super elastic material upon unloading takes place at a fairly constant stress over a significant range of wire activation. These low and continuous loads produced by NITI springs are adequate for biological response [5].

It is generally assumed that optimal tooth movement is achieved by applying forces that are low in magnitude and continuous in nature. Such forces minimize tissue destruction and produce a relatively constant stress in the periodontal ligament during tooth movement [6].

The super elasticity of NiTi arch wires and springs allows the orthodontist to apply an almost continuous light force with larger activations, resulting in the reduction of tissue trauma and patient discomfort, thus facilitating enhanced tooth movement [7].However, there are indirect factors like high or low temperature that should be monitored and are essential parts to be observed during the application of any force by open coil springs or wires in the oral cavity, especially nowadays where different options of hot and icy beverages are available in the markets for people to purchase.

The oral cavity is one of the most inhospitable environments in the human body. Therefore, orthodontic arch wires, coils, or brackets are subject to larger temperature variations than most other parts, coping with ice-cold temperatures (10 ± 3°C) through to hot coffee and soup (45 ± 3 °C) [2]. Therefore, the aim of this study was to evaluate the force degradation of NITI open coil springs after exposure to high and low temperature.

Methods

This study utilized various research instruments to collect data on the force degradation of NITI springs under different temperatures. The materials and methods included:

- **Samples:** Forty-five NITI springs (15.0 mm long) were divided into three groups (n=15).
- **Containers:** Used for soaking springs at 10±3°C (mini refrigerator with ice cubes) and 45±3°C (water heater).
- **Digital Thermometers:** Two thermometers to accurately measure and maintain the specified temperatures.
- **Wires:** Rectangular 0.016 x 0.022 SS wires, 25 mm long, passively inserted into an acrylic block.
- **Acrylic Base:** Designed to hold the SS wire perpendicular to the acrylic plate and insert open coil springs.
- **Manual Digital Force Gauge:** A ZMF-500 manual tester for measuring tensile and compressive strength.
- **Dynamometer:** Device for measuring force, torque, or power.
- **Mini Refrigerator:** FREGO Refrigerator Mini Bar with a capacity of 3.2 cubic feet for maintaining controlled temperatures.

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- **Benchtop Incubator:** Leased for precise temperature control and insulation during the immersion period, with features for temperature range, air flap control, stackability, and data recording via USB.

These tools ensured precise measurements and controlled conditions to evaluate the impact of temperature on the NITI springs' force.

Procedure

45 samples of Niti springs, 15.0 mm long, were be consistent in the grouping (n = 15) according to the temperature before testing.

Hot and cold temperature immersion procedure

The samples are divided into three groups:

Group A: 15 samples of open coil spring in 100 ml of artificial saliva at 37º C for 21 days.

Group B: 15 samples of open coil spring were immersed to hot water (45± 3 °C) for 60 seconds then washed with distilled water then incubation in artificial saliva.

Group C: 15 samples of open coil spring were immersed in cold water (10 ± 3 °C) for 60 seconds then washed with distilled water for 10 seconds. They were then incubated in artificial saliva (8). To determine the temperature, 2 digital thermometers were used. They were used to determine 10 ± 3 ºC and 45 ± 3 ºC (8). During the procedure, a mini refrigerator with ice cubes was used to achieve 10 ± 3 ºC and water heater was used to maintain the temperature at 45± 3 º C. The coil springs were immersed in short-term bath of cold (10± 3 °C) or hot 45± 3 °C).

Water. Initially, the Group B was subjected to 100 mL of hot water for 60 seconds. Group C was subjected to 100 mL of cold water for 60 seconds. After this, heating and cooling process, the wire was examined whether permanent changes in coil springs properties had occurred during heat exposure.

After immersion, the coil springs were collected with tweezer and air dried before compression testing. The response variables were the force rate of open coil springs assessed separately for each sample. The force rate was obtained with the aid of the Manual Digital Force Gauge.

Compression Test:

- Conducted at 43% of the springs' initial size (pre-stretch).
- Springs compressed from 15.0 mm to 8.5 mm.
- Data recorded as compression (mm) versus force (g).

Testing Timeline:

- Day 0: Initial compression test for all samples before immersion.
- Day 1: Compression test after 24 hours of immersion (5 samples per group).
- Day 10: Compression test after 10 days of immersion (5 samples per group).
- Day 21: Final compression test after 21 days of immersion for all samples.

The study assessed changes in the force rate of the springs after exposure to hot and cold temperatures, with periodic testing to track the impact over time. Comparison in between the periods was done to check the effect of high and low temperature on the compression test relative to time. The purpose of the study is to evaluate the effect of High and Low Temperature on force rate of NITI open coil spring compressed at a speed of 10 mm/min (from 15.0 mm to 8.5 mm [8]. the following questions were answered:

Results

Problem NO.1: What is the force rate of NITI open coil spring compressed (from 15.0 mm to 8.5 mm)?

Table 1 represents the force rate of NITI open coil spring compressed (from 15.0 mm to 8.5 mm).

Table 1: Force rate of NITI open coil spring compressed (from 15.0 mm to 8.5 mm)

Sample / coil spring in	Compression test Day 0	Compression test Day 1	Compression test Day 10	Compression test Day 21

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artificial saliva				
1	3.6	3.6	3.1	2.8
2	3.6	3.6	3.2	2.8
3	3.6	3.6	3.1	2.9
4	3.5	3.5	3.9	2.5
5	3.6	3.6	3.3	3.1
6	3.5	Mean: 3.6	3.32	2.82
7	3.2	SD: 0.04	0.33	0.24
8	3.4			
9	3.6			
10	3.6			
11	3.4			
12	3.6			
13	3.5			
14	3.6			
15	3.8			
Mean	3.54			
SD	0.13			

The highest value was recorded at day 0 with 3.8 newton, while the lowest value was 2.5 newton.

Problem NO. 2: What is the force of NITI open coil spring subjected to compression force and immersed in (45± 3 °C) for 60 seconds over the course of day 0, day 1, day 10 and 21 days?

Table 2: Force of NITI open coil spring subjected to compression force and immersed in (45± 3 °C)

Sample / coil spring in high temperature	**Compression test Day 0**	**Compression test Day 1**	**Compression test Day 10**	**Compression test Day 21**
1.	3.6	3.6	3.2	2.8
2	3.7	3.4	3.0	2.9
3	3.5	3.2	3.1	2.9
4	3.5	3.3	3.1	2.8
5	3.2	3.6	3.2	3.1
6	3.2	Mean: 3.4	3.1	2.9
7	3.2	SD: 0.17	0.08	0.12
8	3.6			
9	3.6			
10	3.3			
11	3.4			
12	3.4			
13	3.4			
14	3.6			
15	3.4			
Mean	3.44			
SD	0.16			

Table 2 represents the force of NITI open coil spring subjected to compression force and immersed in (45± 3 °C) for day 0, day 1, day 10 and 21 days. The highest Value was recorded at day 0 with 3.7 newton, while the lowest value was 2.8 newton.

Problem NO.3: What is the force of NITI open coil spring compression test after immersion in cold bath (10± 3 °C) for 60 seconds over the course of day 0, day 1, day 10 and 21 days?

Table 3: Force of NITI open coil spring compression test after immersion in cold bath (10± 3 °C)

Sample / coil spring in low temperature	**Compression test Day 0**	**Compression test Day 1**	**Compression test Day 10**	**Compression test Day 21**
1.	3.2	3.5	3.3	3.2
2	3.5	3.2	3.0	2.8
3	3.2	3.2	3.1	3.1
4	3.1	3.1	3.0	3.0
5	3.5	3.6	3.4	3.0
6	3.6	Mean: 3.3	3.16	3.02
7	3.5	SD: 0.21	0.18	0.14
8	3.6			
9	3.6			
10	3.3			
11	3.2			
12	3.5			
13	3.4			
14	3.5			
15	3.5			
Mean	3.4			

Sample / coil spring in low temperature	Compression test Day 0	Compression test Day 1	Compression test Day 10	Compression test Day 21
SD	0.16			

Table 3 represented the force of NITI open coil spring compression test after immersion in cold bath (10± 3 °C) for 60 seconds over the course of day 0, day 1, day 10 and 21 Days. The highest value was recorded at day 0 with 3.6 newton, while the lowest value was 2.8 newton.

Table 4: Descriptive statistics of the force rate of NITI open coil spring

Time intervals	PARAMETERS	N	Mean	SD
Initial test	Group A control	15	360.93	13.70
	Group B hot	15	349.33	15.89
	Group C cold	15	350.33	18.45
After 24 hours	Group A control	5	365	4.47
	Group B hot	5	339	17.89
	Group C cold	5	349	21.68
After 10 days	Group A control	5	319	14.83
	Group B hot	5	323	8.37
	Group C cold	5	319	18.17
After 21 days	Group A control	5	293.4	29.37
	Group B hot	5	310	12.25
	Group C cold	5	296	11.40

Descriptive Statistics counts (N), Mean and Standard deviation of the force rate of NITI open coil spring.
Table 4 shows the descriptive statistics of the force rate of NITI open coil spring. Descriptive statistics were expressed in terms of counts (N), mean and standard deviation. The mean value of group A (initial test) was 360.93 and the standard deviation was 13.70; for the mean value of group B (initial test) it was 349.33 and the standard deviation was 18.45; while the mean value of group C (initial test) was 350.33 and the standard deviation was 15.89; for the group A (after 24 hours) the mean value was 365 and a standard deviation of 4.47; for the mean value of group B (after 24 hours) it was 339 and a standard deviation of 21.68; while the mean value of group C (after 24 hours)was 349 and a standard deviation of 17.89; then the mean value of group A (after 10 days) was 319 and a standard deviation of 14.83; for the group B (after 10 days) the mean value was 323 and a standard deviation of 18.17; while the mean value of group C (after 10 days) was 319 and a standard deviation of 8.37; and for the mean value of group A (after 21 days) was 293.4 and a standard deviation of 29.37; for the group B (after 21 days) the mean value was 310 and a standard deviation of 11.40; and the mean value of group C (after 21 days) was 296 and a standard deviation of 12.25.
The results of this study are supported by previous conclusions [16]. The examined specimens were thermocycle 100 cycles for 30 secs Between 5°C and 55 °C. The results revealed a change in microleakage and hardness and springiness after subjected to high and low temperature.

Table 5: Shapiro-Wilk test (Test for normality) for the force rate of NITI open coil spring

Time intervals	PARAMETERS	N	p-value
Initial test	Group A control	15	0.735
	Group B hot	15	0.250
	Group C cold	15	0.541
After 24 hours	Group A control	5	0.412
	Group B hot	5	0.470
	Group C cold	5	0.330
After 10 days	Group A control	5	0.930
	Group B hot	5	0.390
	Group C cold	5	0.310
After 21 days	Group A control	5	0.820
	Group B hot	5	0.182
	Group C cold	5	0.960

Table 5 presents the test for normality (Shapiro-Wilk). This was done to test the comparability of the data for a parametric statistical treatment. The p-values of all twelve (12) parameters tested were all above the $p>0.05$ which meant that the data were normally distributed. Thus, a parametric test was

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applied, specifically analysis of variance, which was used to compare the force rate of NITI open coil spring.

4- Is there a significant difference in the force rate of NITI open coil spring immersed in 45± 3 °C, 10± 3 °C and 37 °C?

Table 6: Analysis of variance for the difference force rate of NITI open coil spring

Time intervals	Difference force	p-value
Initial test	44	0.046
After 24 hours	14	0.007
After 10 days	14	0.082
After 21 days	14	0.038

Table 6 presents the result of the analysis of variance. The p-values of the four (4) time frame yielded a p-value below 0.05, these were the following: initial test (0.046), after 24 hours (0.007), after 10 days (0.082), and after 21 days (0.038), which meant that there were significant differences among the force rate of NITI open coil spring when immersed in different temperature.

Table 7: Post Hoc Test using Tukey Test

Time intervals	p-value	Interpretation
Initial test		
Group A vs Group B	<0.001	Significant
Group A vs Group C	<0.001	Significant
Group B vs Group C	<0.001	Significant
After 24 hours		
Group A vs Group B	<0.001	Significant
Group A vs Group C	<0.001	Significant
Group B vs Group C	<0.001	Significant
After 10 days		
Group A vs Group B	<0.001	Significant
Group A vs Group C	<0.001	Significant
Group B vs Group C	<0.001	Significant
After 21 days		
Group A vs Group B	<0.001	Significant
Group A vs Group C	<0.001	Significant
Group B vs Group C	<0.001	Significant

Based on Tukey test, the result yielded significant difference among the different pairings of the three groups that were tested, with all yielding a p-value of < 0.001. the force rate of open coil spring of Group C (cold) is more than Group B (hot) with significant different at p value <0.001. Even the force rate of open coil spring exposed to hot water degraded over time from 24 hours with value 0.470 Newton to another value after 10 days of 0.390 Newton until it reached the lowest value among all groups which is 0.182 Newton.

Moreover, the force rate degradation of the three groups within the same period was as follows: Group B (HOT) < Group C (COLD) < Group A (INITIAL).

Meling et al. [8] supported the results of our study with their findings. The stiffnesses and springiness of the coil springs were greatly affected by the degree of heating and cooling which increased the total deformation. Lastly, the effect of heating was notable but short lasting. Moreover, the effect of temperature alterations at 0.5-mm activation was like the effect of wire heating and cooling at 2.0-mm activation.

Generally, it can be noted that mechanical characteristics of the springs may have been affected by the composition and homogeneity of the NITI alloy that constitutes them, in addition to the external factors that may affect, consequently, its behavior in the generation of forces due to temperature variations [20].

It is essential to consider that external factors that influence the oral cavity, such as hot and cold beverages and fluctuations in temperature, can affect the force exerted by the springs. [9] Observed that small changes in temperature can generate significant changes in the generation of force, that is, the force values at 37°C were twice higher than the cold temperature of 10°C, that is, the force rates deform with increasing temperature as well.

Results by [17, 18] reveals that springiness and force degradation is affected when largely activated, and caused by martensitic transformations of temperature alterations. Furthermore, the stiffnesses were greatly affected by the degree of heating and cooling which increased the total deformation. Moreover, the effect of temperature alterations at 0.5-mm activation was like the effect of samples heating and cooling at 2.0-mm activation [8]. Small changes in temperature can generate significant changes in the generation of force, that is, the force values at 37°C were twice higher than the temperature of 20 °C [9]. that is, the force values increase with increasing temperature, and decrease with reduction [23].

Force Rate of NITI Open Coil Springs:

1. Artificial Saliva Immersion:
   - Initial: 360 N
   - Day 1: 365 N
   - Day 10: 319 N
   - Day 21: 293.4 N
2. Hot Water Immersion (45±3°C):
   - 24 Hours: Mean 349 N, SD 17.89
   - 10 Days: Mean 319 N, SD 8.37
   - 21 Days: Mean 296 N, SD 12.25
3. Cold Water Immersion (10±3°C):
   - 24 Hours: Mean 339 N, SD 21.68
   - 10 Days: Mean 323 N, SD 18.17
   - 21 Days: Mean 310 N, SD 11.40

Statistical Analysis:

- ANOVA Results:
  - Initial Test: $p=0.046$
  - After 24 Hours: $p=0.007$
  - After 10 Days: $p=0.082$
  - After 21 Days: $p=0.038$

These p-values indicate significant differences in the force rates of the springs at different temperatures.

- Tukey Test:
  - Significant differences among all group pairings, $p<0.001$
  - Group B (hot) had significantly higher force rates than Group C (cold), $p<0.001$

Key Observations:

1. Cold Bath Degradation:
   - Force rate decreased over time from 0.470 N at 24 hours to 0.390 N at 10 days, reaching 0.182 N at 21 days.
2. Temperature Effect:
   - Small temperature changes significantly impacted force generation.
   - Force values at 37°C were twice as high as at 20°C.
3. Spring Properties**:**
   - The stiffness and springiness of coil springs were significantly affected by heating and cooling.
   - Temperature changes increased total deformation, with the effect of heating being notable but short-lasting.
   - Similar effects were observed at both 0.5-mm and 2.0-mm activations for temperature changes.

Conclusion

This study aimed to evaluate the effect of High and Low Temperature on force rate of NITI open coil spring compressed at a speed of 10 mm/min (from 15.0 mm to 8.5 mm [8].

Within the limits of this study, and based on the results achieved; the researcher Therefore, concludes the following:

1- The hypothesis is rejected which means there is significant difference in the force rate of NITI open coil spring subjected to compression test before and after of 45± 3 °C, 10± 3 °C and 37 °C.

2- In the oral environment, force degradation and deformation of open coil spring increased with high temperature.

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3- Force rates of OCS with low temperature was statistically different with different time frames. However, high temperature affected the coil spring more significantly than low temperature.

4- There were significant differences among the force rate of NITI open coil spring when immersed in different temperature. Moreover, the results yielded significant difference+

5- among the different pairings of the three groups that were tested.

6- Generally, it can be noted that mechanical characteristics of the springs may have been affected by the composition and homogeneity of the NITI alloy that constitutes them, in addition to the external factors that may affect, consequently, its behavior in the generation of forces due to temperature variations [24].

7- It is essential to consider that external factors that influence the oral cavity, such as hot and cold beverages and fluctuations in temperature, can affect the force exerted by the springs.

It was observed that small changes in temperature can generate significant changes in the generation of force, that is, the force values at 37 °C were twice higher than the cold temperature of 10 °C, that is, the force rates deform with increasing temperature as well [24].

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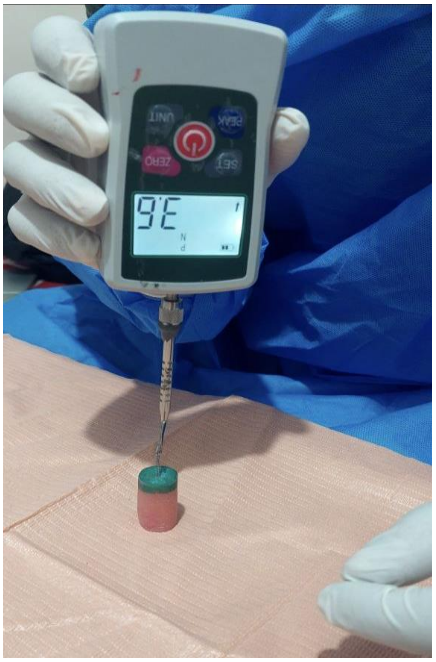
Appendices



Appendix D: Forty-five samples

Red color for hot sample.
Green color for cold sample.
Blue color for control sample.

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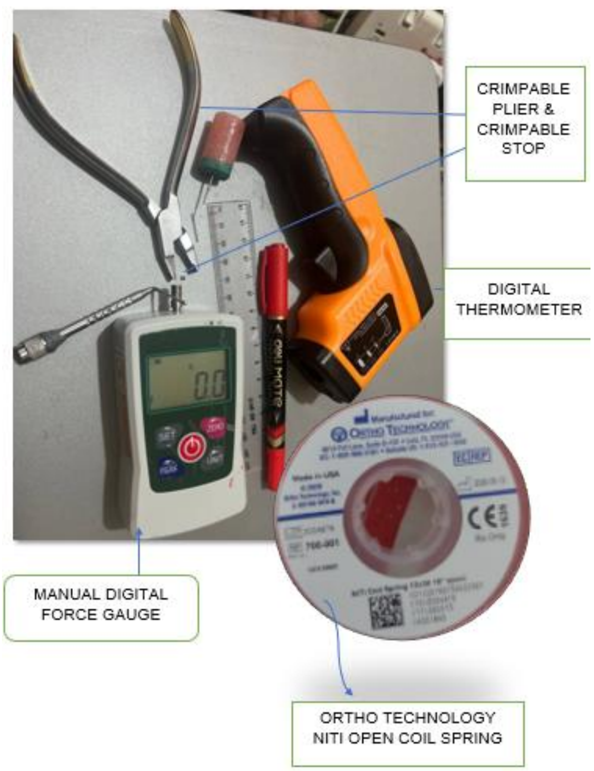
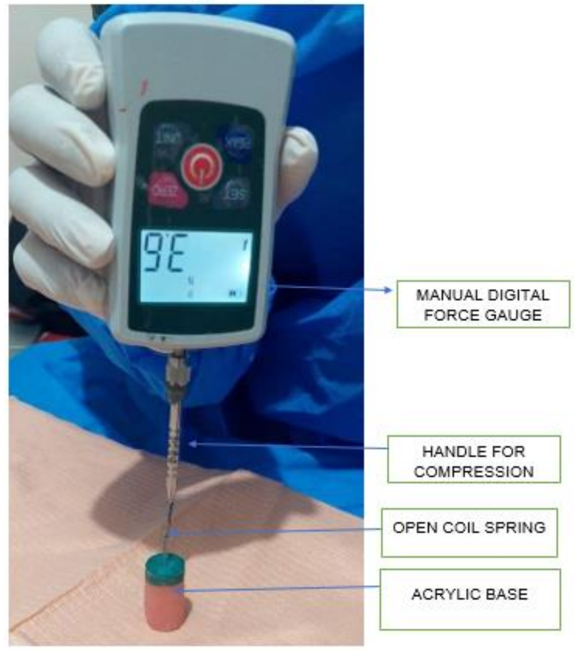
Appendix F: Instruments



Appendix J: Compression Test



The springs underwent a compression test using the Manual Digital Force Gauge, conducted at 43% of their initial size (pre-stretch). Subsequently, the compression continued from 15.0 mm to 8.5 mm, with data recorded.