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Rush University Medical Center

Contribution of Trabecular Bone Properties to Implant Fixation Strength in Rats

Frank C. Ko, Meghan M. Moran, Brittany M Wilson, Ryan D. Ross, Amarjit S. Virdi, D. Rick Sumner

Introduction

- Over 1 million total hip and knee replacement surgeries performed each year (Maradit et al. 2015)

- 20% of patients show evidence of aseptic loosening within 10 years (Marshall et al. 2008)

- Revision rate expected to increase by more than 130% by the year 2030 (Kurtz et al. 2009)

- Maximizing bone-implant construct extends the longevity of primary joint replacements (Malchau et al. 2002; Zhan et al. 2007)


Osteolysis

Gallo et al. 2013

Preclinical Model of Implant Placement

- Intra-articular administration of lipopolysaccharide-doped polyethylene particles induces implant loosening in rats (Liu et al. 2012)

- Anabolic therapy significantly increases implant fixation strength in rats (Virdi et al. 2012)

- Non-destructive quantitation of bone-implant contact (BIC) by microcomputed tomography (microCT) (Meagher et al. 2018)

- Assessing correlations between microCT outcomes and mechanical pull-out strength possible
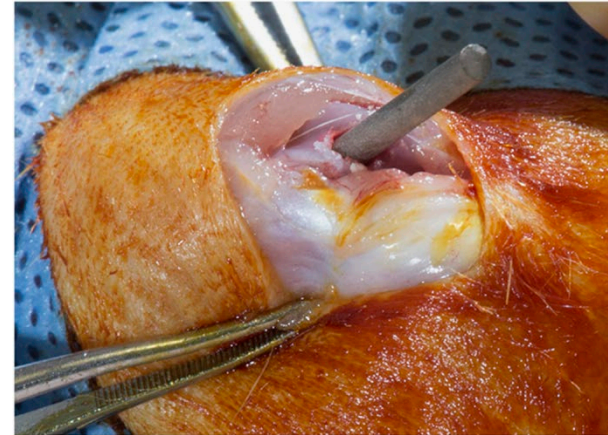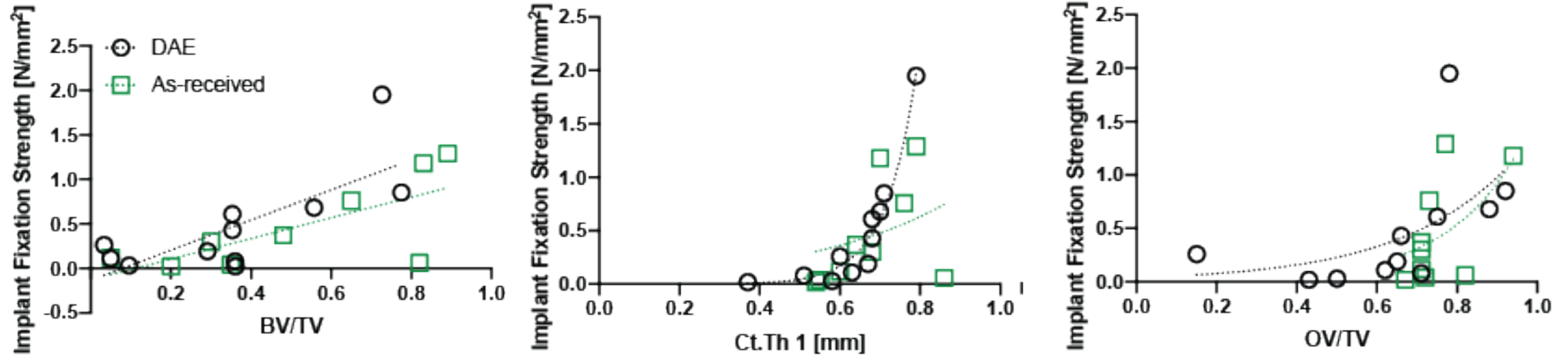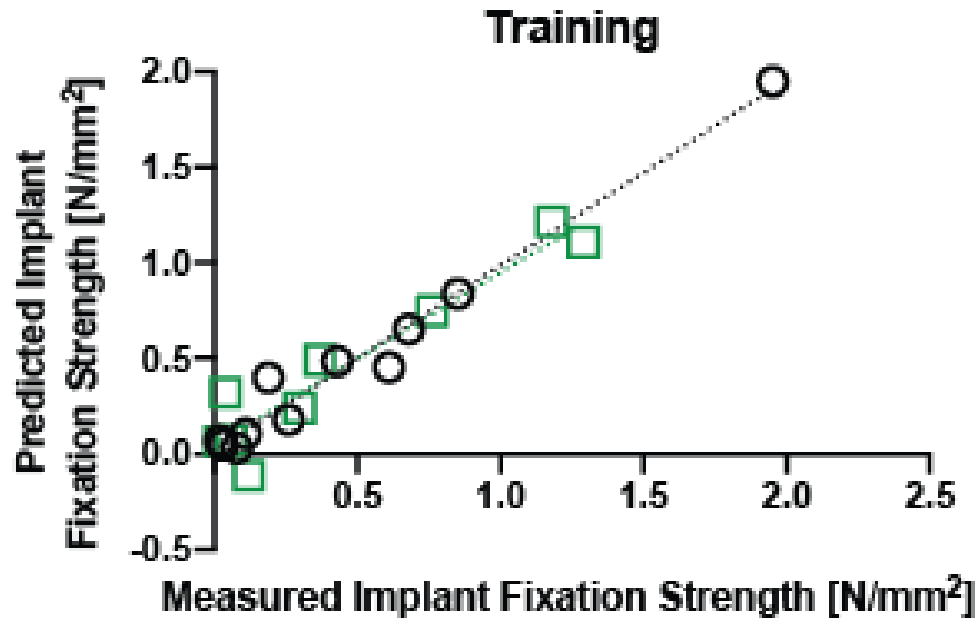

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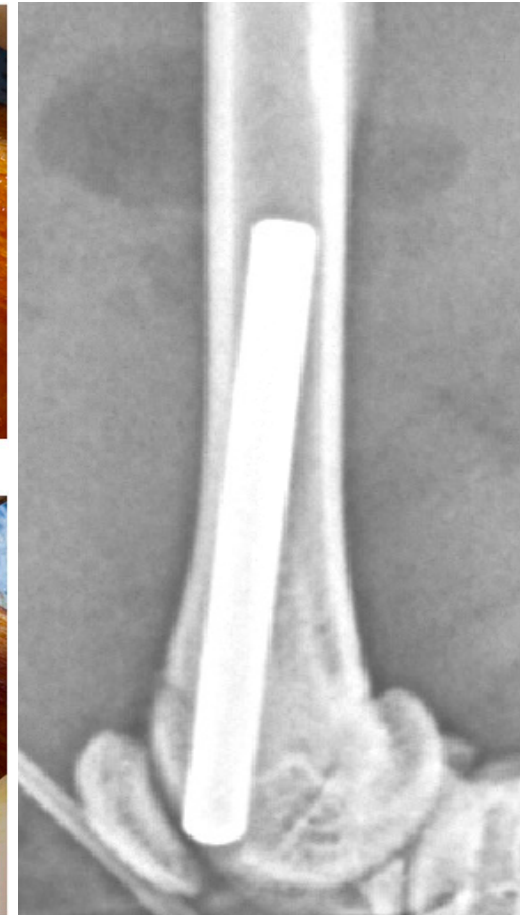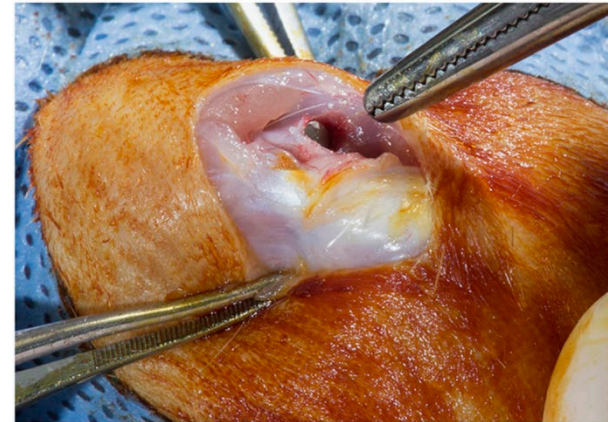
Moran et al. 2016

Contribution of BIC and peri-implant bone properties to implant fixation strength

$$Implant\ fixation\ strength = A(BV/TV) + Be^{C*Ct.Th.} + De^{E*OV/TV} + F$$

Ko et al. 2019

Contribution of BIC and peri-implant bone properties to implant fixation strength

Training

Validation

Correlation			
Type	r^2	p	m
As-received	0.905	<0.0001	0.903
DAE	0.974	<0.0001	0.974
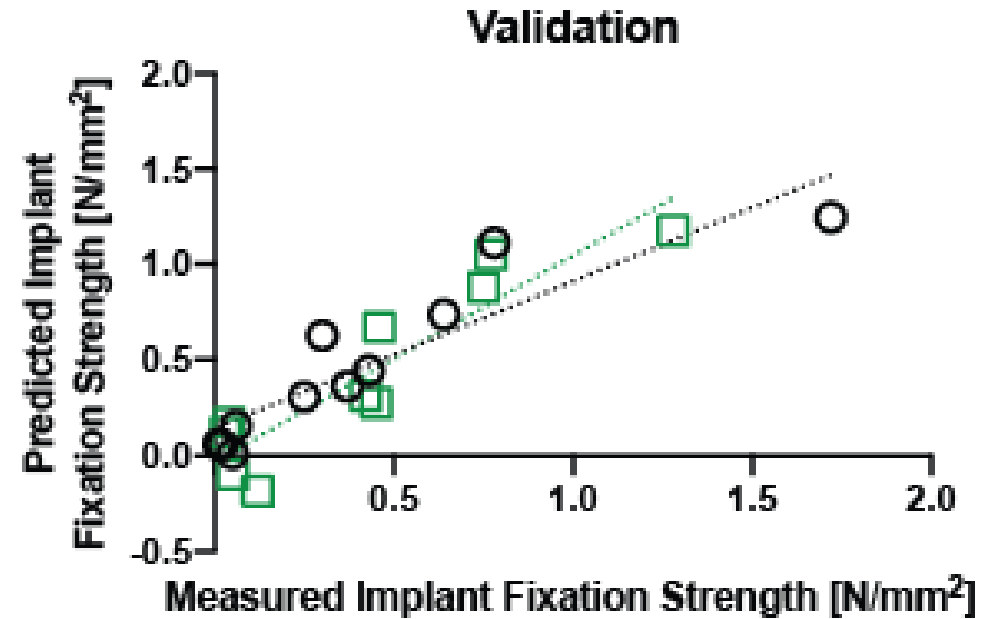
Correlation			
Type	r^2	p	m
As-received	0.843	0.0002	1.079
DAE	0.825	0.0001	0.770

Ko et al. 2019

Contribution of BIC and peri-implant bone properties to implant fixation strength
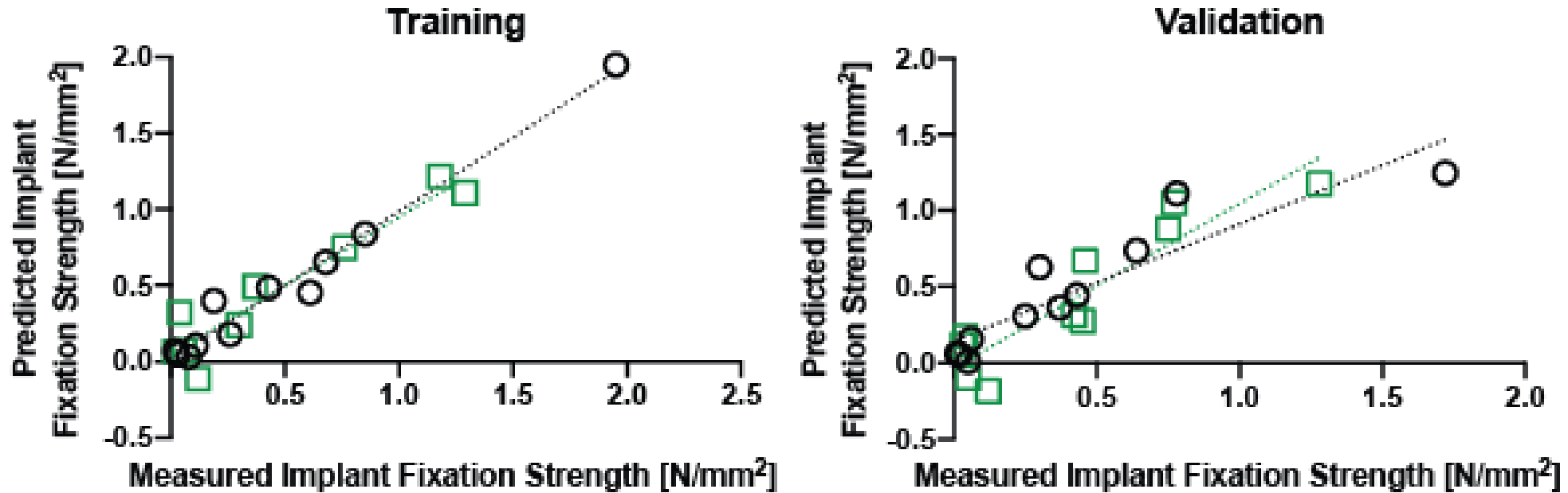
Can other peri-implant trabecular bone properties also predict the implant fixation strength?

Ko et al. 2019

Objective

Use statistical modeling approach to determine which trabecular bone properties are the most important in determining the implant fixation strength in rats

Experimental Design

Male 3 month-old Sprague Dawley Rats

Experimental Design

Male 3 month-old Sprague Dawley Rats

6-week

12-week

Experimental Design

```
                    Male 3 month-old Sprague Dawley Rats

              6-week                                    12-week

   Vehicle    PE    PE + Zol   PE +      Vehicle   PE   PE + Zol   PE +
                               Scl Ab                             Scl Ab
```

n = 10 - 12/group

Experimental Design

Male 3 month-old Sprague Dawley Rats

6-week

12-week

Vehicle | PE | PE + Zol | PE + Scl Ab

Vehicle | PE | PE + Zol | PE + Scl Ab
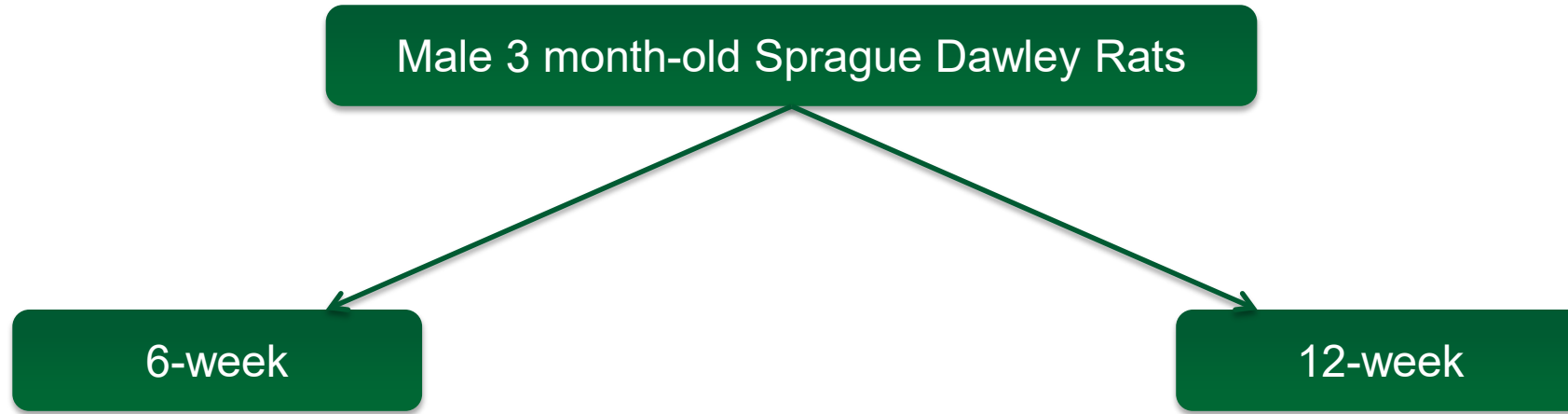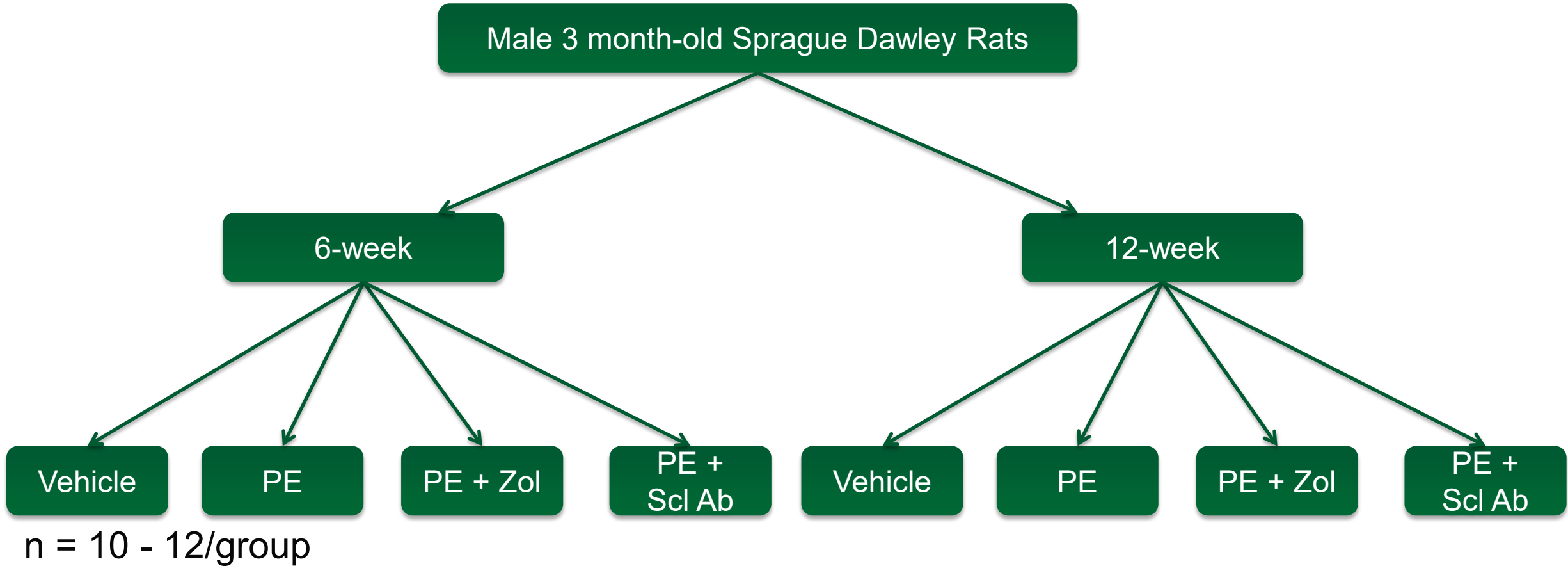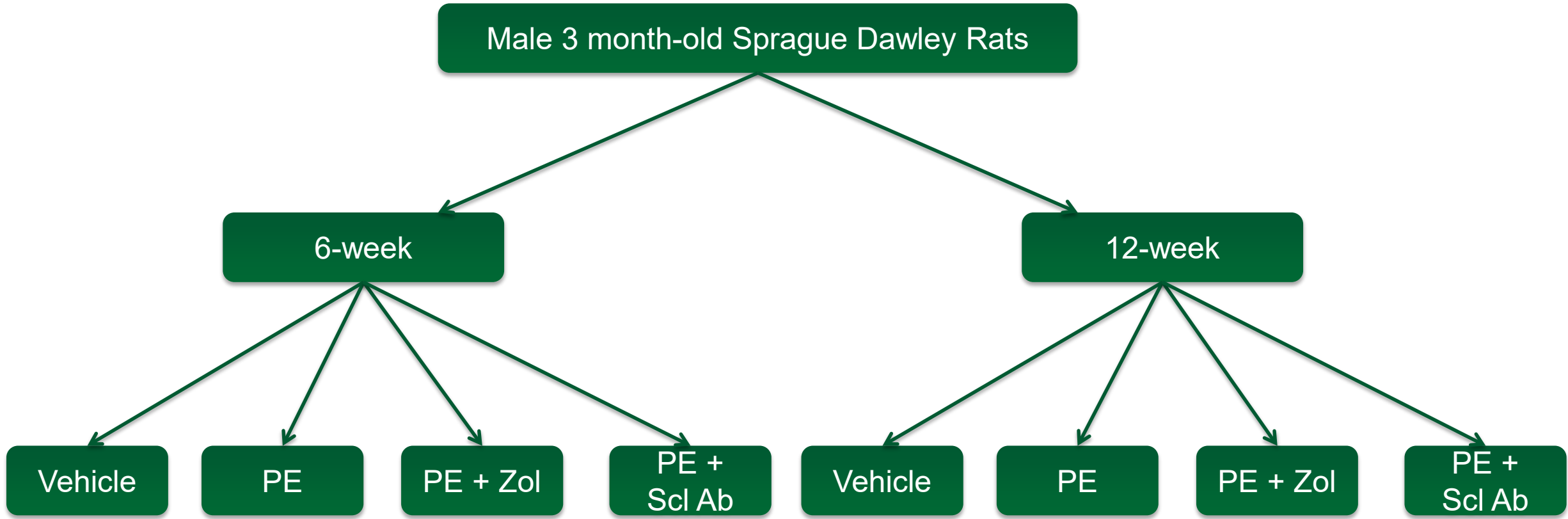
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Maximizing variance in experimental outcome

Experimental Outcome

BV/TV, Tb.Th, Tb.Sp, Tb.N, SMI, ConnD, BS/BV

Experimental Outcome

BV/TV, Tb.Th, Tb.Sp, Tb.N, SMI, ConnD, BS/BV

Implant Fixation Strength

Statistical Modeling

Training and Validation Dataset → **Correlation** → **Step-wise Linear Regression** → **Determine Model Fit** → **Validate Model Fit**

Assigning Training and Validation Dataset

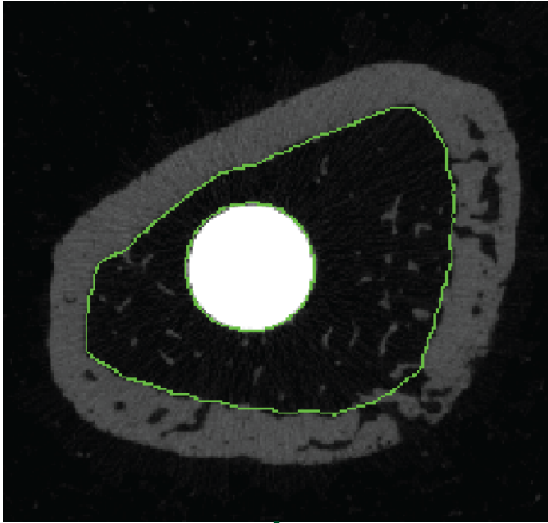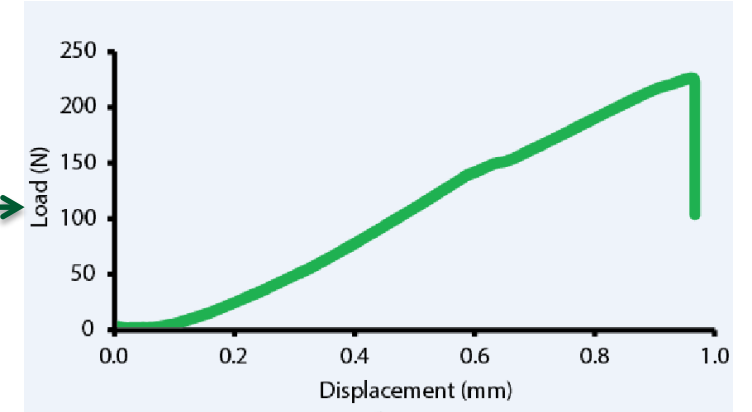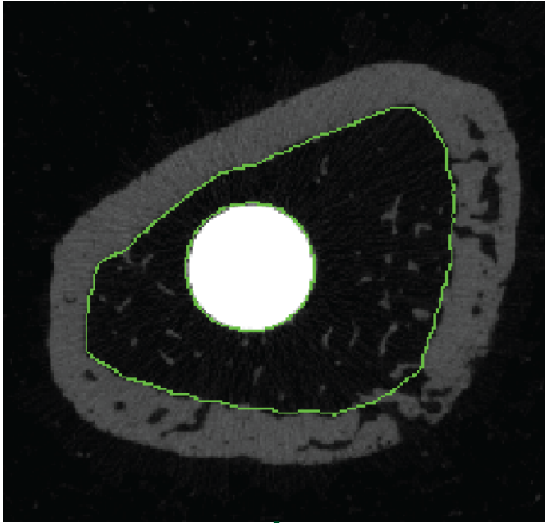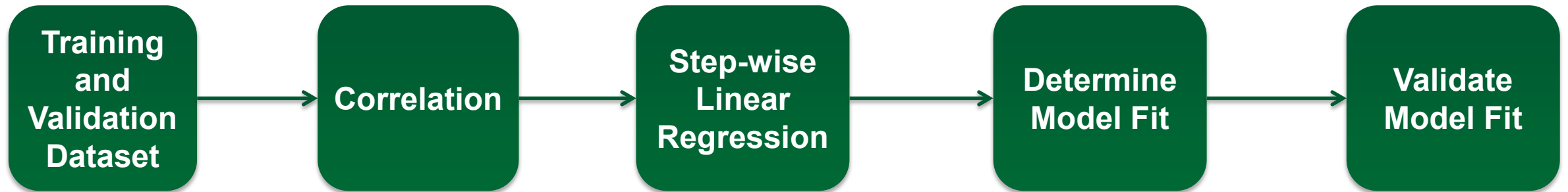| Rat	Group	BV.TV	SMI	Conn.D	Tb.N	Tb.Th	Tb.Sp	BS.BV	DA	Strength	Group
643	PE+Zol 6	0.134	2.063	55.902	2.829	0.077	0.360	38.456	1.641	0.055	**Valid**
615	PE+SclAb 0	0.582	-2.258	35.398	3.484	0.204	0.273	11.272	1.762	0.121	**Train**
651	Vehicle 6	0.147	2.021	62.811	2.753	0.077	0.367	37.638	1.612	0.280	**Valid**
673	Vehicle 6	0.124	2.332	43.602	2.234	0.091	0.463	34.075	1.712	0.300	**Train**
654	PE 6	0.285	1.058	86.128	3.412	0.105	0.296	26.338	1.762	0.512	**Valid**
632	PE 6	0.164	2.046	64.151	2.880	0.089	0.352	34.159	1.734	0.689	**Train**
633	PE 6	0.168	2.367	54.850	2.814	0.117	0.358	30.062	1.617	0.801	**Valid**
612	PE 12	0.135	1.927	52.304	2.759	0.075	0.364	38.498	1.687	0.850	**Train**

Training and Validation Dataset

↓

Correlation

↓

Step-wise Linear Regression

↓

Determine Model Fit

↓

Validate Model Fit

Correlation of Implant Fixation Strength and Peri-Implant Trabecular Bone Properties

Pearson's Correlation

		BV/TV	SMI	ConnD	Tb.N	Tb.Th	Tb.Sp	BS/BV	DA
Strength	Correlation Coefficient	0.793	-0.772	0.155	0.503	0.649	-0.473	-0.662	0.135
	P-value	<0.001	<0.001	0.353	0.001	<0.001	0.003	<0.001	0.417

Training and Validation Dataset

Correlation

Step-wise Linear Regression

Determine Model Fit

Validate Model Fit

Correlation of Implant Fixation Strength and Peri-Implant Trabecular Bone Properties

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Training and Validation Dataset

Correlation

Step-wise Linear Regression

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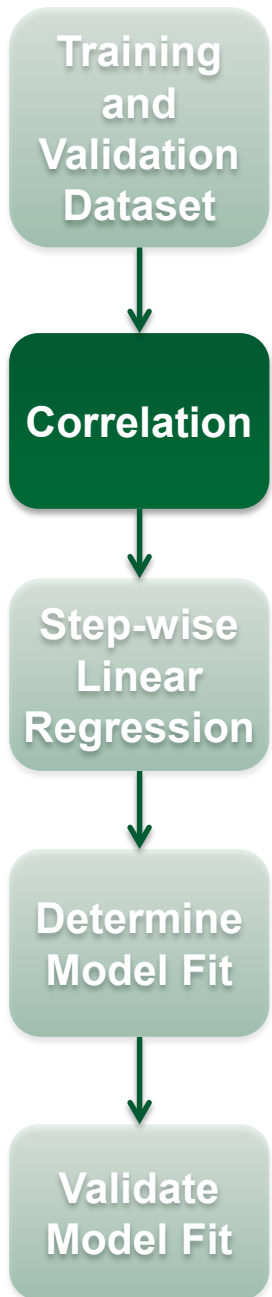
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Spearman's Correlation

		BV/TV	SMI	ConnD	Tb.N	Tb.Th	Tb.Sp	BS/BV	DA
Strength	Correlation Coefficient	0.644	-0.662	-0.095	0.340	0.473	-0.398	-0.540	0.102
	P-value	<0.001	<0.001	0.571	0.037	0.003	0.013	<0.001	0.544

Training and Validation Dataset

Correlation

Step-wise Linear Regression

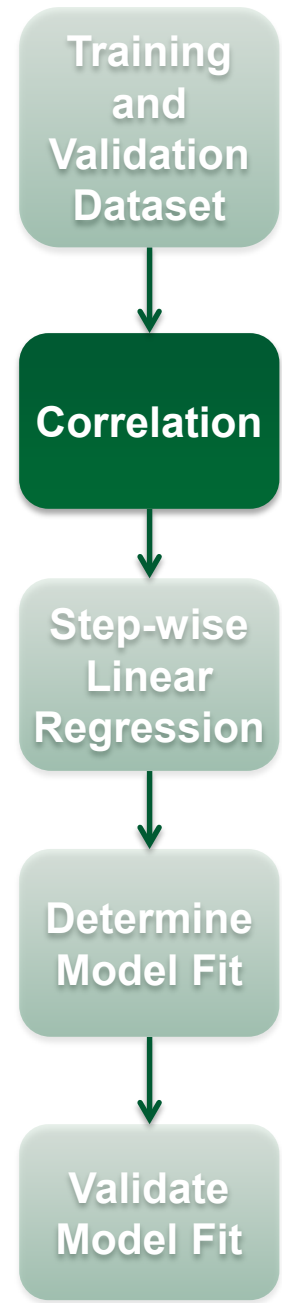Determine Model Fit

Validate Model Fit

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- Training and Validation Dataset
- **Correlation**
- Step-wise Linear Regression
- Determine Model Fit
- Validate Model Fit

Correlation of Implant Fixation Strength and Peri-Implant Trabecular Bone Properties

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Trabecular bone properties are linearly correlated to implant fixation strength

Training and Validation Dataset

Correlation

Step-wise Linear Regression

Determine Model Fit

Validate Model Fit

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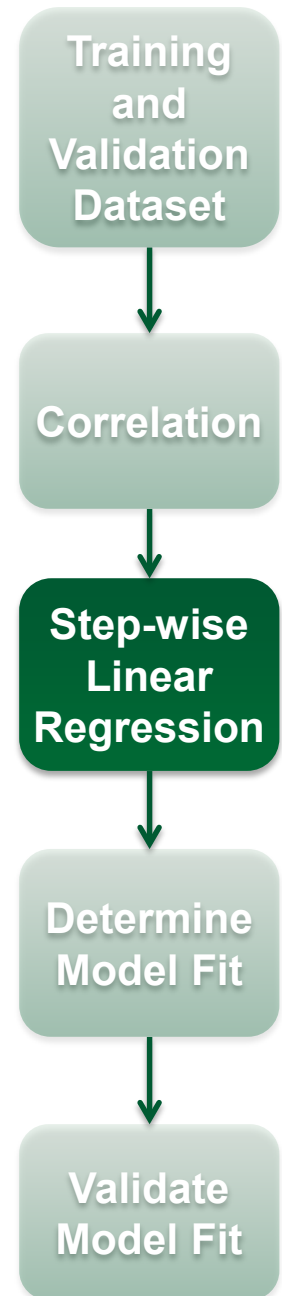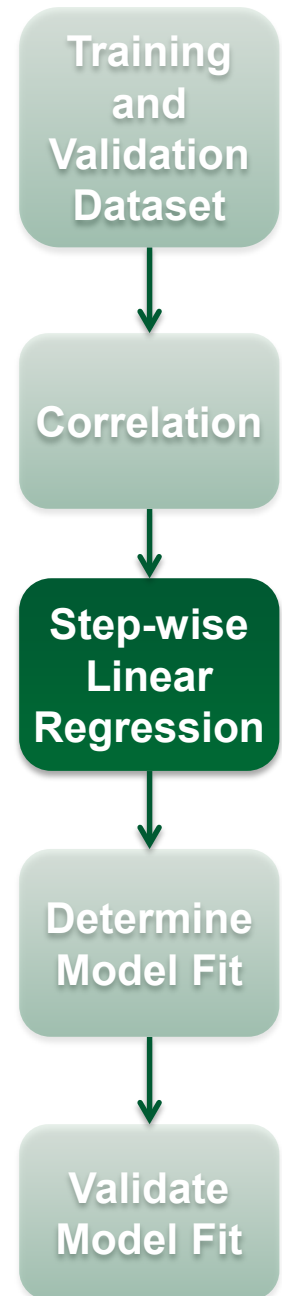# Relative Importance of BV/TV, SMI, Tb.Th, and BS/BV to Implant Fixation Strength

- Step-wise linear regression with F-in ≤ 0.05 and F-out ≥ 0.10

Predictor	Change in Adjusted R Square	Significance of Change	Model Significance	$\triangle r^2$
BV/TV	0.628	<0.001	<0.001	0.628

- BV/TV explained 62.8% variance in implant fixation strength

Training and Validation Dataset

Correlation

Step-wise Linear Regression

Determine Model Fit

Validate Model Fit

Relative Importance of BV/TV, SMI, Tb.Th, and BS/BV to Implant Fixation Strength

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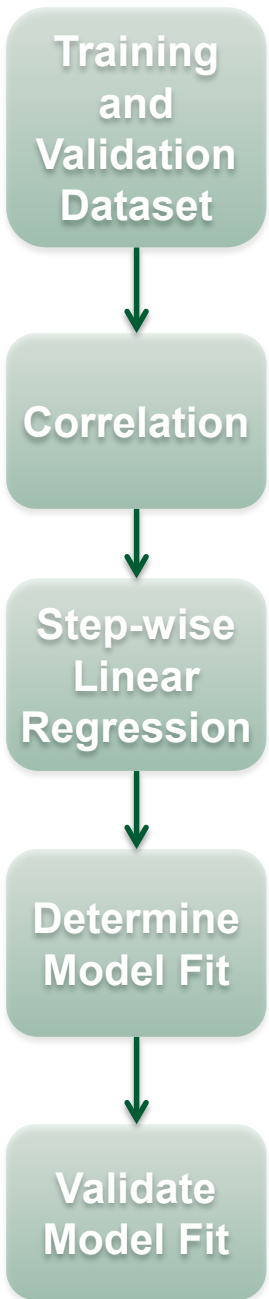| Predictor	Change in Adjusted R Square	Significance of Change	Model Significance	$\triangle r^2$
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- Force-entry of remaining trabecular bone variables
  - SMI: +0.009 in Change in Adjusted R square
  - Tb.Th: +0.003 in Change in Adjusted R square
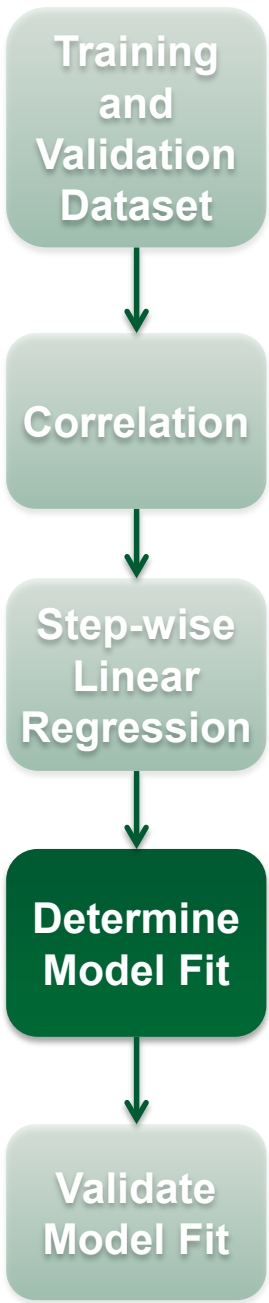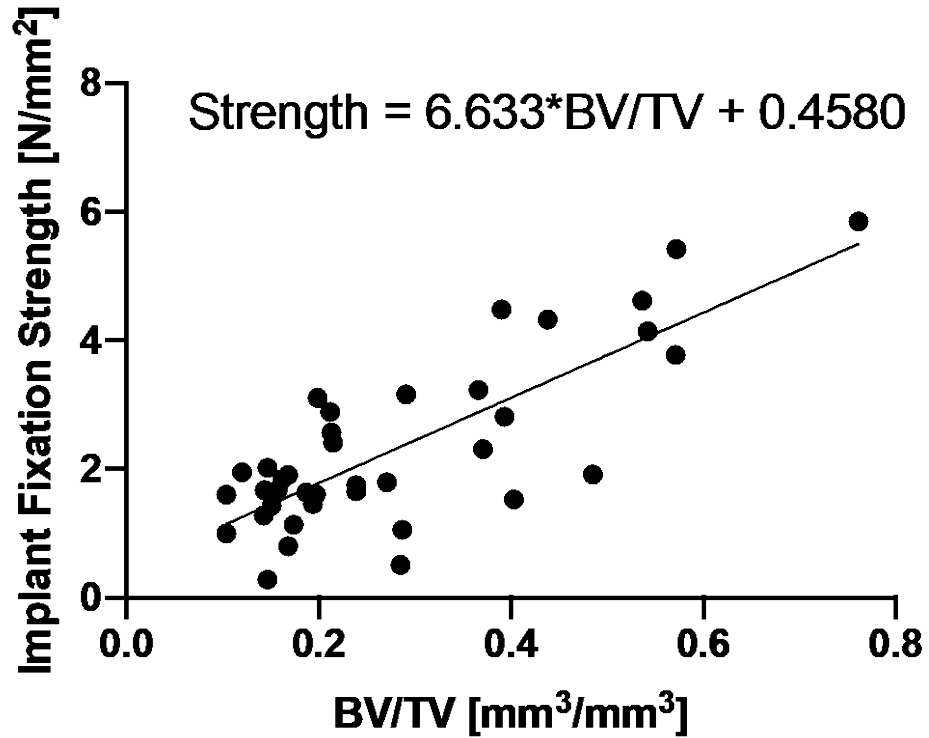 - BS/BV: +0.015 in in Change in Adjusted R square

Training and Validation Dataset

Correlation

Step-wise Linear Regression

Determine Model Fit

Validate Model Fit

Correlation of Among BV/TV, SMI, Tb.Th, and BS/BV

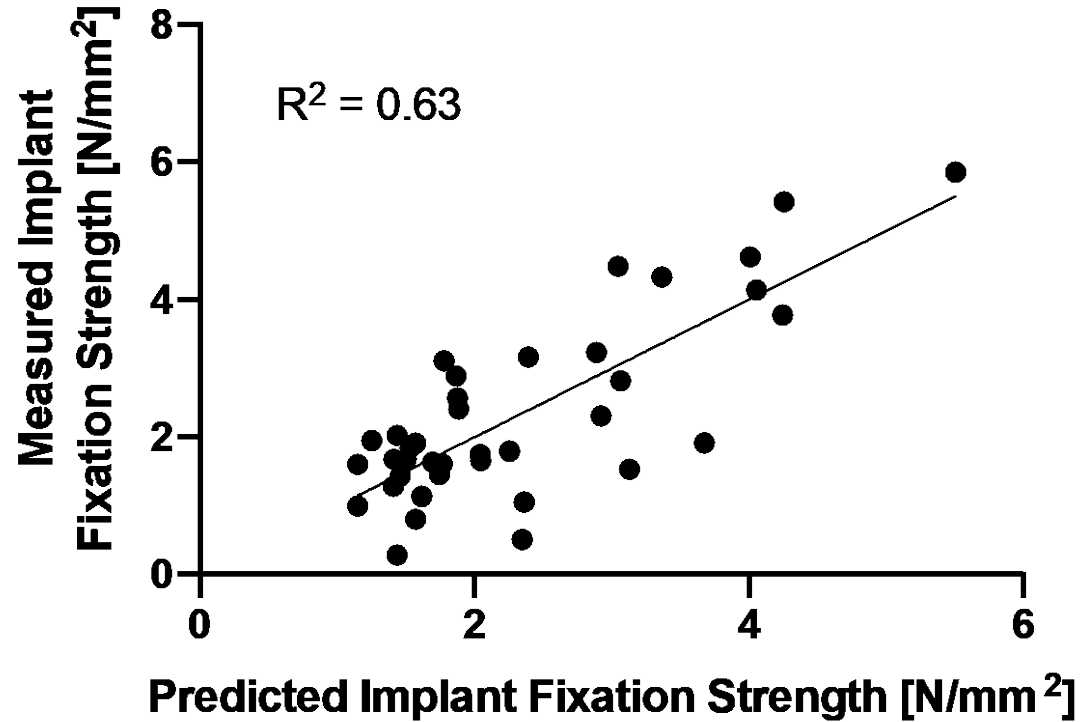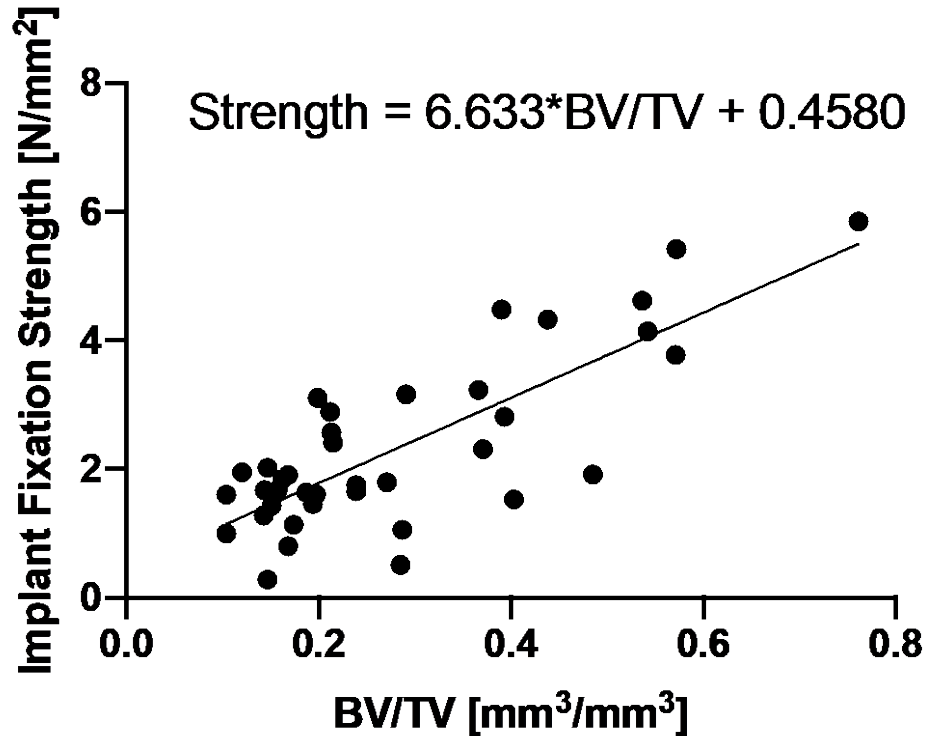|	BV/TV	SMI	Tb.Th	BS/BV
BVTV	1	-0.930	0.853	-0.902
SMI		1	-0.777	0.783
TbTh			1	-0.950

- All four variables highly correlated with each other.
- Use strongest correlated variable to implant fixation strength, BV/TV, to build a statistical model

Training and Validation Dataset

Correlation

Step-wise Linear Regression

Determine Model Fit

Validate Model Fit

Determine Model Fit using BV/TV

Strength = 6.633*BV/TV + 0.4580
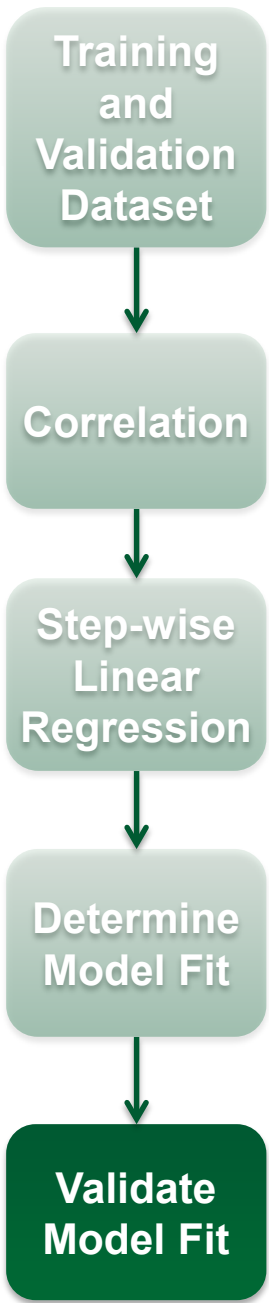

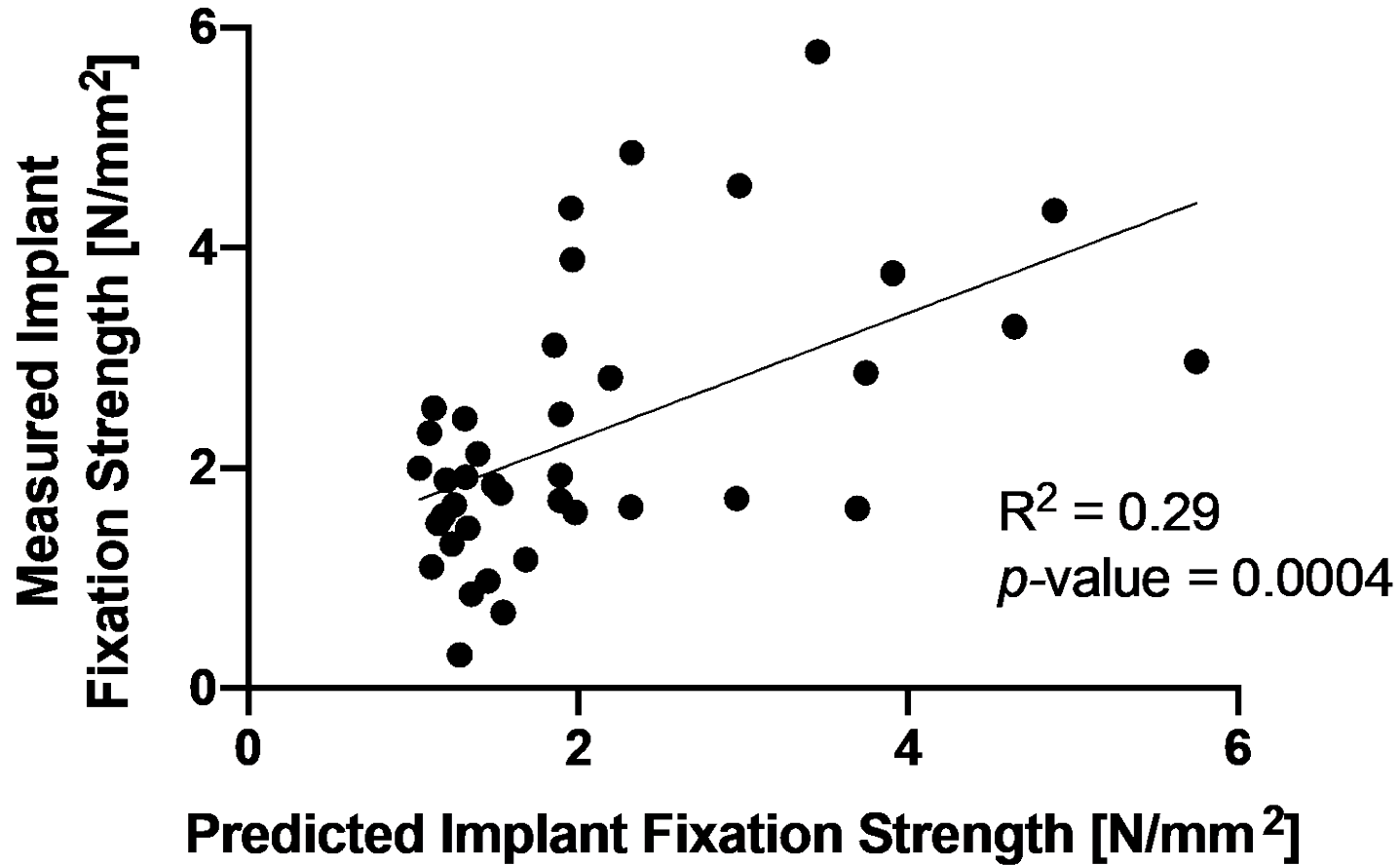Training and Validation Dataset

Correlation

Step-wise Linear Regression

Determine Model Fit

Validate Model Fit

Determine Model Fit using BV/TV

Strength = 6.633*BV/TV + 0.4580

$R^2 = 0.63$

Validating Model Fit

R^2 = 0.29
p-value = 0.0004

(Scatter plot of Measured Implant Fixation Strength [N/mm^2] versus Predicted Implant Fixation Strength [N/mm^2])

Flowchart:
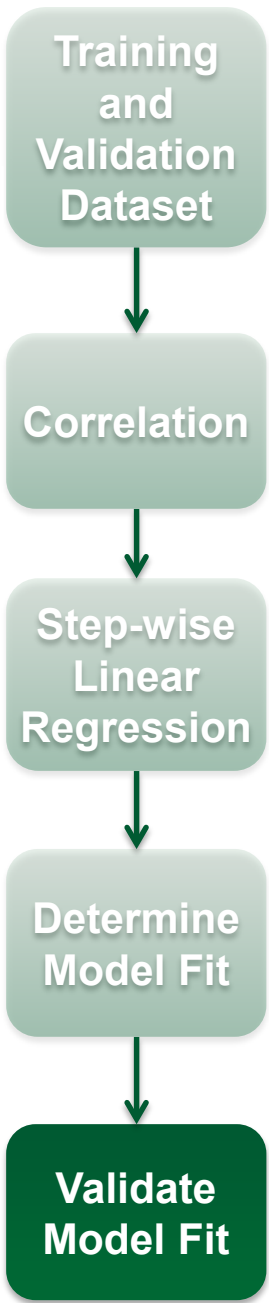- Training and Validation Dataset
- Correlation
- Step-wise Linear Regression
- Determine Model Fit
- Validate Model Fit

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Validating Model Fit

$R^2 = 0.29$
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Correlation of Implant Fixation Strength and Peri-Implant Trabecular Bone Properties – Validation Set

Pearson's Correlation

		BV/TV	SMI	ConnD	Tb.N	Tb.Th	Tb.Sp	BS/BV	DA
Strength	Correlation Coefficient	0.541	-0.391	0.205	0.320	0.538	-0.309	-0.592	-0.215
	P-value	<0.001	<0.014	0.210	0.047	<0.001	0.056	<0.001	0.188

Spearman's Correlation

		BV/TV	SMI	ConnD	Tb.N	Tb.Th	Tb.Sp	BS/BV	DA
Strength	Correlation Coefficient	0.525	-0.610	-0.223	0.126	0.555	-0.110	-0.568	-0.271
	P-value	<0.001	<0.001	0.173	0.444	<0.001	0.504	<0.001	0.095

Training and Validation Dataset
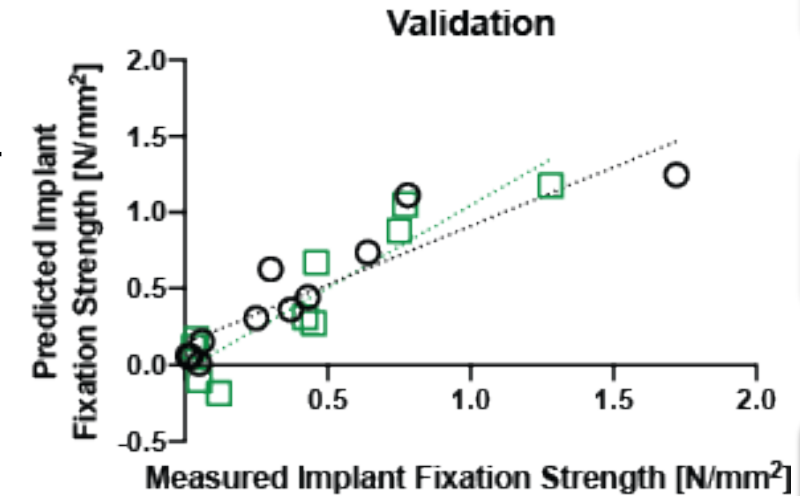
Correlation

Step-wise Linear Regression

Determine Model Fit

Validate Model Fit

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Training and Validation Dataset

↓

Correlation

↓

Step-wise Linear Regression

↓

Determine Model Fit

↓

Validate Model Fit

Discussion

- Decrease in R^2 value from 0.63 (trainings set) to 0.29 (validation set) suggests that BV/TV may not be sufficient to predict implant fixation strength

- Bone-implant contact and peri-implant cortical bone properties also contribute to implant fixation strength (Ko et al. 2019)

- Contribution of material properties to implant fixation strength needs to be determined

Acknowledgement

- NIH R01-AR066562
- NIH R21-AR075130

- OREF – Smith and Nephew

- Sumner Lab

- Rush microCT and Histology core

- Amgen-UCB Pharma