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How Does Femoral Component Design Influence Proximal Femoral Bone Mass After Total Hip Replacement? A Randomized Controlled Trial

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Ethical review statement

The trial was approved by Ottawa Hospital Institutional Review Board (OHSN-REB 2010913-01H) and registered with clinicaltrials.gov (NCT01558752).

Abstract

Aims

In this randomized **controlled** trial **(RCT)**, we aimed to compare post-operative bone remodeling and bone turnover over 2 years following total hip arthroplasty using the short, proximally-coated Tri-Lock 'Bone-Preserving Stem' versus a conventional, fully-coated Corail prosthesis.

Methods

Forty-six participants received the Tri-Lock prosthesis and 40 received the Corail. At baseline, both groups had similar demographics, proximal femoral bone mineral density (BMD), bone turnover markers, radiographic canal flare index, and patient-reported outcome measure scores. Outcomes were **measured** at week 26, 52, and 104.

Results

Loss in periprosthetic bone, measured by high sensitivity Dual-energy X-ray Absorptiometry Region Free Analysis (DXA-RFA) was identified at the calcar and proximal lateral femur in both prosthesis groups ($p<0.05$). However, the conventional prosthesis demonstrated a smaller reduction in BMD versus the bone-preserving prosthesis ($p<0.001$). This effect was most prominent in the region of the femoral calcar **and greater trochanter**. A small gain in BMD was also identified in some areas **that was greater** with the **conventional versus the bone-preserving prosthesis** ($p<0.001$). Both groups experienced similar changes in bone turnover markers and improvement in PROMs scores over the study period ($p>0.05$)**. The** adverse event rate was **also** similar between groups **($p>0.05$).**

Conclusions

This **RCT** shows that prostheses intended to preserve proximal femoral bone do not necessarily perform better in this regard than conventional cementless designs. DXA-RFA is a sensitive tool for detecting spatially-complex patterns of periprosthetic bone remodeling.

Level of Evidence:

Therapeutic Level 1

Introduction

Although pooled data from THA case-series and joint registries shows a 25-year prosthesis survivorship of between 58%-78%[1], the burden of periprosthetic femoral fracture after total hip arthroplasty (THA) continues to increase[2]. This observation has prompted the emergence of shorter-stemmed, ‘bone-preserving’ femoral prostheses intended to mitigate the periprosthetic fracture risk and simplify revision surgery. Those advocating for shorter stems argue for reduced femoral bone removal at surgery, reduced strain-adaptive remodeling (stress shielding) within the proximal femur, and tissue-sparing approaches during femoral canal preparation and prosthesis insertion[3, 4].

At prosthesis design, computational modeling techniques such as finite element analysis (FEA) are commonly used to predict and optimize prosthesis-bone construct stability and load transfer characteristics[5, 6]. In order to validate FEA findings in patients, a clinical measure of bone strain-adaptive remodeling is required, and Dual-energy X-ray Absorptiometry (DXA) is typically used for this purpose[7-9]. However, DXA analysis using the conventional Gruen zone region of interest (ROI) approach has limited ability to resolve spatially-complex patterns of bone remodeling around prostheses[10]. **To address this, DXA-Region Free Analysis (DXA-RFA) was developed, allowing resolution of bone mineral density (BMD) at the individual pixel level[11-14] and because it does not average the pixel-level data into ROIs, there is no loss of resolution and interpretation variations associated with conventional DXA studies**[15].

The primary aim of this randomized **controlled** trial **(RCT)** was to determine whether periprosthetic bone loss measured by DXA-RFA over 2-years after THA using the proximally porous-coated and shorter stemmed Tri-Lock “Bone-Preserving Stem” (BPS®)

femoral prosthesis (DePuy Synthes, Warsaw, USA) is lower than that occurring around the conventional collarless Corail® prosthesis (DePuy Synthes). We also compared biochemical markers of bone turnover, patient-reported outcome measures (PROMs) and adverse events **(AEs)** between groups.

Materials and Methods

Between May 2013 and May 2017, 2485 patients underwent THA at The Ottawa Hospital **amongst six surgeons. Initial screening eliminated 1927 patients for the following two reasons: two surgeons were not participating in the study (n=689); and initial chart reviewed by the research team met the exclusion criteria (n=1238). A consecutive group of 558** patients were **further interviewed** for eligibility out of which 88 patients with idiopathic osteoarthritis of the hip were recruited to the trial (Figure 1). The trial was IRB-approved, registered with clinicaltrials.gov (NCT01558752), and conducted in accordance with the Declaration of Helsinki. Patients with prior hip surgery, severe femoral bone deficiency, femoral neck fracture, known secondary causes of arthritis, **known** metabolic bone disease and past or present use of drugs known to affect bone metabolism, and patients anticipated to receive contralateral hip surgery within **1-year**, were excluded from the study. Using computer-generated, varied block randomization with allocation concealment, patients were randomized during the preoperative outpatient visit. Treatment allocation was made on a 1:1 basis to receive either the Tri-Lock BPS with a modular cementless porous-coated acetabular component (Pinnacle®, Depuy Synthes) using a metal-on-polyethylene bearing surface, or the Corail® prosthesis with a titanium porous-coated monoblock shell (DeltaMotion®, Depuy Synthes) using a ceramic-on-ceramic bearing surface. **The Tri-Lock "Bone-Preserving Stem" (BPS®) femoral prosthesis (DePuy Synthes, Warsaw, USA) is a commonly used example of this philosophy. Manufactured in TiAl6V4 alloy with a stem length of 95 to 119mm, the Tri-Lock prosthesis has a thin tapered-wedge geometry with a reduced lateral shoulder and GRIPTION® porous titanium coating in its proximal (metaphyseal) section (pore size 300 microns, volume porosity 80%) that is designed to closely fit the proximal femoral metaphysis and promote osseointegration. The prosthesis is inserted with a bone-cutting broach. The Corail is also a tapered-wedge stem composed of the same TiAl6V4 alloy, but with a more conventional geometry and is fully hydroxyapatite-coated (HA thickness 155 microns, pore size 250 microns, volume porosity 75%). The Corail is inserted using a compaction broach.** After randomization, two patients allocated to the Corail group received an alternate implant as the femoral canal was deemed by the surgeon to be not suitable for the Corail prosthesis and were excluded from further study. The participant and allied health providers remained blinded to treatment group allocation until after the final study visit (2-years).

Surgical technique. In all, 46 patients received the Tri-Lock prosthesis and 40 received the Corail. Each prosthesis was inserted according to its specific manufacturer's instructions and design philosophy. Four surgeons performed the procedures, each using their preferred surgical approach. In the Tri-Lock group 33 were performed using the anterior approach, 6 lateral, 1 posterior, and 6 posterolateral; and for the Corail 26 were anterior, 8 lateral, 1 posterior, and 5 posterolateral (chi-squared = 0.792, p=0.851). Postoperatively, immediate full weight-bearing was allowed using crutches. Routine postoperative thromboembolic prophylaxis consisted of 5 days of 10mg rivaroxaban daily, followed by 25 days of 81mg aspirin daily.

Outcome measures and monitoring. All DXA scan acquisitions were made using the same GE Lunar iDXA densitometer (GE Healthcare Lunar, Madison, WI) in 'orthopaedic' scan mode and using a standard acquisition protocol[16]. Scans were made at post-operative baseline (within 2-weeks of surgery), and at weeks 26, 52 and 104 postoperatively. Analysis of the acquired pixel-level bone maps was made using the 'Encore' windows-based user interface (GE Healthcare) and implemented in Matlab v9.5 R2018b (Mathworks Inc, Cambridge, MA). Each image was composed of approximately 10,000 pixels (each 0.60mmx0.60mm in size), and analyzed according to a previously described protocol[13]. **A post-operative baseline conventional BMD measurement of the contralateral native hip (without THA) was also made to assess for evidence of pre-existing osteoporosis.** Biochemical markers of bone turnover were measured from morning-fasting serum samples taken at pre-operative baseline and at weeks 12, 26, 52 and 104. Carboxy-terminal telopeptide of type I collagen (CTX), a marker of type-I collagen resorption, was measured by electrochemiluminescent assay (β-CrossLaps, Elecysy, Roche Diagnostics, Indianapolis, USA). Intact amino-terminal propeptide of type I procollagen (PINP), a marker of type-I collagen formation, was also measured using the Elecysy system.

Plain radiographic assessments using anteroposterior pelvic and lateral radiographs, were made post-operatively and at weeks 12, 26, 52, and 104. Differences between preoperative and postoperative global offset, as well as leg length discrepancy, were measured by an arthroplasty surgeon, following previously described methods[7]. The canal flare index was measured as per Boyle et al.[17] (stovepipe<3, normal 3-4.7, champagne flute

>4.7-6.5). Stem alignment was measured and grouped in varus ($\geq +1°$), neutral ($< +1°/> -1°$) and valgus position ($\leq -1°$). Characterization of lucencies and bone resorption was based on the zones described by Gruen with a slight modification for the short stem[18]. Non-progressive periprosthetic lucencies of <2mm, outlined by a thin sclerotic line, were considered as normal[8].

PROMs assessments and recording of AEs were made on the same day as the radiological assessments. PROMs included the modified Harris Hip Score (mHHS)[19], the Western Ontario and McMaster University Osteoarthritis Index (WOMAC)[20] score and the University of California, Los Angeles (UCLA) activity scale [21].

Statistical analysis. All analyses were made 'per-protocol' using two-tailed testing and a critical p-value of 0.05. Categorical data was analyzed using the **chi-squared** test. Continuous data were analyzed parametric and non-parametric tests, as appropriate to each dataset distribution. **Longitudinal continuous data was analyzed by repeated-measures ANOVA. For** DXA-RFA**, these** analyses were made **after** correction for multiple testing by False Discovery Rate (FDR)[14], **and** denoted as q-values **(with** $q \leq 0.05$ considered statistically significant**)**. The power calculation was based upon data for cementless femoral prostheses assuming a between-group difference in Gruen zone 7 of $0.14 g/cm^2$ (10%, standard deviation 0.23) by conventional DXA analysis, giving a sample size of 43 participants per group for 80% power at the 5% significance level.

Source of Funding

The project was funded by Johnson & Johnson Medical Products and Synthes Canada Ltd. (d.b.a. DuPuy Synthes). The funder manufactures all prostheses studied in this

work, took no part in the design or conduct of the trial, analysis or interpretation of the results or preparation of the manuscript.

Results

A total of 47 females and 39 males with a mean age of 59.4±10.6 years old completed follow-up (98% of subjects randomized) and were included in the analysis. Patients in the Tri-Lock group (n=46) were of similar age, sex, body mass index (BMI) as those on the Corail group (n=40, Table 1, p>0.05 all comparisons). **BMD of the contralateral native proximal femur was also similar between groups and within the normal expected reference ranges (BMD, t- and z-scores p>0.05 all comparisons).** There were more patients in American Society of Anaesthesia (ASA) class III in the Tri-Lock versus the Corail group (p=0.049).

At immediate post-operative baseline, the distribution of periprosthetic BMD was similar between groups (Figure **2**). **Subsequent b**one loss around both prostheses was **observed** in the area of the calcar **and** in a cancellous area of the distal greater trochanter **(Figure 3). Bone loss was significantly greater in the Tri-Lock group versus the Corail over the 2-year study period and observed at all interval timepoints (ANOVA p<0.0001, Table 2). Small areas of significant bone gain were also observed over the follow up period that was broadly but sparsely distributed for both prosthesis types (Figure 3). This gain was initially more apparent in the inferior lesser trochanter in the Tri-Lock group (p<0.001), but over the full study period was greater in the Corail group (Table 2 ANOVA p<0.001).**

At pre-operative baseline, serum values for the bone resorption marker CTX and the bone formation marker PINP were similar (P>0.05 both comparisons, Table **1).** Postoperatively both bone turnover markers underwent a transient increase, peaking at week 26, before returning to baseline by week 52 (Figure **4).** No between-group differences in bone turnover markers were identified (ANOVA, p>0.05 both comparisons).

At preoperative radiological assessment, the mean canal flare index was 3.92±0.6, and was similar between groups (p=0.549). On immediate post-operative radiographs, the prosthesis was positioned in greater varus in the Corail versus the Tri-Lock group (mean 2.07° versus 0.78° p=0.001 Table **3).** Other radiographic parameters were similar between groups. Non-progressive, <2mm lucent lines were detected in zones 1 and 7 of one Tri-Lock stem and in the same zones of three Corail stems. No cases had evidence of femoral component loosening.

Patients in both treatment groups had similar **mHHS**, WOMAC and ULCA scores at pre-operative baseline (p>0.05 all comparisons, Table **4).** Both groups experienced similar improvements in all PROM scores at week 104, with no difference in the change scores between groups. There were 8 **AEs** in the Tri-Lock group and 5 in the Corail group (p=0.741). **This included 3 (7.5%) calcar cracks in the Corail group and 1 (2.17%) in the Tri-Lock group; 1 (2.5%) deep infection in the Corail group; 1 (2.2%) femoral nerve palsy in the Tri-Lock group; and 6 episodes of postoperative thigh pain at the latest follow-up (5 [10.9%] in the Tri-Lock group and 1 [2.5%] in the Corail).** One case **(2.2%)** in the Tri-Lock group developed aseptic loosening and underwent revision surgery with a non-modular, distally-fixed, conical stem at week 96.

We used linear regression analysis to explore the relationships between the area of greatest bone loss within the proximal medial femur and possible predictive factors, including age, sex, radiographic and PROMs variables. Although a correlation matrix suggested a relation between prosthesis alignment and BMD change at week 104 (Pearson r= 0.386, p<0.001), this was entirely accounted for by prosthesis group. In the final regression model, only prosthesis group remained a significant predictor of bone loss in the proximal medial femur (adjusted r^2= 0.063, Beta=7.591 (standard error=2.996); p=0.013), with greater loss for the Tri-Lock prosthesis.

Discussion

The goal of modern joint arthroplasty is to create a prosthesis-host construct that provides predictable pain relief and restores function, whilst causing the minimal possible disruption to the local biological environment[18]. The emergence of shorter "bone-preserving" femoral prostheses **follows** that philosophy, but the effect **of these prostheses** on the local bone environment in the patient remains unclear[22] **and is mainly based on FEA modeling[17, 23-26].** In this 2-year **RCT**, **both the Tri-Lock BPS and CORAIL** designs resulted in only a modest disturbance of the natural patterns of strain-adaptive remodeling of the proximal femur, and both performed similarly in terms of plain radiographic **outcomes, PROMs and AE rates. Both designs are tapered wedges made from the same titanium alloy, but differ in stem length, geometry, extent and type of surface coating, and fixation philosophy (3-point fixation versus conventional taper).** However, contrary to our anticipated results, we found better bone conservation around the conventional prosthesis than the proposed bone-preserving one.

In a post-mortem study, Engh[27], demonstrated the effect of prosthesis stiffness on the local bone environment **and whereby short stems would load the proximal femur in a more physiological way, therefore preventing future stress shielding. Several authors have studied this looking at a variety of stem designs with mixed results (Table 5)[28-32]. However, given the diversity of conventional and short stems available**

in the market and each with different load-sharing philosophies[22], our results cannot be extrapolated to other designs that were not subjected to a similar high-resolution DXA-RFA analysis. Similarly, canal preparation technique may also affect periprosthetic bone remodeling. In the non-destructive clinical setting, Hjorth et al **compared** compaction versus standard broaching when implanting the same Bi-Metric stem**, and** found only minor BMD differences in favor of compaction at 1- and 5-years[33]. **Their study used conventional DXA analysis that was not able to resolve the implant-bone interface. Using DXA-RFA we resolved events at pixel level at this interface and found no substantial difference between the implant groups to suggest a meaningful effect of broaching technique on the initial periprosthetic interface BMD. Further, given that the post-operative changes in BMD between the groups were not differentially located at the implant-bone interface, we conclude that the differences in broaching technique between the groups was not a significant contributor to the observed BMD outcomes.**

Modern imaging approaches, such as computational tomography and magnetic resonance imaging, also provide cross-sectional detail at high-resolution. However, despite advances in metal-reduction sequences**, challenges due to beam hardening, metal susceptibility artifacts and other issues remain that limit their application when studying events at or near the implant-bone interface[34-36].** DXA-RFA applied here**, apart from not suffering artifact limitations to the same extent,** uses advanced computer vision algorithms to resolve bone architecture including events at the implant-bone interface[15], and allows study of any prosthesis geometry without the resolution and sampling limitations of ROI-based analysis[37, 38]**. However, as each prosthesis and its canal preparation technique (i.e. different broach designs) are not separable, we were**

unable to comment directly on the independence of each element on the overall observed bone remodeling effects.

Our study also has limitations. **The inclusion of different bearing surface couple for each femoral prosthesis may be considered as a potential confounding factor in respect of axial load transferred to the proximal femur. However, in the design of this study we did not consider this to be a material issue, based upon previous literature addressing this question. In 2007, Kim et al reported the results of an RCT in which 50 subjects undergoing simultaneous, bilateral, cementless THA received an alumina-on-alumina bearing in one hip and an alumina-on-polyethylene in the other, finding no differences in proximal femoral periprosthetic BMD between the bearing couples over 5 years[39].**

The 2-year timeframe does not reflect the service life of the prosthesis. However, this study was constructed to quantitate the effect of each prosthesis philosophy on bone remodeling **over the period when these changes are most dynamic.** Our biochemical marker data confirmed that **the major phase of prosthesis-related** bone remodeling is complete within the **2-year** timeframe used in this study (return of markers to baseline **bone turnover rates**), and are consistent with previous studies of femoral **strain-adaptive** bone remodeling after THA[40, 41]. Our biomarker data did not differentiate the prosthesis brands. Serum biomarker data reflect bone turnover events throughout the body. Whilst the observed biomarker changes reflected the surgical event, it is perhaps not surprising that they were insufficiently sensitive to resolve the subtle differences in local bone remodeling observed between the prostheses. DXA-RFA, like all DXA analyses, provides a 2-dimensional composite of 3-dimensional events. However, this is a limitation of DXA itself rather than the RFA-analysis technology that can also be applied to cross-sectional image data.

Although modestly different in their bone remodeling characteristics, this trial shows that the Corail prosthesis has more favorable bone remodeling characteristics than the Tri-Lock BPS. However, large-scale clinical data also shows us that design features which facilitate proximal load transfer and reduce early periprosthetic fracture rates do not necessarily perform in the same way later in the prosthesis' service life[42]. Ultimately, long-term periprosthetic fracture and loosening-free prosthesis survival in large clinical series will **determine the clinical significance of more physiological loading of the femur in regards to a** cementless prosthesis design's **overall performance**[43, 44].

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Legend to figures

Figure 1. Consort diagram showing patient selection, treatment allocation and analysis between the prosthesis groups.

Figure **2**. Heatmaps showing baseline pixel-level BMD distribution in each prosthesis group measured by DXA-RFA.

Figure **3**. **Heatmaps showing pixel-level change in BMD over 104 weeks in each prosthesis group measured by DXA-RFA. Left 3 panels show percentage BMD change at each timepoint after FDR correction. Right 2 panels show within group areas of significant change (Q value). Between group analyses for areas of loss and gain are by repeated measures ANOVA over 104 weeks.**

Figure **4**. Graphs showing changes in serum concentrations of A) Carboxy-terminal telopeptide of type I collagen (CTX), and B) Amino-terminal propeptide of type I procollagen (PINP) in each prosthesis group over 104 weeks. Analysis is between group by repeated-measures ANOVA **over 104 weeks.**

Table 1. Baseline demographic characteristics of completing participants. Values are mean ± standard deviation. Analyses are between group by †Chi-squared test or ‡t-test.

Variable	Tri-Lock Prosthesis (n=46)	Corail prosthesis (n=40)	p-value
Gender			
Male	22	17	
Female	24	23	0.621†
Age in years	60.4 ± 10.1	58.6 ± 10.2	0.312‡
BMI	27.4 ± 2.9	27.6 ± 2.5	0.859‡
ASA class (Count, %)			
I	1	3	0.049†
II	28	31	
III	17	6	
IV	0	0	
Baseline CTX (ng/ml)	0.425 ± 0.193	0.403 ± 0.186	0.609‡
Baseline PINP (ng/ml)	54.47 ± 21.39	55.92 ± 10.82	0.753‡
	Contralateral native hip (n=36)	**Contralateral native hip (n=33)**	
Total hip BMD (g/cm^2)	1.01 ± 0.14	1.01 ± 0.148	0.966‡
t-score total hip	-0.28 ± 1.07	-0.25 ± 0.99	0.889‡
z-score total hip	0.40 ± 1.18	0.39 ± 0.90	0.953‡

Table 2

Table 2. Pixel-level bone mineral density changes in the Tri-Lock versus Corail Prosthesis groups over 104 weeks. Analysis is number of pixels with change/total number of pixels in Tri-Lock versus Corail group by Repeated Measures ANOVA after False Discovery Rate correction at 5%. †Indicates post-hoc p-value at interval timepoints.

Mean ± SD number of pixels/total per femur with significant BMD decrease			
Time	Tri-Lock	Corail	p-value
26 weeks	927/9460 (9.80%) ± 82	0/11115 (0.00%) ± 0	<0.001†
52 weeks	661/9460 (6.99%) ± 67	504/11115 (4.53%) ± 76	<0.001†
104 weeks	1295/9460 (13.69%) ± 73	1072/11115 (9.64%) ± 50	<0.001†
ANOVA			<0.001
Mean ± SD number of pixels/total per femur with significant BMD increase			
Time	Tri-Lock	Corail	p-value
26 weeks	21/9460 (0.22%) ± 6	0/11115 (0.00%) ± 0	<0.001†
52 weeks	61/9460 (0.64%) ± 7	67/11115 (0.60%) ± 6	0.002†
104 weeks	122/9460 (1.29%) ± 11	374/11115 (3.36%) ± 40	<0.001†
ANOVA			<0.001

Table 3. Radiographic outcomes of both prostheses by week 104. Values are mean ± standard deviation. Analyses are between groups by t-test.

Radiographic variable	Tri-Lock prosthesis (n=46)	Corail prosthesis (n=40)	p-value
Mean global offset difference (mm)	0.02 ± 5.13	-1.57 ± 4.77	0.072
Mean leg length discrepancy (mm)	-0.09 ± 1.82	0.73 ± 1.86	0.028
Mean stem alignment angle (degrees, varus +, valgus -)	0.78 ± 1.52	2.07 ± 2.11	< 0.001
Mean linear bone resorption at calcar (mm)	0.78 ± 0.94	0.65 ± 0.92	0.451

Table 4

Table 4. Patient-reported outcome measures in the Tri-Lock versus Corail groups at pre-operative baseline and at week 104. Values are mean ± standard deviation. Analysis is: † within group between baseline and week 104 by paired t-test, and †† between group improvement in PROM score by independent t-test

PROMs (mean ± SD)	**Tri-Lock Prosthesis (n= 46)**	**Corail prosthesis (n= 40)**	**p-value**	**††p-value change scores between groups**
Pre Harris Hip Score - Pain	17.5 ± 7.19	19.2 ± 7.12	0.231	0.728
Post Harris Hip Score - Pain	35.6 ± 8.43	36.9 ± 8.96	0.342	
†p-value	<0.001	<0.001		
Pre Harris Hip Score - Function	27.7 ± 7.64	29.9 ± 6.83	0.167	0.132
Post Harris Hip Score - Function	42.0 ± 5.77	42.6 ± 7.40	0.275	
†p-value	<0.001	<0.001		
Pre WOMAC - Pain	47.3 ± 17.7	55.0 ± 14.9	0.054	0.362
Post WOMAC - Pain	87.2 ± 16.2	87.8 ± 16.8	0.661	
†p-value	<0.001	<0.001		
Pre WOMAC - Stiffness	43.8 ± 20.7	45.0 ± 19.2	0.518	0.890
Post WOMAC - Stiffness	78.5 ± 21.5	82.6 ± 22.0	0.284	
†p-value	<0.001	<0.001		
Pre WOMAC - Function	47.0 ± 17.1	58.4 ± 17.7	0.007	0.876
Post WOMAC - Function	87.2 ± 14.4	90.6 ± 15.8	0.150	
†p-value	<0.001	<0.001		
Pre UCLA	4.80 ± 1.78	5.23 ± 2.07	0.491	0.329
Post UCLA	6.26 ± 1.89	6.24 ± 2.16	0.654	

†**p-value**	<0.001	<0.001		

Table 5

Table 5: Previous randomized controlled trials (2015-onwards) reporting on bone mineral density results of a variety of stem designs.

Study	No. of hips (n)	Comparison groups	Mean Follow-up	Results	Limitations
Schilcher et al (2017)[28]	60	Standard cementless femoral stem (Taperloc) vs. a 35-mm shorter version (Microplasty).	2-year	Greater bone loss around the shorter stem, although this was not statistically significant.	Underpowered to detect a significant difference in BMD between the prostheses.
Meyer et al (2019)[29]	140	Cementless bone preserving stem (Fitmore) vs. cementless straight stem (CLS Spotorno).	5-year	The bone-preserving Fitmore stem exhibited less proximal femoral bone loss that the CLS Spotorno conventional stem.	Different stem length of the 2 implants used with a modification to Gruen zones for better comparability.
Salemyr et al (2015)[30]	51	Ultra-short stem (Proxima) vs. conventional tapered stem (Bi-metric).	2-year	The conventional stem had greater bone loss (mainly in Gruen zones 1 and 7).	Lack of patient blinding. Possibly underpowered.
Freitag et al (2016)[31]	144	Cementless bone preserving stem (Fitmore) vs. cementless straight stem (CLS Spotorno).	1-year	Although both designs had implant-specific stress-shielding, the Fitmore stem had less proximal femoral bone loss that the CLS Spotorno stem (at ROI 6).	Short follow-up.
Kim et al (2016)[32]	400	Ultrashort anatomic	12-year	BMD was greater in the ultrashort stem group than in	Difficulty at evaluating

		cementless stem (Proxima) vs. conventional anatomic cementless stem (Profile)		the conventional stem group (mostly in zones 1 and 7).	longitudinal BMD changes using conventional DEXA of 2 different stem designs (e.g. slight changes in femoral rotation can affect precision of the measurement).

Figure 1

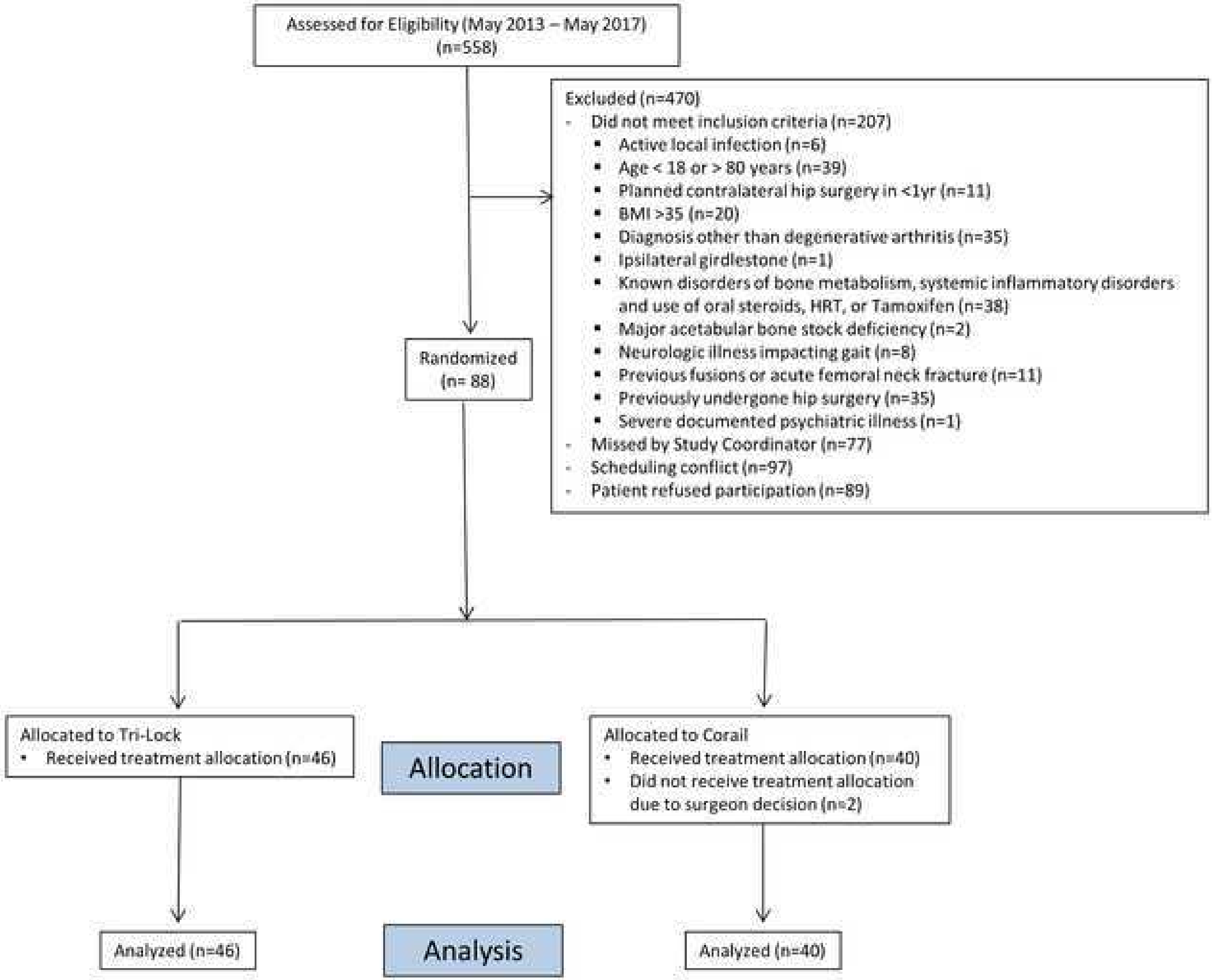

Assessed for Eligibility (May 2013 – May 2017)
(n=558)
Excluded (n=470)
- Did not meet inclusion criteria (n=207)
Active local infection (n=6)
Age < 18 or > 80 years (n=39)
Planned contralateral hip surgery in <1yr (n=11)
BMI >35 (n=20)
Diagnosis other than degenerative arthritis (n=35)
Ipsilateral girdlestone (n=1)
Known disorders of bone metabolism, systemic inflammatory disorders and use of oral steroids, HRT, or Tamoxifen (n=38)
Major acetabular bone stock deficiency (n=2)
Neurologic illness impacting gait (n=8)
Previous fusions or acute femoral neck fracture (n=11)
Previously undergone hip surgery (n=35)
Severe documented psychiatric illness (n=1)
- Missed by Study Coordinator (n=77)
- Scheduling conflict (n=97)
- Patient refused participation (n=89)
Randomized
(n= 88)
Allocated to Tri-Lock
Received treatment allocation (n=46)
Allocation
Allocated to Corail
Received treatment allocation (n=40)
Did not receive treatment allocation due to surgeon decision (n=2)
Analyzed (n=46)
Analysis
Analyzed (n=40)

Figure 2

Click here to access/download;Figure;Figure 2_v16Jun2020.tif

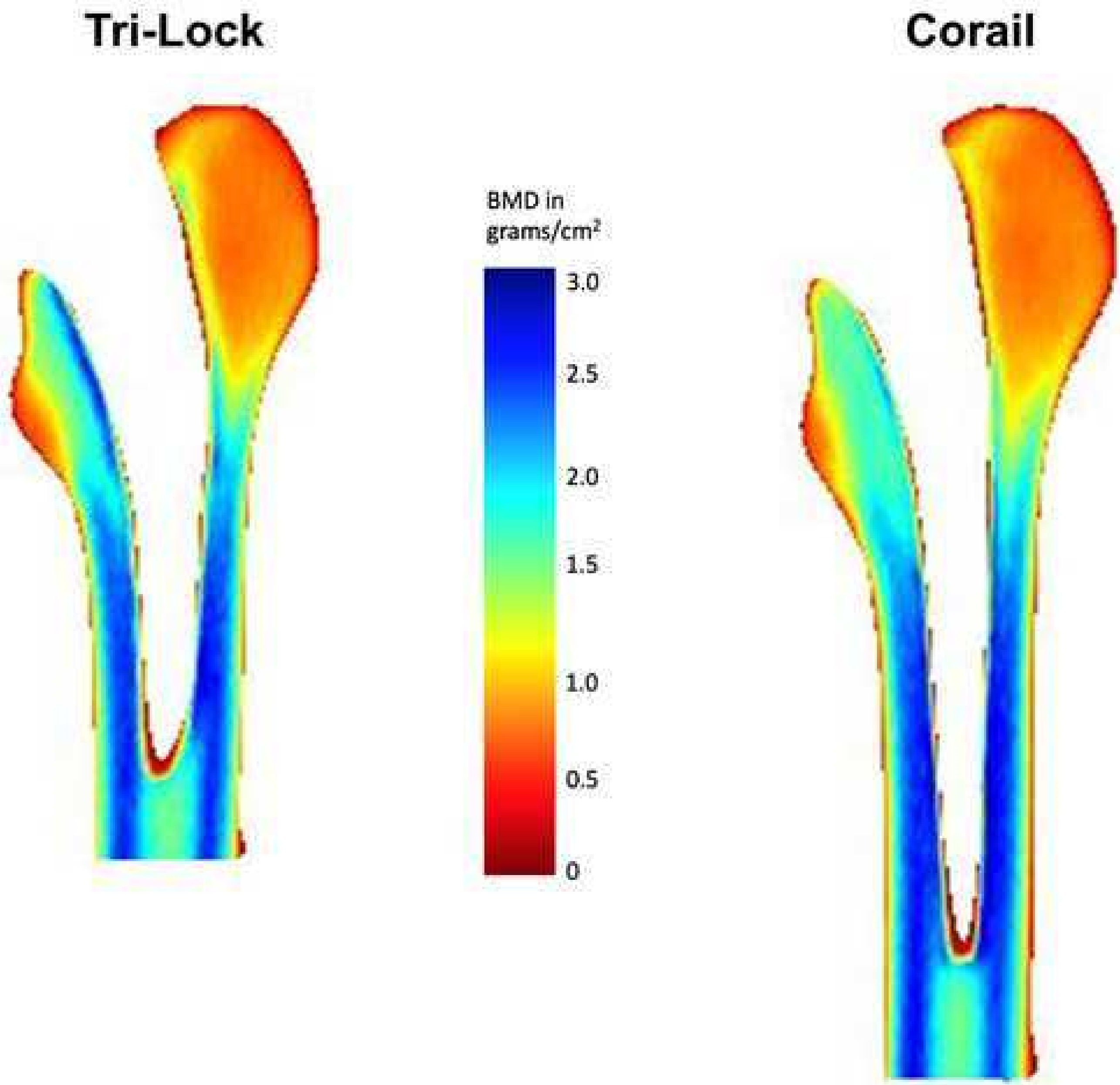


Figure 3

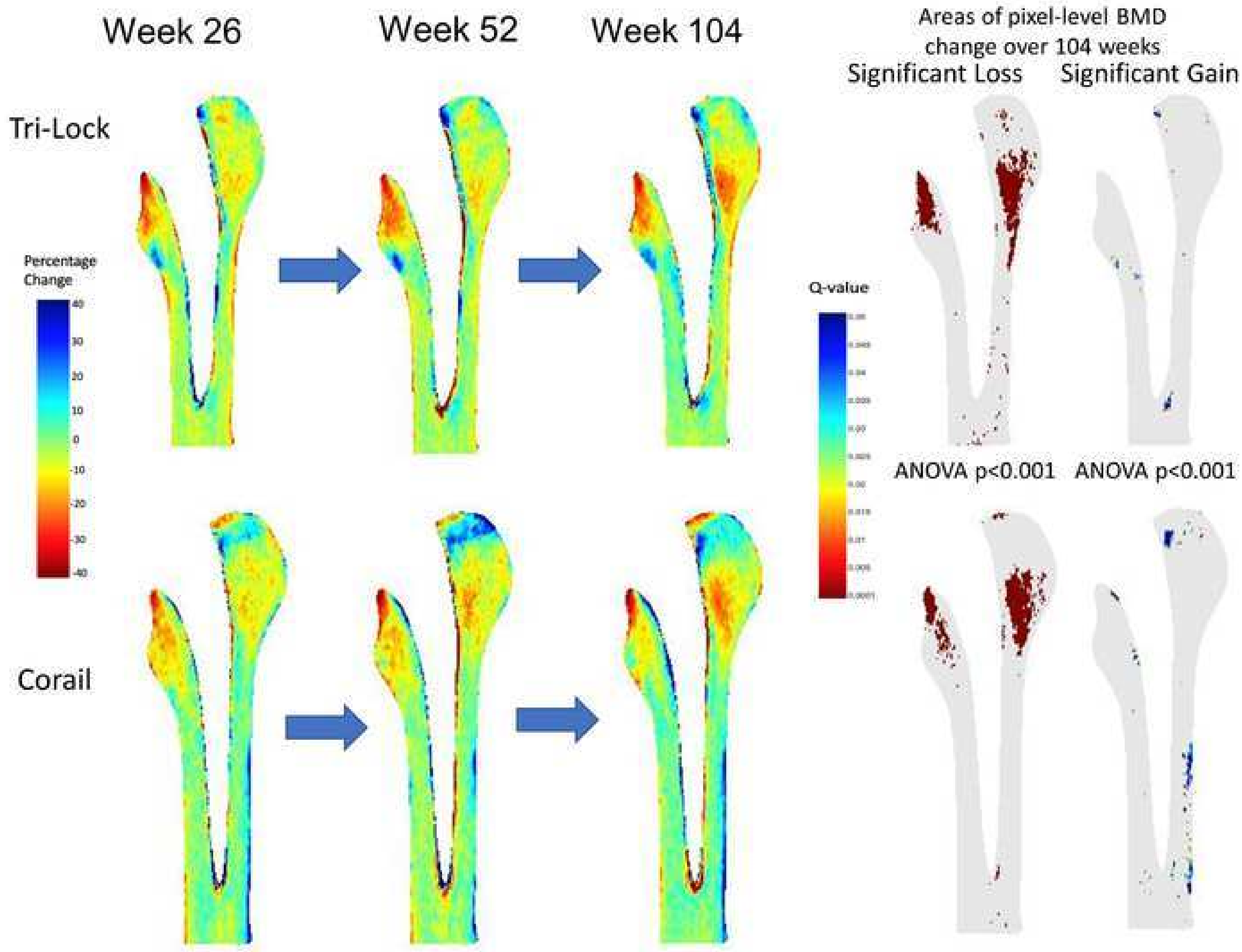
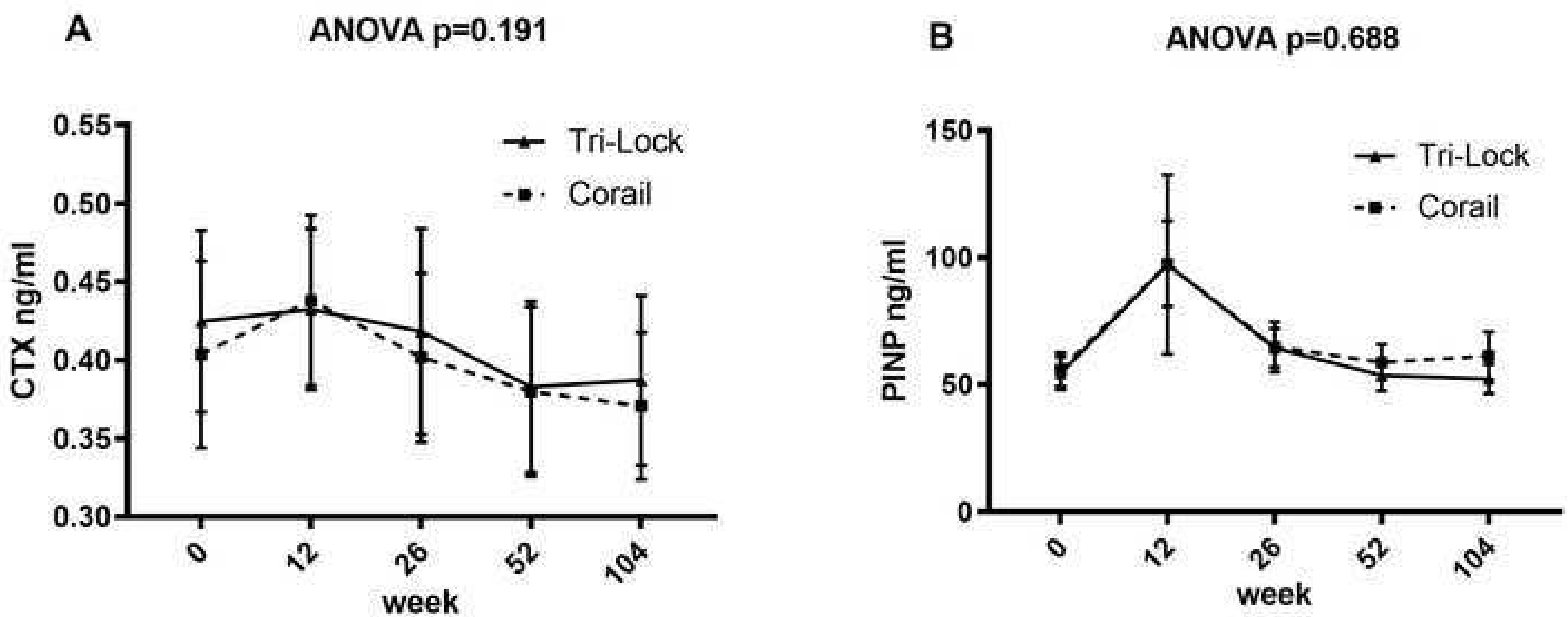

Week 26
Week 52
Week 104
Areas of pixel-level BMD change over 104 weeks
Significant Loss
Significant Gain
Tri-Lock
Corail
Percentage Change
Q-value
ANOVA p<0.001
ANOVA p<0.001

Figure 4


A
ANOVA p=0.191
0.55
0.50
0.45
0.40
0.35
0.30
CTX ng/ml
Tri-Lock
Corail
0
12
26
52
104
week
B
ANOVA p=0.688
150
100
50
0
PINP ng/ml
Tri-Lock
Corail
0
12
26
52
104
week