

# The SPECTRA Collaboration OMERACT Special Interest Group: Current Research and Future Directions

Kathryn S. Stok, Stephanie Finzel, Andrew J. Burghardt, Philip G. Conaghan, and Cheryl Barnabe, for the SPECTRA Collaboration

**ABSTRACT. Objective.** High-resolution peripheral quantitative computed tomography (HR-pQCT) has the potential to improve radiographic progression determination in clinical trials and longitudinal observational studies. The goal of this work was to describe the current state of research presented at Outcome Measures in Rheumatology (OMERACT) 2016 and ensuing future directions outlined during discussion among attendees.

**Methods.** At OMERACT 2016, SPECTRA (Study group for xtrEme-Computed Tomography in Rheumatoid Arthritis) introduced efforts to (1) validate the HR-pQCT according to OMERACT guidelines, focusing on rheumatoid arthritis (RA), and (2) find alternatives for automated joint space width (JSW) analysis. The Special Interest Group (SIG) was presented to patient research partners, physicians/researchers, and SIG leaders followed by a 40-min discussion on future directions.

**Results.** A consensus definition for RA erosion using HR-pQCT was demonstrated through a systematic literature review and a Delphi exercise. Histopathology and perfusion studies were presented that analyzed the true characteristics of cortical breaks in HR-pQCT images, and to provide criterion validity. Results indicate that readers were able to discriminate between erosion and small vascular channels. Moderate reliability (ICC 0.206–0.871) of direct erosion size measures was shown, which improved ( $> 0.9$ ) only when experienced readers were considered. Quantification of erosion size was presented for scoring, direct measurement, and volumetric approaches, as well as a reliability exercise for direct measurement. Three methods for JSW measurement were compared, all indicating excellent reproducibility with differences at the extremes (i.e., near-zero and joint edge thickness).

**Conclusion.** Initial reports on HR-pQCT are promising; however, to consider its use in clinical trials and longitudinal observational studies, it is imperative to assess the responsiveness of erosion measurement quantification. (J Rheumatol First Release August 1 2017; doi:10.3899/jrheum.161197)

## Key Indexing Terms:

RADIOGRAPHIC COMPUTED TOMOGRAPHY  
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From the Institute for Biomechanics, ETH Zurich, Zurich, Switzerland; Department of Biomedical Engineering, University of Melbourne, Melbourne, Victoria, Australia; Department of Rheumatology and Clinical Immunology, Faculty of Medicine, University of Freiburg, Freiburg, Germany; Department of Radiology and Biomedical Imaging, University of California, San Francisco, California, USA; Leeds Institute of Rheumatic and Musculoskeletal Medicine, University of Leeds and UK National Institute for Health Research (NIHR) Leeds Biomedical Research Centre, Leeds, UK; Departments of Medicine and Community Health Sciences, University of Calgary; McCaig Institute for Bone and Joint Health, University of Calgary, Calgary, Alberta, Canada.

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K.S. Stok, PhD, Senior Lecturer, Institute for Biomechanics, ETH Zurich, and Department of Biomedical Engineering, University of Melbourne;

S. Finzel, MD, Senior Attending Physician, Department of Rheumatology and Clinical Immunology, Faculty of Medicine, University of Freiburg;

A.J. Burghardt, BS, Research Specialist, Department of Radiology and Biomedical Imaging, University of California; P.G. Conaghan, MD, PhD, Professor, Leeds Institute of Rheumatic and Musculoskeletal Medicine, University of Leeds and NIHR Leeds Biomedical Research Centre;

C. Barnabe, MD, MSc, Associate Professor, Departments of Medicine and Community Health Sciences, University of Calgary, and McCaig Institute for Bone and Joint Health, University of Calgary.

Address correspondence to Dr. K.S. Stok, Department of Biomedical Engineering, University of Melbourne, Parkville, Victoria, 3010, Australia. E-mail: kstok@unimelb.edu.au

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Radiographic progression is a key outcome in randomized controlled trials for inflammatory arthritis. Unfortunately, the power of this assessment is limited in the early diagnosis and treat-to-target paradigm in rheumatoid arthritis (RA), with most patients demonstrating little baseline joint damage or progression during trials. This is compounded with early timing of rescue therapies and limited exposure durations. In observational studies, plain radiography is the most feasible method for assessing damage progression, but only provides a 2-dimensional evaluation of a 3-D surface, resulting in errors related to positioning and overlapping bony interfaces. Current radiographic scoring schemes are based on ordinal scoring of joint space width (JSW) and erosions, predisposing results to floor and ceiling effects, and significant progression is required to reach the incremental worsening threshold to detect score progression. For these reasons, diagnostic imaging biomarkers with higher sensitivity to change, such as high-resolution peripheral quantitative computed tomography (HR-pQCT), could improve radiographic progression determination in clinical trials and longitudinal observational studies, as well as adding new outcomes for detection of pre-

erosive bony changes<sup>1</sup>, quantification of joint space narrowing (JSN), and assessment of bone densitometry and microarchitecture<sup>2</sup>.

HR-pQCT is a relatively new imaging modality for quantitative evaluation of cortical and trabecular bone mineral density and bone microstructure, typically at the distal radius and tibia<sup>3,4</sup>. Quantitative measurements obtained with HR-pQCT are well established as biomarkers and outcome measures in osteoporosis research<sup>5</sup>. HR-pQCT uses a very low irradiation dose (< 5  $\mu$ Sv to image a 1-cm region of interest) and is approved by the US Food and Drug Administration. There are 70–75 sites worldwide, distributed on all continents, using either 82  $\mu$ m or 60  $\mu$ m isotropic resolution technology (SCANCO Medical AG). Advantages of HR-pQCT adoption in peripheral small joint imaging include high resolution and detection of periarticular bone damage such as erosions, cysts, JSN, and bone proliferations in inflammatory and degenerative disease not visualized sensitively with other imaging technologies such as plain radiography, ultrasound, and magnetic resonance imaging (MRI)<sup>6,7</sup>.

Pilot studies in inflammatory arthritis conditions demonstrated that scanning protocols were well tolerated by patients with active inflammation and those with chronic joint changes. Because motion artifact is a concern in image acquisition, scanning protocols were developed, along with position holders to stabilize the area of interest. Patient positioning and image acquisition take 5–10 min compared to other imaging modalities such as conventional computed tomography (10–15 min) or MRI (20–45 min). Costs for 1 measurement by HR-pQCT vary between countries, but are comparable to a standard bone densitometry (dual-energy x-ray absorptiometry) scan.

From this early pilot work, independent laboratories began to test the application of HR-pQCT for imaging peripheral joints. Some initial publications described visible pathological manifestations<sup>6</sup>, while others compared findings at different stages of RA<sup>8,9</sup>, as well as different types of inflammatory arthritis, degenerative arthritis, and normal states<sup>10,11</sup>. Since then, 44 individual studies using HR-pQCT for arthritis assessment have been published or presented as abstracts<sup>12</sup>, and led to the involvement of the SPECTRA (Study group for xtrEme-Computed Tomography in Rheumatoid Arthritis) collaboration in the formal Outcome Measures in Rheumatology (OMERACT) validation process. The collaboration is a global network of rheumatologists, clinicians, epidemiologists, engineers, radiologists, fellows, students, physicists, pediatricians, and industry partners. The inaugural SPECTRA meeting in Calgary, Alberta, Canada in 2011 focused on standardizing image acquisition across centers<sup>13</sup>. Since then, membership has grown to 20 investigative sites from 5 continents, demonstrating clear interest in applying this technology in arthritis assessment for clinical research. The principal aims of SPECTRA are to (1) investigate

HR-pQCT for arthritis assessment in clinical trials, (2) validate HR-pQCT as a new imaging modality in clinical trials using OMERACT's incremental validation process, and (3) harmonize SPECTRA's global efforts for efficiency.

SPECTRA adheres to the OMERACT filter 1.0 incremental validation process — truth, feasibility, discrimination; and filter 2.0 — pathophysiological manifestations<sup>14</sup>. The goal has been to target evaluation for findings sensitive to change in biologically relevant intervals not identified by current imaging techniques, and to improve the correlation of imaging findings to function, which is significantly delayed with existing technologies. The aim of our work is to describe the current state of research as presented at OMERACT 2016 and the ensuing future directions outlined during the discussion among attendees.

## MATERIALS AND METHODS

At OMERACT 2016 in Whistler, British Columbia, Canada in May 2016, SPECTRA introduced HR-pQCT as a new imaging modality for outcome measures in clinical trials and longitudinal observational studies in a Special Interest Group (SIG). The collaboration's current research in validating HR-pQCT according to OMERACT guidelines was presented, focusing on the definition and evaluation of erosion in RA, and an automated algorithm for JSW analysis.

The SIG was presented to patient research partners, physicians/researchers, and SIG leaders at OMERACT 2016. Following a 20-min presentation, a 40-min discussion on important next steps and future directions was moderated by 2 SIG leaders, with the other 2 SIG leaders collecting minutes.

## RESULTS

The SPECTRA SIG at OMERACT 2016 was attended by 2 patient research partners, 16 physicians/researchers, and 4 SIG leaders.

### *Pathophysiological manifestations visible with HR-pQCT.*

Table 1<sup>12,14,15,16,17,18</sup> shows current and ongoing research efforts presented at the SIG, as well as future research directions allowing conformity to OMERACT guidelines.

*Definition and evaluation of erosions in RA.* A consensus definition for RA erosions visualized by HR-pQCT was deemed an essential first step toward development of measurement frameworks. A systematic literature review was presented, and identified multiple approaches for defining erosion in HR-pQCT images<sup>8,19,20,21</sup>. These are consistent in that a cortical break must be present, and was expanded to assert that the break must be visible over multiple slices and in multiple planes. Erosion shape definition was also important<sup>15</sup>, and differentiation between erosions and vessel channels was deemed necessary (Figure 1).

Eleven readers reviewed the definition and performed 2 scoring exercises to further refine it. A final scoring exercise on 58 joints gave 90% agreement on erosion presence,  $\kappa$  0.52 (95% CI 0.37–0.63) for all readers (of varying experience), and for experienced readers,  $\kappa$  0.76<sup>16</sup>. Experienced readers were those with more than 5 years' experience. These results were presented to 11 separate investigators and a Delphi

Table 1. Pathophysiological manifestations visible with HR-pQCT. The state of current and future research goals of SPECTRA within the OMERACT guidelines.

Variables		Erosions	Joint Space Width	Osteophytes	Bone Microarchitecture
Definition	SLR	✓ <sup>12</sup>	✓ <sup>12</sup>	✓ <sup>12</sup>	✓ <sup>12</sup>
	Consensus	✓ <sup>15</sup>			
Criterion validity	Histopathology	✓ <sup>16</sup>			
Quantification – manual	Reliability	✓ <sup>15</sup>	—		—
	Responsiveness	o	—		—
Quantification – semiautomated	Reliability	o	—		—
	Responsiveness	o	—		—
Quantification – automated	Reliability	o	✓ <sup>14,17,18</sup>		
	Responsiveness	o	o		

HR-pQCT: high-resolution peripheral quantitative computed tomography; SPECTRA: Study group for xtrEme-Computed Tomography in Rheumatoid Arthritis; OMERACT: Outcome Measures in Rheumatology; SLR: systematic literature review; ✓: completed tasks; —: unplanned tasks; o: ongoing tasks; empty cells: in future research directions.

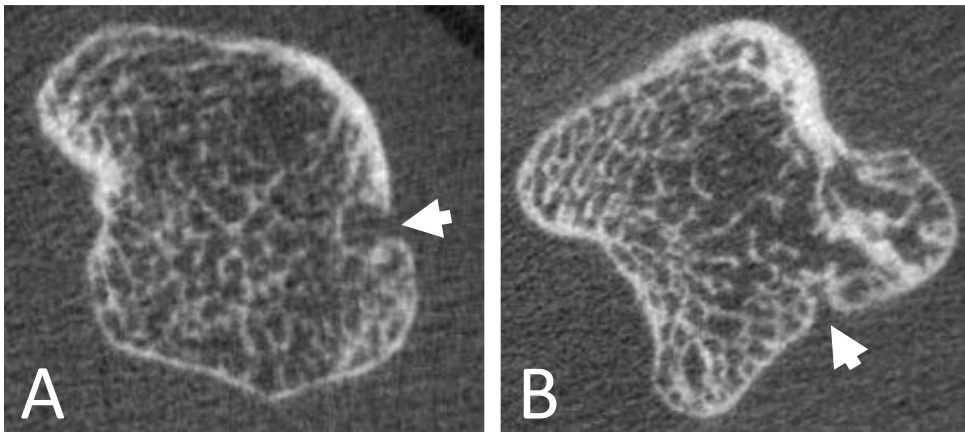


Figure 1. HR-pQCT image of the metacarpophalangeal head, transverse view. Arrows indicate examples of (A) an erosion and (B) a vessel channel. HR-pQCT: high-resolution peripheral quantitative computed tomography.

exercise was performed. Results indicated 100% acceptance of the proposed definition.

A histopathology study was presented, which analyzed the true characteristics of cortical breaks in HR-pQCT (criterion validity), and provides anatomic data supporting the SPECTRA definition. A perfusion study with barium sulphate was presented, which correlates linear cortical channels with penetrating blood vessels<sup>22</sup>. These data confirm the SPECTRA definition of erosion and that HR-pQCT can distinguish bone erosion from small vascular channels, a critical distinction for discrimination between healthy controls and individuals with early RA who exhibit both physiologic vascular channels and small bone erosions<sup>22</sup>.

Multiple approaches to measure erosion have been identified<sup>17</sup>, using a semiquantitative score, a direct measurement from 2-dimensional images, or volumetric approximation. Given that volumetric methods are not widely available, results from direct measurement were presented.

Consensus was reached on a standard approach, which was tested for reliability in the RELEX-1 reading exercise. Moderate reliability was obtained [perpendicular width root mean square coefficient of variance (RMSCV) 12.3%, ICC 0.206; axial width RMSCV 20.6%, ICC 0.665; perpendicular depth RMSCV 24.0%, ICC 0.783; axial depth RMSCV 22.2%, ICC 0.871]<sup>16</sup>. ICC increased to >0.9 for experienced readers only. Plans were described for a second study investigating responsiveness of the direct measurement approach (RELEX-2), as well as automated quantitative strategies consistent with the SPECTRA definition.

*Ways to measure JSW.* JSW is an indirect measure of arthritis disease activity. A systematic literature review was presented that identified published approaches to joint space measurement<sup>18,19,23</sup>. Specifically, 3 techniques for high-throughput, robust, reproducible, fully automated, quantitative 3-D measurements of JSW from HR-pQCT-derived data have been published<sup>18,19,23</sup>.



To standardize JSW measurement among the SPECTRA consortium, a study has been performed to reach consensus on one method; either 1 of the 3 published or a hybrid. The methods were compared to test JSW measurement reliability (1) across a spectrum of RA disease (early to late), (2) in scan/rescan (including re-positioning), and (3) for the same joints measured on the 2 HR-pQCT devices available commercially (XtremeCT and XtremeCT II, Scanco Medical AG). Results indicate excellent reproducibility, with all 3 methods able to discriminate JSW across a spectrum of disease, and mean and minimum JSW estimates comparable between them. This comparison revealed that maximum JSW estimates were significantly different between the 3 methods, while minimum JSW reliability was sensitive to scan/rescan errors, particularly in joints with substantial narrowing because of differences in handling zones with zero or near-zero thickness (Figure 2). There was no difference in JSW when measured using the 2 models of HR-pQCT.

## DISCUSSION

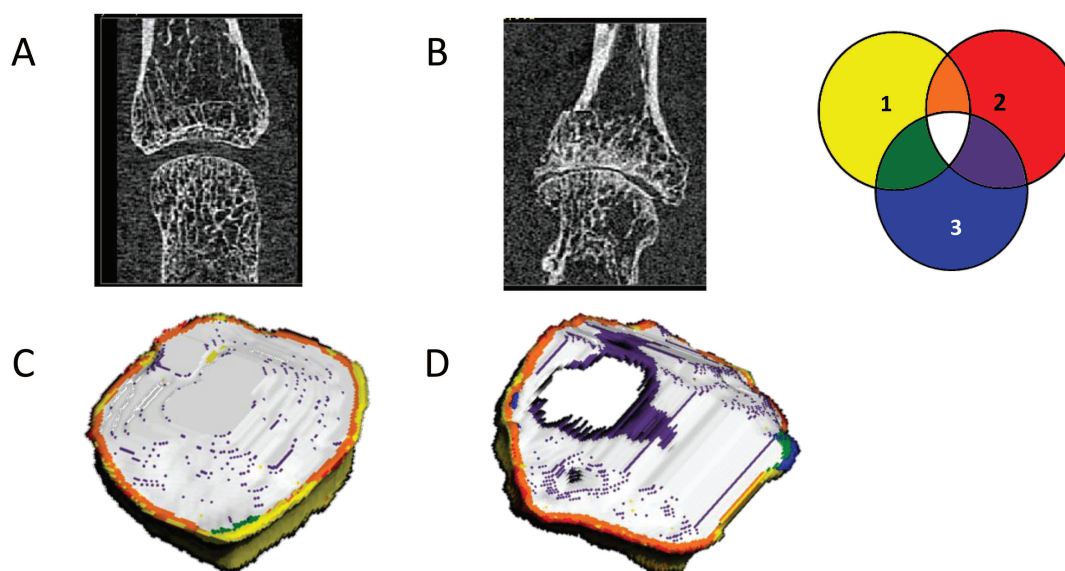
*SIG discussion and future research directions.* Following presentation of our current research, future research directions were discussed. A consensus emerged that it is now imperative to perform a longitudinal study assessing the responsiveness of erosion measurement quantification, in which one scoring method (direct measurement or automated measurement) must be selected that gives reliable estimates of change over time and with treatment. If a manual method is selected, calibration of readers is required. Consequently,

identification of disease-specific cutoffs in erosion and JSW metrics, compared to normal findings in healthy controls, is necessary.

Further, it was recommended that performance of the HR-pQCT be tested for detecting and quantifying pathological manifestations in comparison to other modalities (e.g., ultrasound, MRI)<sup>15,17</sup>, as well as other rheumatological diseases (e.g., osteoarthritis, psoriasis, and psoriatic arthritis), and crystal arthropathies. Translation of the methods to other sites of interest, for example the wrist<sup>23</sup> or metatarsophalangeal joints, would also aid in increasing sensitivity to detect activity in site-specific diseases.

## APPENDIX 1.

List of study collaborators. SPECTRA: Steven K. Boyd (Calgary, Canada); Liam Martin (Calgary, Canada); Susan G. Barr (Calgary, Canada); Lynne Feehan (Vancouver, Canada); Mira van Veenendaal (Toronto, Canada); Angela Cheung (Toronto, Canada); Rae Yeung (Toronto, Canada); Georg Schett (Erlangen, Germany); Nikolay Tzaribachev (Bad Bramstedt, Germany); Klaus Engelke (Erlangen, Germany); Xiaojuan Li (San Francisco, USA); Valentina Pedoia (San Francisco, USA); Yebin Jiang (Michigan, USA); Karen Troy (Worcester, USA); Josh Baker (Pennsylvania, USA); Joop van den Bergh (Maastricht, The Netherlands); Piet Geusens (Maastricht, The Netherlands); Bert van Rietbergen (Eindhoven, The Netherlands); Paul Willems (Maastricht, The Netherlands); Joost de Jong (Maastricht, The Netherlands); Astrid van Tubergen (Maastricht, The Netherlands); Hubert Marotte (Saint-Etienne, France); Roland Chapurlat (Lyon, France); Stephanie Boutroy (Lyon, France); Denis Jullien (Lyon, France); Eric Lespessailles (Orleans, France); Nada Ibrahim (Orleans, France); Kristian Stengaard-Pedersen (Aarhus, Denmark); Kresten Keller (Aarhus, Denmark); Ellen-Margrethe Hauge (Aarhus, Denmark); Roland Kocijan (Vienna, Austria); Christian Dejaco (Graz, Austria); Nicolas Vilaythiou (Zurich, Switzerland); Sebastian Kraus (Baden, Switzerland);



*Figure 2.* (A) and (B) show 2 examples of HR-pQCT images of the MCP II joint at different stages of arthritis disease, and (C) and (D) their corresponding joint space masks. Colors indicate where each of the 3 algorithms (1, 2, 3) had full (white), partial (orange, purple, green), or no agreement (yellow, red, blue) in defining the joint space mask volume. Joint space volume for (A) was 90 mm<sup>3</sup>, 94 mm<sup>3</sup>, and 70 mm<sup>3</sup>, and (B) was 106 mm<sup>3</sup>, 114 mm<sup>3</sup>, 87 mm<sup>3</sup> for algorithms 1, 2, and 3, respectively. HR-pQCT: high-resolution peripheral quantitative computed tomography; MCP: metacarpophalangeal.

## REFERENCES

1. Geusens PP, Finzel S. Imaging: bone erosions in rheumatoid arthritis: better to see more? *Nat Rev Rheumatol* 2013;9:385-6.
2. Paccou J, Edwards M, Moss C, Dennison E, Cooper C. High-resolution imaging of bone and joint architecture in rheumatoid arthritis. *Br Med Bull* 2014;112:107-18.
3. Mueller TL, Stauber M, Kohler T, Eckstein F, Muller R, van Lenthe GH. Non-invasive bone competence analysis by high-resolution pQCT: an in vitro reproducibility study on structural and mechanical properties at the human radius. *Bone* 2009;44:364-71.
4. Krug R, Burghardt AJ, Majumdar S, Link TM. High-resolution imaging techniques for the assessment of osteoporosis. *Radiol Clin North Am* 2010;48:601-21.
5. Cheung AM, Adachi JD, Hanley DA, Kendler DL, Davison KS, Josse R, et al. High-resolution peripheral quantitative computed tomography for the assessment of bone strength and structure: a review by the Canadian Bone Strength Working Group. *Curr Osteoporos Rep* 2013;11:136-46.
6. Stach CM, Bäuerle M, Englbrecht M, Kronke G, Engelke K, Manger B, et al. Periarticular bone structure in rheumatoid arthritis patients and healthy individuals assessed by high-resolution computed tomography. *Arthritis Rheum* 2010;62:330-9.
7. Finzel S, Kraus S, Schmidt S, Hueber A, Rech J, Engelke K, et al. Bone anabolic changes progress in psoriatic arthritis patients despite treatment with methotrexate or tumour necrosis factor inhibitors. *Ann Rheum Dis* 2013;72:1176-81.
8. Fouque-Aubert A, Boutroy S, Marotte H, Vilayphiou N, Bacchetta J, Miossec P, et al. Assessment of hand bone loss in rheumatoid arthritis by high-resolution peripheral quantitative CT. *Ann Rheum Dis* 2010;69:1671-6.
9. Zhu TY, Griffith JF, Qin L, Hung VW, Fong TN, Au SK, et al. Alterations of bone density, microstructure, and strength of the distal radius in male patients with rheumatoid arthritis: a case-control study with HR-pQCT. *J Bone Miner Res* 2014;29:2118-29.
10. Finzel S, Sahinbegovic E, Kocijan R, Engelke K, Englbrecht M, Schett G. Inflammatory bone spur formation in psoriatic arthritis is different from bone spur formation in hand osteoarthritis. *Arthritis Rheumatol* 2014;66:2968-75.
11. Goldhahn J, Stok K, Mueller TL, Müller R, Kolling C. Imaging of finger micro-architecture with high-resolution pQCT for monitoring of erosive destructions and implant anchorage. *Swiss Med Wkly* 2010;140:44.
12. Nagaraj S, Finzel S, Stok KS, Barnabe C; SPECTRA Collaboration. High-resolution peripheral quantitative computed tomography imaging in the assessment of periarticular bone of metacarpophalangeal and wrist joints. *J Rheumatol* 2016; 43:1921-34.
13. Barnabe C, Feehan L; SPECTRA (Study Group for XTrEme-CT in RA). High-resolution peripheral quantitative computed tomography imaging protocol for metacarpophalangeal joints in inflammatory arthritis: the SPECTRA collaboration. *J Rheumatol* 2012;39:1494-5.
14. Boers M, Kirwan JR, Gossec L, Conaghan PG, D'Agostino MA, Bingham CO 3rd, et al. How to choose core outcome measurement sets for clinical trials: OMERACT 11 approves filter 2.0. *J Rheumatol* 2014;41:1025-30.
15. Finzel S, Ohrndorf S, Englbrecht M, Stach C, Messerschmidt J, Schett G, et al. A detailed comparative study of high-resolution ultrasound and micro-computed tomography for detection of arthritic bone erosions. *Arthritis Rheum* 2011;63:1231-6.
16. Barnabe C, Toepfer D, Marotte H, Hauge EM, Scharnga A, Kocijan R, et al; SPECTRA Collaboration. Definition for rheumatoid arthritis erosions imaged with high resolution peripheral quantitative computed tomography and interreader reliability for detection and measurement. *J Rheumatol* 2016;43:1935-40.
17. Srikhum W, Virayavanich W, Burghardt AJ, Yu A, Link TM, Imboden JB, et al. Quantitative and semiquantitative bone erosion assessment on high-resolution peripheral quantitative computed tomography in rheumatoid arthritis. *J Rheumatol* 2013;40:408-16.
18. Boutroy S, Hirschenhahn E, Youssof E, Locrelle H, Thomas T, Chapurlat R, et al. Importance of hand positioning in 3D joint space morphology assessment. *Arthritis Rheum* 2013;65:S840.
19. Barnabe C, Szabo E, Martin L, Boyd SK, Barr SG. Quantification of small joint space width, periarticular bone microstructure and erosions using high-resolution peripheral quantitative computed tomography in rheumatoid arthritis. *Clin Exp Rheumatol* 2013;31:243-50.
20. Yang H, Yu A, Burghardt AJ, Virayavanich W, Link TM, Imboden JB, et al. Quantitative characterization of metacarpal and radial bone in rheumatoid arthritis using high resolution- peripheral quantitative computed tomography. *Int J Rheum Dis* 2017; 20:353-62.
21. Zhu Y, Griffith JF, Qin L, Hung VW, Fong TN, Au SK, et al. SAT0095 Periarticular bone loss in female patients with rheumatoid arthritis: a case-control study using HR-PQCT. *Ann Rheum Dis* 2013;72 Suppl 3:A611.
22. Boutroy S, Chapurlat R, Vanden-Bossche A, Locrelle H, Thomas T, Marotte H. Erosion or vascular channel? *Arthritis Rheumatol* 2015;67:2956.
23. Burghardt AJ, Lee CH, Kuo D, Majumdar S, Imboden JB, Link TM, et al. Quantitative in vivo HR-pQCT imaging of 3D wrist and metacarpophalangeal joint space width in rheumatoid arthritis. *Ann Biomed Eng* 2013;41:2553-64.