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Original Article

Please Don't Move—Evaluating Motion Artifact From Peripheral Quantitative Computed Tomography Scans Using Textural Features

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Abstract

Most imaging methods, including peripheral quantitative computed tomography (pQCT), are susceptible to motion artifacts particularly in fidgety pediatric populations. Methods currently used to address motion artifact include manual screening (visual inspection) and objective assessments of the scans. However, previously reported objective methods either cannot be applied on the reconstructed image or have not been tested for distal bone sites. Therefore, the purpose of the present study was to develop and validate motion artifact classifiers to quantify motion artifact in pQCT scans. Whether textural features could provide adequate motion artifact classification performance in 2 adolescent datasets with pQCT scans from tibial and radial diaphyses and epiphyses was tested. The first dataset was split into training (66% of sample) and validation (33% of sample) datasets. Visual classification was used as the ground truth. Moderate to substantial classification performance (J48 classifier, kappa coefficients from 0.57 to 0.80) was observed in the validation dataset with the novel texture-based classifier. In applying the same classifier to the second cross-sectional dataset, a slight-to-fair (κ = 0.01–0.39) classification performance was observed. Overall, this novel textural analysis-based classifier provided a moderate-to-substantial classification of motion artifact when the classifier was specifically trained for the measurement device and population. Classification based on textural features may be used to prescreen obviously acceptable and unacceptable scans, with a subsequent human-operated visual classification of any remaining scans.

Key Words: Bone QCT; machine learning; morphology; precision; repeatability.

Introduction

It is widely acknowledged that computed tomography scans are susceptible to methodological issues such as partial volume effect and beam hardening, operating errors such as positioning errors, and movement of the individual during

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a scan, the last of which manifests as movement artifact (1). Although some methodological issues are unavoidable, operator errors can be minimized with training, and movement artifacts can be rectified by rescanning. However, rescanning is not always desirable or practical given the additional radiation dose and time required. Moreover, rescanning may occasionally not be required as it is well established that a limited amount of visible motion artifact does not invalidate a scan (1–5). Anecdotally, children are particularly fidgety (1) and the operator is often left with a scan that has conspicuous signs of motion artifact (streaking and discontinuity of cortical structure (1–6)) and the decision of whether or not to rescan. The acceptable levels of motion artifact have been defined for both high-resolution (2–5) and regular computed tomography (1). However, the method developed for regular peripheral computed tomography (pQCT) (1) is applicable only to bone shafts and not to distal or proximal bone sites with narrow cortices.

The effects caused by motion artifact on the image reconstruction in computed tomography have been explored by Yang et al (6), but even with this comprehensive understanding of motion-caused artifacts, a consistent standard operating procedure for motion artifact quantification has yet to emerge. The approaches used to detect motion artifact include subjective visual scaling (1,4,5,7), quantification of translation and rotation based on the measured sinogram (measured projections) (2–4), and exploring analysis results utilizing varying analysis thresholds (1). The objective quantification of translation based on the sinogram can only be done before reconstructing the image with filtered back projection (2). All computed tomography devices measure the sinogram, but the sinogram cannot be extracted from some devices and hence is not an applicable method in all cases. Although the agreement between raters for visual scaling is rather good for normal and high-resolution pQCT (1,4,5), an automated method may prove helpful in optimizing consistency and reliability, particularly in very large datasets and multisite studies.

Because visual scaling is based on the appearance of the image after reconstruction, and the motion artifact typically includes streaking and discontinuities of the bone cortex (6), textural analysis could provide a suitable option for the semiquantitative detection of motion artifact from computed tomography scans in the absence of the measured sinogram. Many textural analysis approaches capturing various properties of texture in medical imaging have been presented in the literature (e.g., reviewed in References 8 and 9). Of the various approaches, local binary patterns (LBPs) appear particularly well suited for motion artifact detection because LBP capture streaking in images (10) have been successfully applied in an automated radiographic image measurement site annotation in the past (11) and are computationally efficient to implement (10). However, LBP has yet to be tested as a feature to quantify motion artifact.

The purpose of the present study was to develop and validate automated motion artifact classifiers to quantify motion artifact in pQCT scans. Specifically, the aim was to evaluate whether LBP could provide a better classification performance using visual inspection as the ground truth compared to applying current state-of-the art objective motion artifact measures as classification features.

Materials and Methods

The present study is a reanalysis of previously published AMPitup (12) (described further) and Griffith University Bone Densitometry Research Laboratory (13–20) datasets (described in the section Griffith Dataset).

AMPitup Dataset

The AMPitup Program is an exercise intervention program for adolescents with a movement disorder (21) being conducted at the University of Notre Dame Australia and is reported as the AMPitup dataset in the present paper. The initial bone results of the program have been published previously (12). In brief, participants were aged between 12 and 18 yr and were eligible for the AMPitup program if they had a Neuromuscular Development Index of 85 or below (≤1 standard deviation compared to the healthy mean, mild motor disability) using the McCarron Assessment of Neuromuscular Development (22,23) and a history of movement difficulties (such as poor coordination or clumsiness, slowness, and inaccuracy of motor skills that negatively impact daily living, school, leisure, and play activities (24)). Participants with significant intellectual or physical disabilities that limited their ability to participate in the exercise program were excluded. The present study was approved by the University of Notre Dame Australia Human Research Ethics Committee. Before enrolment, written informed consent was provided by the primary caregiver and assent was given by the adolescents.

Anthropometry

Height was measured using a stadiometer (Mentone Educational Centre, Victoria, Australia), and recorded to the nearest 0.1 cm, and weight was measured to the nearest 0.1 kg using a digital weight scale (HoMedics, Victoria, Australia).

Bone Assessments

Peripheral quantitative computed tomography (pQCT, XCT-3000; Stratec Medizintechnik GmbH, Pforzheim, Germany) was used to evaluate cross sections of the tibia and radius at 4% and 66% (defined from a scout view) of the tibial (from medial malleolus toward the knee joint cleft) and ulnar (from the styloid process of the ulna toward the olecranon) lengths from the distal endplates, respectively (in-plane pixel size 0.4 × 0.4 mm, slice thickness 2.3 mm). All AMPitup participant scans were conducted at Princess Margaret Hospital for Children in the Department of Radiology, Perth, Western Australia. Participants were seated in a stationary chair adjusted to their height. The pQCT