ORIGINAL ARTICLE

Towards Quantifying the Prevalence, Severity, and Cost Associated With Patient Motion During Clinical MR Examinations

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Abstract

Purpose: To assess the prevalence, severity, and cost estimates associated with motion artifacts identified on clinical MR examinations, with a focus on the neuroaxis.

Methods: A retrospective review of 1 randomly selected full calendar week of MR examinations (April 2014) was conducted for the detection of significant motion artifacts in examinations performed at a single institution on 3 different MR scanners. A base-case cost estimate was computed from recently available institutional data, and correlated with sequence time and severity of motion artifacts.

Results: A total of 192 completed clinical examinations were reviewed. Significant motion artifacts were identified on sequences in 7.5% of outpatient and 29.4% of inpatient and/or emergency department MR examinations. The prevalence of repeat sequences was 19.8% of total MRI examinations. The base-case cost estimate yielded a potential cost to the hospital of $592 per hour in lost revenue due to motion artifacts. Potential institutional average costs borne (revenue forgone) of approximately $115,000 per scanner per year may affect hospitals, owing to motion artifacts (univariate sensitivity analysis suggested a lower bound of $92,600, and an upper bound of $139,000).

Conclusions: Motion artifacts represent a frequent cause of MR image degradation, particularly for inpatient and emergency department patients, resulting in substantial costs to the radiology department. Greater attention and resources should be directed toward providing practical solutions to this dilemma.

Key Words: MRI, motion, cost estimate, economics, motion correction

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INTRODUCTION

Patient motion can be a frequent cause of image degradation in MR examinations (estimated to occur in 10% to 42% of sequences in a select adult population) [1]. Associated motion artifacts (such as ring artifacts and image blurring) may result in suboptimal image quality that negatively affects radiologic interpretation [2-5], potentially impacts patient safety, and increases the medicolegal risks associated with interpreting motion-degraded images. Motion artifacts can worsen when advanced MR techniques that rely on higher spatial resolution and involve greater sequence complexity are used [3,5-7]. Surprisingly, the prevalence and severity of motion artifacts that result in significantly degraded clinical MR examinations is poorly documented in the literature, as is their impact on throughput and organizational finances. Although several motion-correction techniques have been proposed [8-16], the newest and most promising methods are available primarily in the research domain, outside the realm of routine clinical use where they might be of substantial benefit.

Motion artifacts may be recognized at the time of image acquisition. At our institution, MR technologists are instructed to repeat sequences that depict significant motion artifacts (with input from the radiologists, when

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possible). Nonetheless, correcting for motion artifacts can extend the time (and possibly increase patient discomfort) associated with an MR examination, which affects patient and provider time, hospital cost, and other resources associated with imaging.

Furthermore, nothing guarantees that patients will be better able to lie motionless during the repeated sequence, and the additional time requirements to have them try to do so have not been previously evaluated. We sought to assess the prevalence of significant motion artifacts and repeat sequences identified on MR examinations obtained in a clinical population at an academic, level I trauma center, with a focus on examinations of the neuroaxis. In addition, we sought to estimate the potential financial loss associated with motion artifacts during MR examinations.

METHODS

A retrospective, HIPAA-compliant study, approved by an institutional review board, was undertaken; patient consent was waived. This study included radiologic review of 1 full, randomly selected calendar week (April 2014) of clinical MR examinations sent to a Centricity PACS (General Electric, Milwaukee, Wisconsin), by neuroradiologists who were blinded to all medical history, clinical presentation, and patient disposition (ie, whether imaging occurred for an outpatient [OP], inpatient [IP], or emergency department [ED] patient). Cases were identified on the scanner console and subsequently sent for image evaluation on PACS.

All examinations were performed at a single hospital, on 3 different MR scanners: a 1.5-T OP-only scanner (Avanto; Siemens Healthcare, Erlangen, Germany) operating on weekdays only, and 2 in-hospital scanners: a 1.5-T SignaHD (GE Healthcare, Milwaukee, Wisconsin) and a 3-T Tim Trio (Siemens Healthcare, Erlangen, Germany). The in-hospital scanners operate 24 hours per day, 7 days per week, and can accommodate IP, ED, and OP examinations.

A preliminary evaluation identified that not all attempted sequences and/or failed examinations are consistently sent to PACS [17]. That is, MR technologists may refrain from sending some failed or interrupted sequences to PACS. However, all these unsuccessfully attempted sequences and/or examinations remain available for review directly on the MR console.

Data Acquisition and Analysis

In recognition of the preceding observation, a radiologic review of all attempted sequences and examinations was first performed directly at each independent MR scanner console (each attempted examination was reviewed daily at the scanner console, and cross-referenced with the MR schedule for that day, to ensure that no examinations were bypassed). The data obtained directly from the scanner consoles included recordings of all individual sequence acquisition times (beginning to end), scan times for original and repeat sequences, and recordings of the total number of sequences attempted per examination. The preparation (lag) time between acquired sequences was not recorded. This documentation was performed independently, in blinded fashion, by 3 neuroradiologists (who had 6, 36, and 5 years of experience, respectively). They recorded the temporal duration of each MR examination, the number of repeat sequences, the fact that the sequence repeat was due to patient-related motion artifacts (rather than technical or other sources), the time lost per sequence (when repeated), and the number of sequences and examinations that were prematurely terminated.

PACS Review

All acquired images that were part of the final clinical examination were visually reviewed by 2 blinded neuroradiologists at a PACS station to achieve consensus, for detectable motion artifacts. A graded 5-tier scale was devised to incorporate the impact of motion artifacts on diagnostic image quality (Table 1). Using this scale, moderate and severe motion artifacts were judged to negatively affect clinical interpretation of the images. Subtle movements of the globes, pulsation artifacts, breathing and cardiac-related motion, and minimal motion artifacts appearing on a single imaging slice were disregarded in all examinations.

Typical Patient Population

This study was performed across a broad patient population with a wide range of illnesses. Our institution has a focus on neurologic diseases (especially vascular, traumatic, and infectious), spinal axis abnormalities (both traumatic and degenerative), and musculoskeletal diseases. Most ED patients for whom an MR examination is requested are admitted. Their MR examinations are subsequently performed when they are IPs, to facilitate nursing support during the scanning process.

Time and Cost Estimation

The cost estimation was done from an institutional perspective, using a simplified average of recently available