Osteoarthritis and Cartilage 24 (2016) 1167–1171

Osteoarthritis and Cartilage

OARSI OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

Brief Report

Value of tomosynthesis for lesion evaluation of small joints in osteoarthritic hands using the OARSI score

K. Martini[*] [a], A.S. Becker [a], R. Guggenberger, G. Andreisek, T. Frauenfelder

Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, Switzerland

ARTICLE INFO

Article history:
Received 2 October 2015
Accepted 24 January 2016

Keywords:
Tomosynthesis
Osteoarthritis
Computed tomography
Early detection
Small joints

SUMMARY

Objective: To determine the diagnostic performance of tomosynthesis in depicting osteoarthritic lesions in comparison to conventional radiographs, with use of computed tomography (CT) as standard-of-reference.

Methods: Imaging of 12 cadaveric hands was performed with tomosynthesis in dorso-palmar (dp) projection, conventional radiographs (dp) and multi-detector CT. Distal interphalangeal joint (DIP)II, DIPIII, proximal interphalangeal joint (PIP)II, PIPIII, first carpometacarpal (CMC) and scaphotrapezo-trapezoidal joint (STT) were graded by two independent readers using the Osteoarthritis Research Society International (OARSI) score. The mean score for each feature was calculated for all modalities. Additional wrists were evaluated for presence of calcium pyrophosphate disease (CPPD). CT served as reference-standard. Inter-reader agreement (ICC) was calculated.

Results: Comparing tomosynthesis and conventional radiographs to CT, the sensitivity for the presence of osteophytes was 95,7% vs 65,2%; for joint space narrowing 95,8% vs 52,1%; for subchondral sclerosis 61,5% vs 51,3%; for lateral deformity 83.3% vs 83,3%; and for subchondral cysts 45,8% vs 29,2%. Erosions were not present. While tomosynthesis showed no significant difference in OARSI score grading to CT (mean OARSI-score CT: 16.8, SD = 10.6; mean OARSI-score Tomosynthesis: 16.3, SD = 9.6; $P = 0.84$), conventional radiographs had significant lower mean OARSI scores (mean OARSI-score X-ray: 11.1, SD = 8.3; $P = 0.04$). Inter-reader agreement for OARSI scoring was excellent (ICC = 0.99). CPPD calcifications present in CT, were also visible with tomosynthesis, but not with conventional radiography.

Conclusion: In conclusion, tomosynthesis depicts more osteoarthritic changes in the small joints of the hand than conventional radiography using the OARSI scoring system and CT as the standard of reference.

Introduction

Osteoarthritis (OA) of the hand is a frequent condition in the aging population and typically affects the proximal and distal interphalangeal, metacarpophalangeal, and carpometacarpal (CMC) joints in the hands[1]. Due to short examination time, broad access and low cost[2] traditionally conventional radiographs are used for diagnosis and follow up of OA[1]. However, conventional radiographs are associated with a lower sensitivity in the detection of early OA compared to other imaging modalities[3].

Conventional radiography is a projection-based imaging method, i.e., a three-dimensional structure is projected onto a two-dimensional image. Therefore, despite the high spatial resolution, it often lacks the possibility to differentiate structures with equal density adjacent to one another or suffers from superposition of normal structures[3]. Thus, the assessment of small or narrow joints for the presence of OA is often hampered and the degree of osteoarthritic changes might be underestimated i.e., when compared to computed tomography (CT). CT uses fan-beam X-ray geometry acquiring datasets with lower but isotropic spatial resolution that allow for arbitrary reconstruction planes and hence more accurate assessment of anatomic structures, as for example bone. However, compared to conventional radiographs, CT is associated with higher radiation doses and costs.

Tomosynthesis is an in-between method: It is a projection-based X-ray imaging modality operating at low radiation dose, which consists of a moving tube and detector during image acquisition. This allows for focusing on a defined depth by blurring

* Address correspondence and reprint requests to: K. Martini, University Hospital Zurich, Department of Diagnostic and Interventional Radiology, Rämistrasse 100, CH-8091 Zürich, Switzerland. Tel: 0041-0-44-255-93-83; Fax: 0041-0-44-255-44-43.

E-mail address: Katharina.Martini@usz.ch (K. Martini).

[a] Equal contribution.

http://dx.doi.org/10.1016/j.joca.2016.01.982
1063-4584/

the adjacent structures allowing generating thin image slices similar to CT, but with higher in plane resolution[4–6]. Over the past few years, various implementations of tomosynthesis have been investigated, including vascular, dental, mammographic, chest, orthopedic and bone imaging[4,6,7]. Tomosynthesis is a FDA approved medical device, which is commercially available by several major vendors of conventional X-ray systems, and already widely accepted for breast imaging[7].

Because of the tweener nature of tomosynthesis, we hypothesized that it could improve the diagnosis of OA in the hand (compared to conventional radiography) similar to CT without its drawbacks. Potential applications for tomosynthesis in OA may include all cases where conventional radiographs are ambiguous or where only limited access to CT is granted.

Thus, the aim of this *ex-vivo* study was to determine the diagnostic performance of tomosynthesis in depicting osteoarthritic lesions in comparison to conventional radiographs, with use of CT as standard-of-reference.

Material and methods

Cadaveric hands

The study was approved by the local ethics committee and cadaveric hands were treated in accordance with local ethical laws and regulations. 12 cadaveric hands (four right, eight left) from five female and three male subjects (mean age 85.5 years; SD 9.09 years; range 70–98 years) were provided by the anatomic institute of our university after preparation with Thiel-Solution (mean duration of Thiel-fixation 4.75 y; SD 1.91). This ensures maintenance of physiologic, mechanic tissue properties without altering tissue density. All hands where subsequently imaged using conventional radiography, tomosynthesis and CT in one imaging session.

Conventional radiograph

Conventional radiographs were performed using standard clinical radiography unit (FDR AcSelerate, Fujifilm, Dusseldorf, Germany) and included dorso-palmar (dp) projections of the hand. They were obtained at a tube voltage of 50 kV and a current of 40 mA, according to the standard protocol of our department. The dose area product (DAP) was of 0.84 Gy m^2.

Tomosynthesis

Tomosynthesis was performed using the same radiography unit (FDR AcSelerate, Fujifilm Europe GmbH) which was equipped with the vendor-specific tomosynthesis tool. Imaging included dorsopalmar-projections at a tube voltage of 50 kV and a tube current of 40 mA. The position of the detector was fixed, while the X-ray tube fulfilled a continuous movement from $-20°$ to $20°$ (tube angle $40°$). The tomographic image acquisition resulted in 36 coronal section images with a 2 mm increment. Mean DAP was of 1.4 Gy m^2 (SD $\pm$ 0.115), the DAP was of 1.56 Gy m^2.

CT

Multi-detector CT was performed on a third-generation dual-source CT (SOMATOM Force; Siemens Healthcare; Forchheim, Germany) equipped with an integrated high-resolution circuit detector (Stellar Technology; Siemens Healthcare; Forchheim, Germany). Image acquisition included a tube voltage of 70 kV and an adjusted tube current time product of 16 mA s quality reference. Axial sections with a thickness of 0.6 mm were obtained. Images were reconstructed in the coronal plane with a slice thickness of 1 mm at 0.6 mm increment. The mean computed tomography dose index (CTDI*vol*) was 7.75 mGy.

Image evaluation/OARSI scoring

Two independent readers (two senior radiologists with 12 and 15 years of experience) evaluated the degree of OA in the distal interphalangeal joint (DIP) II, DIP III, proximal interphalangeal joint (PIP) II, PIP III, first CMC, and scaphotrapezotrapezoidal joint (STT) using the Osteoarthritis Research Society International (OARSI) score according to Hunter *et al.*[8]. Imaging features were evaluated and classified as followed: presence of osteophytes (not present-distinct, 0-3), joint space narrowing (normal-distinct, 0-3), subchondral sclerosis (not present-present, 0-1), lateral deformity (not present-present, 0-1), subchondral cysts (not present-present, 0-1), and central subchondral erosion as sign for erosive OA (not present-present, 0-1). Total score for the hand is defined as the summation of the single scores for each articulation. Total scores range from 0 to 60. Sensitivity for detection of pathologic findings was calculated. Additionally images were evaluated for presence of soft tissue calcification (yes/no/questionable) as possible sign of CPPD. CT

Table I
Sensitivity, Specificity, NPV and PPV for detection of pathologic changes in 72 joints: NPV, PPV, CT, Reader 1 (R1), Reader 2 (R2), 95% Confidence interval (CI) Number of joints $n = 72$ in 12 cadaveric hands

Sensitivity, specificity, NPV and PPV for detection of pathologic changes in 72 joints												
CT		Osteophytes		Joint space narrowing		Subchondral sclerosis		Lateral deformities		Subchondral cysts		Central subchondral erosions
	Frequency (n)	46		48		39		12		24		0
Tomosynthesis		***R1***	***R2***	***R1***	***R2***	***R1***	***R2***	***R1***	***R2***	***R1***	***R2***	***R1/R2***
	Sensitivity (%)	95,7	91,3	95,8	95,8	61,5	61,5	83,3	83,3	45,8	33,3	(–)
	95 % CI	80–100	90–100	90–100	90–100	83–100	83–100	66–100	88–99	56–100	44–96	(–)
	Specificity (%)	96.6	88.5	100	91.7	97.1	94.2	100	100	97.9	97.9	(–)
	95 % CI	80–100	38–73	82–100	62–95	83–100	80–99	93–100	51–97	88–100	82–98	(–)
	NPV (%)	96.4	88.9	88.5	90.9	72.3	71.7	96.8	98.3	73.4	73.8	(–)
	PPV (%)	97.8	75.0	97.9	92.0	100	92.3	96.0	83.3	100	81.8	(–)
Radiography		***R1***	***R2***	***R1***	***R2***	***R1***	***R2***	***R1***	***R2***	***R1***	***R2***	***R1/R2***
	Sensitivity (%)	65,2	67,4	52,1	54,2	51,3	51,3	83,3	41,7	29,2	33,3	(–)
	95 % CI	82–100	86–100	83–100	84–100	80–100	80–100	56–100	46–100	68–100	60–100	(–)
	Specificity (%)	93.1	69.2	100	83.3	97.1	94.2	100	96.7	100	93.8	(–)
	95 % CI	80–100	65–95	82–100	72–99	87	100	80–99	93–100	93–100	91–100	(–)
	NPV (%)	65.9	62.2	48.9	50.0	65.4	66.0	92.3	91.0	78.7	74.6	(–)
	PPV (%)	96.8	88.6	96.2	92.9	100	90.9	100	100	100	88.9	(–)

Table II
Mean OARSI scoring: calculated from the OARSI scores of the 12 hands. OARSI score of CT = 16.8 ± 10.6, CT, *P*-values of OARSI score obtained with respective imaging technique comparted to OARSI score obtained by CT

Mean OARSI scoring				
Reader	Tomosynthesis		Radiographs	
	OARSI score	*P-value*	*OARSI score*	*P-value*
R1	16.3 ± 9.6	0.84	11.1 ± 8.3	0.01
R2	16.0 ± 9.1	0.80	10.8 ± 8.8	0.04

served as standard of reference with CT images evaluated separately in consensus by both readers after a time interval of 4 weeks.

Statistical analysis

Continuous variables were expressed as means ± SD, and categorical variables were expressed as frequencies or percentages. To determine inter-observer agreement for OARSI scoring of the cadaveric hands, the interclass correlation was calculated between each pair of variables. According to Meyers *et al.*[9] an ICC < 0.69 was defined as poor, ICC between 0.70 and 0.79 as fair, ICC between 0.80 and 0.89 as good and ICC > 0.9 as high. Kolmogorow–Smirnow test was used to test for normality of the distribution. Generalized estimating equation (GEE) analysis has been performed to address statistical dependency of osteoarthritic changes between the corresponding hand-pairs (left and right). A *P*-value < 0.05 was considered to indicate statistical significance. All statistical analyses were performed using commercially available software (SPSS, version 19, IBM, Somers, NY, USA).

Results

Cadaveric hands and reference standard

In the 12 cadaveric hands, 72 joints (6 joints per hand) were evaluated. The mean OARSI score based on CT as the reference standard was 16.8 (SD ± 10.6, range 1–32) (Tables I and II).

Image evaluation and OARSI scoring

ICC of both readers for OARSI scoring was excellent (ICC = 0.99).

Comparing tomosynthesis and conventional radiographs to CT, the sensitivity was higher between tomosynthesis and CT than between conventional radiographs and CT for the presence of osteophytes, joint space narrowing, subchondral sclerosis, lateral deformity, subchondral cysts as well as for erosion (Table I). While

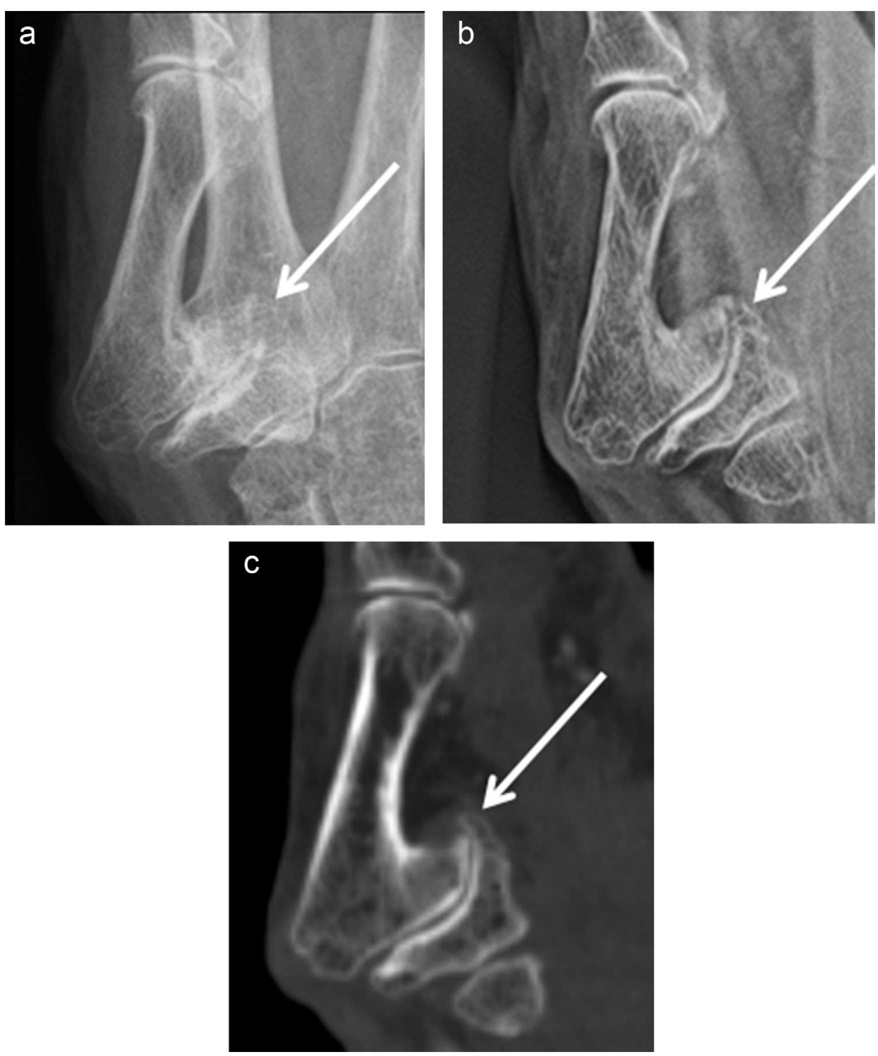

Fig. 1. Carpo-metacarpal joint of a cadaver hand with subchondral sclerosis, lateral deformities and subchondral cysts. While the subchondral cysts located at the edge of the trapezium (arrows) are visible on the tomosynthesis (b) scan and on the CT-scan (c), the subchondral cyst at this location are not visible on the conventional radiograph (a) due to the projection of a three-dimensional structure onto a two-dimensional image.

tomosynthesis showed no significant difference for both readers in OARSI score grading compared to CT (mean OARSI-score CT = 16.8, SD = 10.6; mean OARSI-score tomosynthesis: Reader 1 OARSI = 16.3, SD = 9.6, $P = 0.84$; and Reader 2 OARSI = 16.0, SD = 9.1, $P = 0.80$), conventional radiographs had significant lower mean OASIS scores compared to CT (mean OARSI-score X-ray: Reader 1 OARSI = 11, SD = 8.3, $P = 0.01$; and Reader 2 OARSI = 10.7, SD = 8.8; $P = 0.04$) (Table II). While all cases of CPPD evident in CT were depicted also in tomosynthesis (six cases out of six), CPPD was only seen in four of six cases in conventional radiography (Figs. 1 and 2). Central subchondral erosions a sign for erosive OA were present in none of the 12 hands.

Sensitivity, specificity, negative predictive value (NPV) as well as positive predictive value (PPV) for the detection of joint degenerations with tomosynthesis and radiography are shown in detail in Table I.

Discussion

Several authors state that CT allows for better assessment of bone in complex anatomic regions, such as the carpus, compared to radiography[3,10]. However, CT has the negative aspect of higher doses and higher costs compared to radiography. Tomosynthesis might be considered a tweener and might have the power to fill this gap, with its higher (potential) sensitivity compared to radiographs, but at lower costs compared to CT. The higher sensitivity of tomosynthesis compared to radiographs is thought to be due to the thin sections and high in-plane resolution, allowing a detailed, free from superposition analysis of the bones[3]. An explanation for the still relatively low diagnostic accordance of tomosynthesis compared to CT is the missing possibility of multiplanar reconstructions[3].

Our results show that the OARSI score obtained with tomosynthesis was not significantly different from CT ($P \geq 0.80$), while conventional radiographs show a significantly lower OARSI score ($P \leq 0.04$) in the evaluation of OA. In our study, with tomosynthesis more osteophytes, more severe joint space narrowing, more subchondral sclerosis and more joint deformities were detected compared to radiography. Thus, our results in the hand are in perfect agreement with a prior study by Hayashi *et al.*[11] who investigated the detection rate of tomosynthesis for osteophytes and subchondral cysts in 80 osteoarthritic knees. Their results showed that tomosynthesis depicted more osteophytes and subchondral cysts than did radiography[11]. Thus, it seems that the results for tomosynthesis may apply for both, the large knee joint as well as the small joints of the hand.

Our results are also in agreement with gross findings in other studies comparing tomosynthesis and radiography in patients with rheumatoid arthritis[3,11–14]. Canella *et al.* found that the depiction of bone erosions in RA was significantly better with tomosynthesis compared to radiography. In our cohort, none of the patients had RA or central subchondral erosion suggestive for erosive OA. Thus, we could not prove if tomosynthesis would also show more erosions than radiography. However, this was already shown by Aoki *et al.* who compared tomosynthesis with radiography using MR as reference standard. They evaluated 50 hands in 20 patients with RA and five healthy volunteers and found that significantly more erosions were seen with tomosynthesis than with radiography ($P < 0.01$). In the latter study, sensitivity, specificity, and accuracy were 68.1%, 97.5%, and 86.7% for radiography and 94.8%, 97.8%, and 96.7% for tomosynthesis.

Our study has limitations. First, we did not compare the spatial resolution of radiography, tomosynthesis and CT. However, data on this can be found in the literature. For example, Flynn *et al.* reported

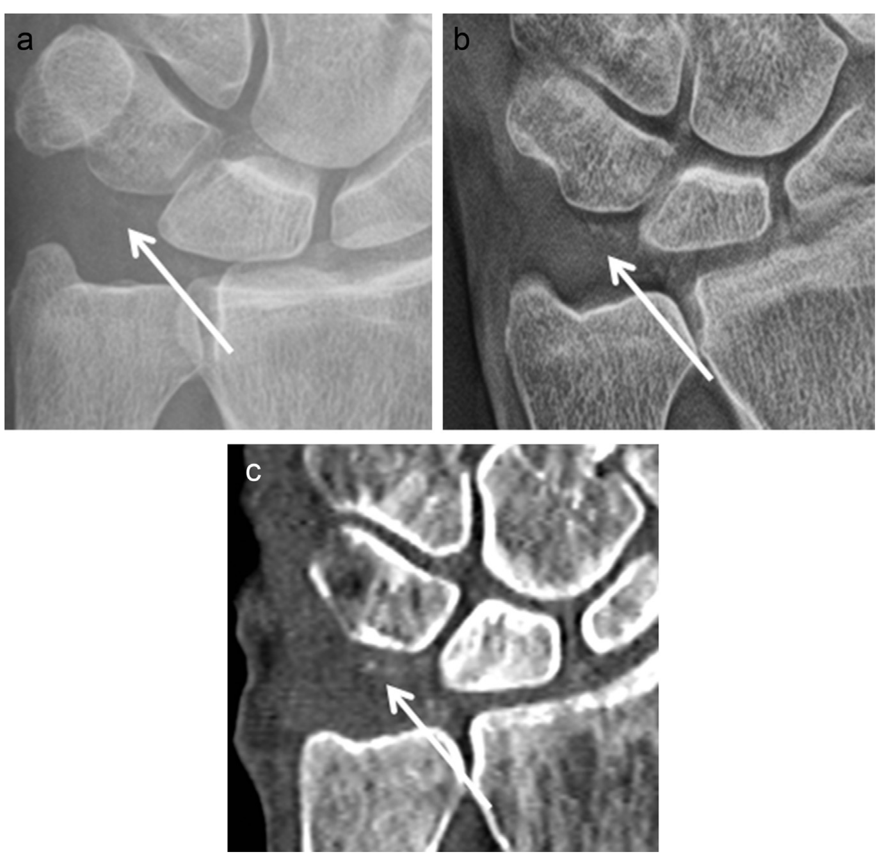

Fig. 2. Cadaver hand with CPPD. While calcifications are clearly visible on a) CT and b) tomosynthesis, on c) conventional radiography no calcifications are evident.

a threefold improvement in spatial resolution using tomosynthesis in imaging bone compared to CT scans[13]. Flynn *et al.* also compared the radiation doses and found a considerably lower radiation dose for tomosynthesis compared to CT. We did not perform dose measurements in our study as this would have exceeded the aim of the study. A future study is planned with the purpose to compare radiation dose between wrist radiography, tomosynthesis and CT[3]. Second, interpretation of tomosynthesis images of the hand requires experienced readers since the technology is relatively new and un-experienced readers may miss findings or may misinterpret findings i.e., in the presence of artefacts (e.g., blurring of structures that are out of the fulcrum plane)[15]. In our study, both readers were very experienced with reading thousands of bone radiographs and bone CTs every year for many years. Third, we only performed one single dp projection. This was mainly due to handling reasons of the cadaveric specimen, which could be placed for dp views much more standardized. Fourth, we evaluated a relatively small number of cadaveric specimens and all cadaveric hands were from elderly subjects. This may create a selection bias, but on the other hand allowed for a higher likelihood of osteoarthritic changes. For ethical reasons and due to limited availability of cadavers, it was not possible to perform the study with more samples.

In conclusion, tomosynthesis depicts more osteoarthritic changes in the small joints of the hand than conventional radiography using the OARSI scoring system and CT as the standard of reference.

Author contributions

All persons designated as authors qualify for authorship, and all those who qualify are listed as authors. Each author has participated sufficiently in the work to take public responsibility for appropriate parts of the content.

All authors have made *substantial contributions to all three of sections (1), (2) and (3) below:*

(1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data
(2) drafting the article or revising it critically for important intellectual content
(3) final approval of the version to be submitted

Katharina Martini: Conception and design, Analysis and interpretation of the data, Drafting of the article, Critical revision of the article for important intellectual content, Statistical expertise, Collection and assembly of data.
Anton S Becker: Analysis and interpretation of the data, Drafting of the article, Critical revision of the article for important intellectual content, Provision of study materials and cadaveric wrists, Statistical expertise, Collection and assembly of data.
Roman Guggenberger: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Statistical expertise.
Gustav Andreisek: Drafting of the article, Critical revision of the article for important intellectual content, final approval of the article, Statistical expertise.
Thomas Frauenfelder: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, final approval of the article, Statistical expertise.

Thomas Frauenfelder (thomas.frauenfelder@usz.ch) takes responsibility for the integrity of the work as a whole, from inception to finished article.

Conflict of interest

The authors or author institutions have no conflicts of interest.

Acknowledgments

Thanks are due to Joerg Müller from FUJIFILM Europe GmbH (Düsseldorf, Germany) for the technical support and the provided additional technical background information for tomosynthesis which were necessary to conduct the study and to write this paper. The authors or author institutions have no conflicts of interest.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.joca.2016.01.982.

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