General Obstetrics and Gynecology

Linear measurements in 2-dimensional pelvic floor imaging: The impact of slice tilt angles on measurement reproducibility

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OBJECTIVE: Magnetic resonance imaging techniques have improved the study of female pelvic dysfunction. However, disagreements between magnetic resonance measurements and their derived 3-dimensional reconstructions were noted. We tested the hypothesis that these discrepancies stemmed from variations in magnetic resonance acquisition angle.

STUDY DESIGN: Images from the pelvis of the Visible Human Female (a thinly sliced cadaveric image data set) were obtained. Slices in the axial plane were rotated around pivot points in the pelvis to yield a set of similar-appearing para-axial images. A parameter that described the maximum anterior-posterior dimension of the levator hiatus was defined. This levator hiatus parameter was measured on all of the rotated images and compared with an expected value that was calculated from trigonometry. The levator hiatus was also measured on a group of similar-appearing slices rotated slightly around a defined point.

RESULTS: In 1 group of slices, expected levator hiatus variation was 1.5 to 6.1%, whereas measured variation was 4% to 15%. Among the similar-appearing rotated slices, 4.8% to 16.0% variations were seen in the levator hiatus.

CONCLUSION: Identical measurements made on radiologic images can vary widely. Slice acquisition must be standardized to avoid errors in data comparison. (Am J Obstet Gynecol 2001;185:537-44.)

Key words: Magnetic resonance imaging (MRI), slice acquisition angle, visible human female, 3-dimensional reconstruction, trigonometric.
sional reconstructions. These discrepancies were of concern because they had the potential to confound the quantitative analysis that we attempted on radiologic data. Therefore, we sought to understand their cause.

We hypothesized that these discrepancies stemmed from variations in the angle of acquisition of the MRI slices with respect to the long axis of the subject being scanned. Acquisition angle variations can come from 2 sources. First, the actual anatomic orientation of the subject in the MRI scanner can vary; second, the MRI operator can alter the angle at which the scanner acquires the slices. The resulting variations in slice angle can lead to systematic errors in the measurements on the 2-dimensional images, thereby yielding inconsistent measurements. This is because the acquisition angle constrains the plane in which the measurements must be taken. The artifact can probably be best understood by considering Fig 1, which is an example of a cylinder that is cut perpendicular to its long axis. The cut surface reveals a circle with diameter y. If the same cylinder is cut at an oblique angle (θ), the cut surface yields an ellipse with a larger width x, when compared with the first cut. From trigonometric analysis, the cut-plane distances are related by the equation:  

\[ y = x \cdot \cos(\theta) \]

Specifically, for a 45-degree change in the angle theta, the distance x is 41% larger than y. A 30-degree change in slice angle would yield a 15% difference in the measures. This means that any given linear measurement can theoretically vary substantially, based only on alterations in the position of the subject or the slice angle chosen by the MRI operator.

If this hypothesis is proved, it will explain the reason that linear measurements can differ when performed on different acquisitions from the same patient (eg, pre- and postoperative anatomic comparison). The problem is further complicated if measurement comparison is attempted between images that are acquired from different subjects. If this holds true, then precise methods of standardizing the slice acquisition angles would have to be put in place to allow accurate comparisons between linear measures performed on 2-dimensional image slices.

Three-dimensional reconstruction neutralizes this artifact by allowing the user to perform the measurements on 3-dimensional models independently of the acquisition angles, which are best suited for the specific measurement. An example of 1 tool for 3-dimensional reconstruction and analysis is the 3-dimensional slicer, which we have used in our work. However, given that 3-dimensional reconstruction and analytic tools like the 3-dimensional slicer are not widely available to investigators, other methods of standardization must be considered also.

To test this hypothesis, we obtained and compared measurements on image slices that were obtained from the Visible Human Female data set, resliced at arbitrary angles to model variations in slice acquisition angle.

Material and methods

Arbitrarily sliced images from the pelvis of the Visible Human Female were obtained with the use of the Ecole Polytechnique Fédérale de Lausanne Slice and Surface server (http://visiblehuman.epfl.ch/surface/index.html). Slices were derived from the axial plane, passing through the mid symphysis. With the pivot line anchored at the mid symphysis, the slice plane was rotated in 10-degree increments through a 90-degree arc, as demonstrated on the sagittal image given in Fig 2. The zero-degree plane was designated the reference plane. The measured parameter (levator hiatus) was defined as the distance from the mid symphysis to the midline aspect of the levator sling. It defines the height of the levator hiatus as viewed in the axial plane. Resliced images were loaded into the Adobe Photoshop software package (Adobe Systems, Mountain View, Calif) for measurement. Linear distances were measured in pixels and converted to millimeters with the use of the conversion factor of 0.33 mm per pixel. The levator hiatus distance was measured once on each slice and recorded for comparison. The percent variation of the distance on each slice with respect to the reference axial slice was calculated and compared with the expected variation, based on the change in slice angle.

In a second set of images, a pivot point was anchored in the anterior wall of the rectum, near the center of the field of view, and the intersecting plane was rotated around 2 axes, creating several views, which appeared visually similar to the reference axial plane. The levator hiatus measurement was performed on each of these slices and compared with the measurements from the original axial slice.

Results

The reslicing was performed unremarkably. The resliced images were imported into Photoshop without difficulty. Measurements were straightforward. The reference (zero degree) axial image is presented in Fig 3, A. The figure is marked to show the parameter levator hiatus from the reference slice, together with levator hiatus measurements from rotated slices described next. Resliced images at plus or minus 10 degrees are also presented (Fig 3, B and C), with the lines illustrating the levator hiatus measurement in each case. The levator hiatus measurement was also taken on plus or minus 20-degree slices, but these images are not shown. The data are given in Table I, with the expected variation also presented for comparison. These data show an expected variation of 1.5% to 6.1%, whereas the variation in the actual measured values is higher at 4% to 15%.

An anchoring point was chosen in the anterior wall of the rectum near the center of the field of view. This point is illustrated on a sagittal view in Fig 4. The slices were then rotated arbitrarily around this point; the views are shown in Fig 5. For the sake of comparison, the reference acquisition is given in Fig 5, A, where lines that represent...
the levator hiatus measurement from the other slices (Fig 5, B-F) are superimposed and labeled. These images appear generally similar. The measurements are presented in Table II, with the reference axial slice measurement presented for comparison. These data demonstrate measurement variations of 4.8% to 16%.

**Comment**

Identical linear measurements made on 2-dimensional source images can vary solely on the basis of the slice acquisition angle. The acquisition angle can vary depending on the position of the subject in the scanner and on the scanning angle selected by the MRI operator. From our simple experiments, we demonstrated measurement variations of up to 15% for slice angle variations as low as 20 degrees. The actual variation exceeded the variation predicted by trigonometric analysis because the trigonometric predictions assumed that the structures that were being measured were cylindrical in shape, whereas the actual anatomic structures were irregularly shaped. The noncylindrical nature of the actual pelvic floor anatomic structures (e.g., vagina, levator) worsens the effect of slice angle variations on measurement variability. Furthermore, for similar-appearing axial slices rotated slightly with respect to each other, identical measurements varied by up to 16%.

These findings suggest that to accurately compare linear measurements on 2-dimensional images, a method for standardizing the slice acquisition angle must be adopted. This can be accomplished in a couple of ways. First, the patient’s position in the scanner could be standardized, and a standard acquisition angle could be used in all studies. This could become tedious because it would involve lining up the patient axially in the scanner and adjusting the tilt of their pelvis as well. Second, this method would involve reslicing the MRI data into standardized planes after it has been acquired, similar to the technique that was used in the present analysis. This approach has the advantage of eliminating the need for the exact alignment of the patient in the scanner; however, it is likely that the reslicing would result in a degradation of the image quality, which may be ameliorated with the postprocessing techniques.12, 13

Optimal plane standardization would depend on the measurement goals. For the evaluation of levator sling structural integrity and levator hiatus width and height, a plane parallel to and at the level of the levator sling (pubopectalis) is optimal. We demonstrate an example for such a plane in Fig 6, A, in which a sagittal image shows the plane defined by a line running from the superior aspect of the symphysis to the external anal sphincter. The view seen from this plane is given in Fig 6, B, which clearly demonstrates the arms of the levator sling (L1 and L2) and the landmarks for the measurement of the levator hiatus width (the level of the urethra) and height (apex to urethra). To evaluate the bladder neck descent, levator plate angle, and posterior urethrovesical angle, the well-known midsagittal plane is probably appropriate. However, it is important that this plane be rigorously specified to avoid measurement artifacts. Sound definitions of appropriate standardized planes will require further assessment and agreement between investigators in the manner achieved by Bump et al14 for quantifying pelvic organ prolapse. We plan to investigate and submit for consideration possible standardizations for these planes and options for the coronal plane in the future.

These experiments are presented to demonstrate the theoretic basis of a fundamental flaw that confounds accurate comparison of measurements performed on raw 2-dimensional image data. Accordingly, we chose to demonstrate the principle that uses a single measurement parameter (levator hiatus) and an immobile subject (a cadaver) to retain clarity while shedding light on the basic principle and the prospects for overcoming the flaw. Any linear measurement performed on nonstandardized 2-dimensional data is subject to the variations described. The actual variations observed will depend on the acquisition angle and on the actual shape of the organ or region being measured. Structures that closely resemble a cylinder (eg, blood vessels) will show variations similar to those predicted by trigonometric analysis, whereas those structures that are less regular will demonstrate unpredictable variations as the acquisition angle is altered.

The experiments were limited to the Visible Human Female data set because the reslicing tools were readily

### Table I. Levator hiatus (LH) measurement versus slice angle

<table>
<thead>
<tr>
<th>Angle (degree)</th>
<th>LH (pixels)</th>
<th>LH (mm)</th>
<th>Actual % of variation*</th>
<th>Expected % of variation†</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>317</td>
<td>104.6</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>10</td>
<td>354</td>
<td>116.8</td>
<td>11.67</td>
<td>1.5</td>
</tr>
<tr>
<td>20</td>
<td>365</td>
<td>120.4</td>
<td>15.1</td>
<td>6.1</td>
</tr>
<tr>
<td>–10</td>
<td>350</td>
<td>108.9</td>
<td>4.0</td>
<td>1.5</td>
</tr>
<tr>
<td>–20</td>
<td>355</td>
<td>110.55</td>
<td>5.6</td>
<td>6.1</td>
</tr>
</tbody>
</table>

*Computed as: 100 · (LH[0 degree] – LH[angle])/LH(0 degree).
†Computed as: 100 · (LH – LH · cosine[angle])/LH.

### Table II. Levator hiatus (LH) measurement versus arbitrary slice angle

<table>
<thead>
<tr>
<th>Slice</th>
<th>LH (pixels)</th>
<th>LH (mm)</th>
<th>Actual % of variation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref axial</td>
<td>311</td>
<td>104.6</td>
<td>—</td>
</tr>
<tr>
<td>Rotated-b</td>
<td>279</td>
<td>92.07</td>
<td>10.9</td>
</tr>
<tr>
<td>Rotated-c</td>
<td>277</td>
<td>91.41</td>
<td>10.9</td>
</tr>
<tr>
<td>Rotated-d</td>
<td>361</td>
<td>119.13</td>
<td>16.0</td>
</tr>
<tr>
<td>Rotated-e</td>
<td>299</td>
<td>98.67</td>
<td>3.8</td>
</tr>
<tr>
<td>Rotated-f</td>
<td>326</td>
<td>107.5</td>
<td>4.8</td>
</tr>
</tbody>
</table>

LH is normalized to 1 unit at 0-degree angle.
*Computed as: 100 · (LH[0 degree] – LH[angle])/LH(0 degree).
**Fig 1.** A cylinder is cut perpendicular to its long axis to reveal a circle with diameter \( y \). The identical cylinder is cut at an oblique angle (theta), yielding an ellipse with a width \( x \), such that \( x > y \): \( y = x \cos(\theta) \).

**Fig 2.** Midsagittal image of the visible human female; the *lines* represent reslicing planes used to obtain the measurements. The reference plane is designated zero degrees. The other planes are marked with their offset in degrees from the reference. The mass in the rectum is a rectal tumor.
Fig 3. A, The reference (zero degree) axial image is presented and marked to show the parameter levator hiatus. For reference (line A) and resliced (lines B, C) axes. B, Resliced images at +10 degrees, with levator hiatus measurements marked. C, Resliced images at –10 degrees, with levator hiatus measurements marked.
**Fig 4.** Mediosagittal plane shows the anchor point (A) in the anterior rectal wall, around which the slices are rotated (see Fig 5).

**Fig 5.** Resliced images rotated around 2 axes relative to the reference axial plane through the point in Fig 4. A, The reference (zero degree) axial plane. B-F, Arbitrary but similar resliced images. In Fig 5A, the lines that represent the levator hiatus measurement from the reference and other slices (B-F) are superimposed and labeled (A-F).
available to operate on this data set. We are presently refining our reslicing tools to apply them to MRI data sets to confirm the experiments on data from living subjects.

The problem of measurement variations caused by acquisition angle is not unique to gynecology. Obstetric ultrasonographers have always taken care to carefully orient the scan plane with respect to the bilateral fetal thalami to achieve a standard “biparietal diameter,” which, together with other measurements, can provide estimates of the fetal weight. Despite these accommodations, weight estimate errors of ±15% are common.

To determine accommodations made in other disciplines for this type of artifact, we performed a literature search using the National Library of Medicine’s PubMed search engine on MEDLINE for related work that was published between January 1989 and February 2001. Investigators in orthodontics and orthopedics circumvented the problem by using volume data or 3-dimension–derived linear measurements when comparing data without discussing their reasons for not using 2-dimensional measurements. In looking at the cross-sectional geometry of cardiac vessels, other authors implicitly constrained their analysis by slicing the vessels perpendicularly to obtain similarly oriented cross sections but did not discuss the issue of slicing angle variations.

In microscopy, Bradl et al. were concerned about the
impact of the viewing angle on the variation of measured distances in interphase cell nuclei. They reported on a tilting device to control the viewing angle of the cells under study, to standardize their observations. They illustrated the effect of this device with a series of 2-dimensional images of 2 nuclei, each image being tilted by 10 degrees relative to its neighbors. The effect seen is identical to that described by us, resulting in changes in shape of the nuclei as the viewing angle was varied.

Waterton et al\(^{20}\) used nuclear MRI to study endometrial response to estrogen stimulation in macaque uteri. They describe a technique called oblique imaging, in which they varied the slice thickness, location, and angle on each scan to obtain a fixed number of uniformly oriented slices between cervix and fundus of each subject. This technique allowed them to take maximum advantage of the superior in-plane resolution of the MRI technology by helping them to uniformly capture and quantify a variably placed relatively small organ, namely the uterus. It also helped to present a consistent orientation for image analysis. Other authors who discuss planar measurements made from MRI slices do not address slice acquisition angle as a possible source of error,\(^{21}\) although 1 group noted that 3-dimensional evaluations allowed for more accurate evaluations of thin (1-mm) computed tomography slices.\(^{22}\)

These reports demonstrate a variable appreciation of the measurement errors that may be introduced by the artifact of slice acquisition angle. Complications have been made to attempt to neutralize its effects. Ours appears, however, to be the first presentation of its simple theoretic basis and a systematic strategy for overcoming the barrier it presents to quantitative 2-dimensional image comparison. As has been pointed out, 3-dimensional reconstruction techniques are optimal for neutralizing these artifacts, but the 3-dimensional technique is not widely available to investigators. Therefore, we submit that consistent slice angle acquisition protocols be established to facilitate accurate comparisons between MRI- and computed tomography–derived imaging measurements.

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REFERENCES