A
dominant polycystic kidney disease (ADPKD) is the most common inherited renal disease and is the fourth-leading cause of end-stage renal disease (1–3). ADPKD is progressive in nature, but the rate of progression is variable (4); in light of this variability, a readily available tool to determine individualized rate of progression is valuable in ADPKD management (5).

Increases in renal cyst number and size leading to observable enlargement of the kidneys (4) precedes renal dysfunction in ADPKD, often by many years to decades (4). Therefore, quantifying renal enlargement emerged as a robust marker of progression in ADPKD (6,7). This concept was extended to imaging-based classifications (6) used to individualize prognosis and make treatment decisions (8–10). It is now recommended that all patients with ADPKD have an assessment of renal size as part of their initial evaluation (8,10,11).

Whereas various methods of renal size assessment have been reported (6,7,12), total kidney volume (TKV) has emerged as the most accurate assessment method and is most strongly associated with clinical outcomes (5). MRI-derived TKV is accurate and reproducible but the reference standard method of manual planimetry is time consuming (11,13,14), which limits translation into clinical practice. Alternative methods have been developed that estimate TKV on the basis of a more rapidly obtained series of measurements, although familiarity with these methods is limited in many clinical settings (6,14–16). In addition, image acquisition can be a challenge for clinicians who practice in settings where MRI access is limited (17). CT is known to help provide accurate TKV assessment (6,18), but there are concerns regarding radiation exposure; however, this has not been re-evaluated in the context of modern dose-reducing imaging techniques (19).
Abbreviations
ADPKD = autosomal dominant polycystic kidney disease, LD = low dose, RMSE = root-mean-square error, TKV = total kidney volume, ULD = ultra LD

Summary
Dose-reducing CT protocols and ellipsoid volume measurement equations based on a discrete set of linear measurements can yield accurate and reliable total kidney volume results in autosomal dominant polycystic kidney disease that are comparable to the reference standard of MRI planimetry.

Key Points
- Dose-reducing CT protocols can yield total kidney volume values that are comparable to MRI; the lowest dose protocol used in this study produced accurate results with median dose-length product of 59 mGy · cm and CT dose index of 1.2 mGy.
- Total kidney volume measurement methods based on an ellipsoid calculation derived from discrete linear measurements that were performed in 4.6–5.2 minutes yielded results that were highly correlated (r² > 0.98) and had minimal variation (5.9%–11.5% mean volume) compared with the reference standard of manual planimetry (mean time, 28 minutes).
- The combination of a dose-reducing CT protocol and total kidney volume measurement via ellipsoid calculation provides a method of volume measurement that is an accurate and reliable alternative to MRI planimetry; although it is a reference standard volume measurement technique, access to MRI planimetry is a challenge.

Imaging methods that are widely available and interpreta-
tion methods that are feasible for clinical radiologists across diverse practice settings are required to bring TKV measurement into routine clinical practice. MRI planimetry continues to be used in research settings where accuracy is necessary to detect small interval changes in renal volumes (5). However, in the clinical setting, there may be a trade-off wherein more readily obtainable and less onerous methods are the practical choices for widespread use. Therefore, our study was conducted to examine available combinations of imaging modalities and measurement techniques to determine whether TKV measurements comparable to the reference standard of MRI planimetry could be obtained by using dose-reducing CT protocols for image acquisition and time-saving volume measurement equations.

Materials and Methods
Participants
Thirty participants with ADPKD (age, ≥18 years; estimated glomerular filtration rate, ≥45 mL/min) were recruited as a convenience sample from our institution’s general nephrology clinic. These participants were screened and chosen to reflect the different clinical characteristics of the population patient group. Participants underwent one MRI examination and two CT examinations on the same day (Fig 1). Institutional review board approval was obtained for this prospective study conducted September 2016 to June 2017, and participants provided written informed consent. There was no external financial support.

Imaging Protocols
We performed MRI without contrast agent enhancement by using a 1.5-T imager (GE Healthcare, Milwaukee, Wis). Axial and coronal two-dimensional steady-state free precession gradient sequences were performed, and no sagittal plane was acquired. Imaging parameters were as follows: 4-mm section thickness; reconstructed every 4 mm; repetition time msec/echo time msec, 6.0–7.0/2.2–2.3; field of view, 36 cm; and 256 × 256 matrix. Total imaging time was 7 minutes. No antispasmodic medication was administered.

Two noncontrast agent–enhanced CT examinations were performed on a 64-row CT scanner (HD750; GE Healthcare) with a vendor-specific tube current modulation software (Auto-
ma3D; GE Healthcare) that sets the noise properties (ie, noise index) as a linear function. On the basis of the prespecified noise indexes, the scanner software modulates tube current to provide images with the desired noise properties (20). The two examinations were termed low dose (LD) and ultra LD (ULD); scan parameters (in kilovolt peak and milliamperes) were planned on the basis of a standard noise index for LD and ULD CT examinations of 43.7 kVp and 80 mA, respectively. Our institution’s standard abdomen-pelvis CT noise index is 31, thus the LD and ULD labels. Participants first underwent the ULD CT examination with coverage from diaphragm to pelvis (120 kVp, 20–30 mA on the basis of the noise index). From the ULD CT examination, technologists determined z-axis coverage for the LD for the kidneys only (120 kVp, 100–130 mA), which limited radiation dose. LD and ULD CT data were reconstructed with a department-standard reconstruction algorithm (60% filtered back projection and 40% adapted statistical iterative reconstruction blend). ULD CT data was also reconstructed with model-based iterative reconstruction (Veo; GE Healthcare). Axial, sagittal, and coronal (2.5-mm section thickness, 2.5-mm spacing) images were created for all data sets. Radiation dose was reported as both CT dose index (in milligray) and dose-length product (in milligray-centimeters).

TKV Measurement Methods
Slight variations of three previously reported measurement equations (6,15,16) were applied to all image sets (Fig 1). Manual planimetry was performed only at MRI to serve as the reference standard (6). Interpreting radiologists were general radiologists without ADPKD specialization, but they adhered to predefined measurement instructions (Appendix E1 [online]).

Planimetry was assisted by using software (ImageJ version 1.51d; https://imagej.nih.gov/ij/) (21,22), which was used to create a custom plug-in for image segmentation and volume computation. Each kidney was traced on transaxial images (every two to three images for this MRI protocol). Spline-based three-di-
mensional interpolation was used to generate three-dimensional segmentation (Fig 2). Each kidney was individually labeled and volumes (in milliliters) were obtained by multiplying number of voxels with voxel size.

The three volume measurement equations were based on a discrete set of linear measurements (Figs 3, 4). The radiologists who performed these measurement equations...
Kidney Volume Measurement in Autosomal Dominant Polycystic Kidney Disease

To assess image and equation performance, each combination of image type and measurement equation was compared with the reference standard of MRI planimetry by using Spearman correlation. Simple linear regression with the reference standard as the independent variable and the estimator as the dependent variable was used to assess accuracy. Root-mean-square error (RMSE) was reported to show data distribution around the line of best fit. Intraclass correlation coefficient based on a two-way random effects model was used to assess agreement between the two radiologists. P values less than .05 indicated statistical significance. Statistical analyses were completed by using statistical software (SAS version 9.4; SAS Institute, Cary, NC).

Images were interpreted by two radiologists who worked independently (H.S., with 4 years of experience, and C.J.H., with 12 years of experience). To eliminate learning effect, technologists provided blinded worklists to the readers such that no two images from the same participant were read in sequence. Each image set was interpreted in isolation without access to other image sets, and radiologists were blinded to any other measurement results for the participant of interest. The readers recorded time to complete measurements as they were performed. For planimetry, this was only available for one reader; for the other measurement methods, time data were available for both readers.

Figure 1: Flowchart shows imaging modalities and volume measurement methods. Each participant underwent three examinations: MRI, low-dose (LD) CT, and ultra-low (ULD) CT. The ULD CT was also reconstructed with model-based iterative reconstruction (MBIR) to yield a fourth image set. These four image sets were analyzed with three total kidney volume equations (traditional ellipsoid, Mayo ellipsoid, and midsection method). MRI examinations were also analyzed with manual planimetry, which served as the reference standard; planimetry was not performed on the other image sets.

Figure 2: Demonstration of software-assisted manual planimetry tracings and three-dimensional (3D) rendering for the MRI in a 33-year-old female participant with autosomal dominant polycystic kidney disease with a total kidney volume of 733 mL based on manual planimetry measurements (right kidney, green, 316 mL; left kidney, red, 418 mL). Image on the left shows a coronal T2-weighted steady-state free precession MRI image with the kidneys outlined per manual planimetry. Image on the right shows a volume-rendered reformat of the T2-weighted steady-state free precession MRI data set.
Results
Thirty participants underwent imaging of TKV; each participant underwent CT and MRI, which yielded a total of 120 discrete image sets. Characteristics of the study participants are shown in Table 1. Median age was 41 years (age range, 24–67 years). Nineteen of 30 participants were women (63%; median age, 40 years; age range, 28–67 years) and 11 were men (27%; median age, 49 years; age range, 24–66 years). Median estimated glomerular filtration rate was 77 mL/min/1.73 m², median height was 172 cm (interquartile range, 167–180 cm), median weight was 76 kg (interquartile range, 65–87 kg), median body mass index was 26 kg/m² (interquartile range, 24–28 kg/m²), and 70% (21 of 30) of participants had liver cysts manifest at imaging.

CT Radiation Dose
The median radiation exposure (dose-length product) for participants who underwent two CT examinations was 168.0 mGy · cm (interquartile range, 128.2–228.3 mGy · cm). The ULD CT examination had a lower radiation exposure ($P = .01$) than did the LD CT examination (median dose-length product, 58.8 mGy · cm [interquartile range, 51.7–79.7 mGy · cm] and 115.5 mGy · cm [interquartile range, 77.2–161.8 mGy · cm], respectively). As a result of our study protocol, which aimed to limit exposure with the LD CT examination, the z-axis coverage for the ULD CT examination was greater than that for the LD, and we also measured the CT dose index. ULD CT dose index exposure was lower than the LD CT dose index exposure (median exposure, 1.23 mGy [interquartile range, 1.1–1.6 mGy] vs 3.9 mGy [interquartile range, 2.9–4.9 mGy], respectively; $P < .001$).

TKV Results
As calculated by the reference standard of MRI planimetry, mean TKV was 1368.9 mL ± 1149.0 (standard deviation). Mean TKVs were as follows: traditional ellipsoid, 1296.4 mL ± 1146.1; Mayo ellipsoid, 1200.8 mL ± 1045.9; and midsection method, 1318.0 mL ± 1127.7. TKV results as measured by the reference standard of planimetry and the three volume calculation equations are in Table 2. Table 2 also displays the median and interquartile range because there was a wide range of TKVs observed among the 30 participants (TKV range, 270.4–4358.1 mL).
Modality and Measurement Methods Compared with Reference Standard

All combinations of imaging techniques and methods of volume measurement were compared with the reference standard of MRI planimetry; with four imaging types and three measurement equations, there were 12 combinations of image type and measurement equations that were compared with the reference standard. All combinations of image type and measurement equation were correlated with the reference standard, and reference standard. Whereas the sample size was too small to allow for statistical testing between RMSE values, as observed in Table 3, RMSE values were lowest for the Mayo ellipsoid method. RMSE values were lower for MRI compared with the three CT methods (LD, ULD, and model-based iterative reconstruction) but all three CT modalities yielded similar RMSE values.

Volume calculation with the three equations inputs of several component linear measurements (length, width, and depth), and therefore the distributions of these component measurements were analyzed to determine whether one or some combination of component measures was a predominant contributor to variation. No single component measurement disproportionately contributed to variation, and variation of these component measurements did not statistically significantly differ based on the modality used (Fig E2 [online]).

Interrater Agreement and Measurement Times

The agreement between the two radiologists was assessed by using intraclass correlation coefficient; all measurement equation

Table 1: Demographics and Physical Characteristics of Participants

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of participants</td>
<td>30</td>
</tr>
<tr>
<td>No. of women*</td>
<td>19 (63)</td>
</tr>
<tr>
<td>No. of men*</td>
<td>11 (37)</td>
</tr>
<tr>
<td>Mean age (y)†</td>
<td>41 (24–67)</td>
</tr>
<tr>
<td>Entire cohort</td>
<td>172 (167–180)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76 (65–87)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26 (24–28)</td>
</tr>
<tr>
<td>Creatinine (µmol/L)</td>
<td>86 (73–111)</td>
</tr>
<tr>
<td>eGFR (mL/min/1.73 m²)</td>
<td>77 (53–97)</td>
</tr>
</tbody>
</table>

Note.—Unless otherwise indicated, data are median and data in parentheses are interquartile range. BMI = body mass index, eGFR = estimated glomerular filtration rate. * Data in parentheses are percentages. † Data in parentheses are range.

Table 2: Total Kidney Volume Results

<table>
<thead>
<tr>
<th>Method of TKV Measurement</th>
<th>Mean TKV (mL)</th>
<th>Median TKV (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI manual planimetry</td>
<td>1368.9 ± 1149.0</td>
<td>1011.84 (628.9–1466.5)</td>
</tr>
<tr>
<td>Traditional ellipsoid</td>
<td>1296.4 ± 1146.1</td>
<td>864.5 (563.8–1420.1)</td>
</tr>
<tr>
<td>Mayo ellipsoid</td>
<td>1200.8 ± 1045.9</td>
<td>806.2 (520.7–1352.8)</td>
</tr>
<tr>
<td>Midsection method</td>
<td>1318.0 ± 1127.7</td>
<td>863.5 (605.5–1448.0)</td>
</tr>
</tbody>
</table>

Note.—Mean data are ± standard deviation; data in parentheses are interquartile range. Manual planimetry was only performed at MRI. Traditional ellipsoid, Mayo ellipsoid, and midsection method results include all volumes from the four imaging methods: low-dose CT, ultra-low-dose CT, model-based iterative reconstruction, and MRI. There were no statistically significant differences among these methods (P = .31). TKV = total kidney volume.

Table 3: Correlation with Reference Standard and Variance of Total Kidney Volume Measurements Obtained by Using Combinations of Imaging Modalities and Measurement Equations

<table>
<thead>
<tr>
<th>TKV Equation</th>
<th>MRI</th>
<th>LD CT</th>
<th>ULD CT</th>
<th>Model-based Iterative Reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r^2$ Value</td>
<td>RMSE (mL)</td>
<td>$r^2$ Value</td>
<td>RMSE (mL)</td>
</tr>
<tr>
<td>Traditional ellipsoid</td>
<td>0.99</td>
<td>95.8 (19.0)</td>
<td>0.99</td>
<td>140.3 (74.2)</td>
</tr>
<tr>
<td>Mayo ellipsoid</td>
<td>0.99</td>
<td>80.5 (Ref)</td>
<td>0.99</td>
<td>92.7 (15.1)</td>
</tr>
<tr>
<td>Midsection method</td>
<td>0.98</td>
<td>144.1 (79.0)</td>
<td>0.99</td>
<td>118.9 (47.7)</td>
</tr>
</tbody>
</table>

Note.—Data in parentheses are the comparative unexplained variance obtained by using the lowest root-mean-square error that was observed with the Mayo ellipsoid as the reference. LD = low dose, Ref = reference, RMSE = root-mean-square error, TKV = total kidney volume, ULD = ultra LD.
types showed high interrater agreement, with intraclass correlation coefficient values of 0.985 for the traditional ellipsoid, 0.986 for the Mayo ellipsoid, and 0.987 for the midsection method.

The two ellipsoid methods were based on the same linear measurements (mean measurement times for MRI, LD CT, ULD CT, and model-based iterative reconstruction: 5.20 minutes ± 0.94, 4.62 minutes ± 0.96, 4.79 minutes ± 1.15, and 4.76 minutes ± 1.11, respectively). The MRI linear measurement times were significantly different from that of CT ($P < .001$), whereas the CT linear measurement times were not significantly different from each other ($P = .39$). Planimetry was performed only on MRI to serve as the standard; planimetry measurement time was available from one reader (mean, 27.7 minutes; range, 14–60 minutes).

**Discussion**

Our study examined the precision, accuracy, and radiation exposure associated with available combinations of imaging modalities and total kidney volume (TKV) measurement techniques in autosomal dominant polycystic kidney disease (ADPKD) to determine whether results comparable to the reference types showed high interrater agreement, with intraclass correlation coefficient values of 0.985 for the traditional ellipsoid, 0.986 for the Mayo ellipsoid, and 0.987 for the midsection method.

The two ellipsoid methods were based on the same linear measurements (mean measurement times for MRI, LD CT, ULD CT, and model-based iterative reconstruction: 5.20 minutes ± 0.94, 4.62 minutes ± 0.96, 4.79 minutes ± 1.15, and 4.76 minutes ± 1.11, respectively). The MRI linear measurement times were significantly different from that of CT ($P < .001$), whereas the CT linear measurement times were not significantly different from each other ($P = .39$). Planimetry was performed only on MRI to serve as the standard; planimetry measurement time was available from one reader (mean, 27.7 minutes; range, 14–60 minutes).

**Figure 5:** Linear regression comparison of volumes obtained by the reference standard compared with those obtained by the Mayo ellipsoid measurement method. Graphs show linear regression results for (a) MRI, (b) low-dose CT, (c) ultra-low-dose CT, and (d) ultra-low-dose CT with model-based iterative reconstruction.

**Table 4: Simple Linear Regression Results for Combinations of Imaging Types and Measurement Equations**

<table>
<thead>
<tr>
<th>TKV Equation</th>
<th>MRI Intercept (mL)</th>
<th>MRI Slope (mL)</th>
<th>LD CT Intercept (mL)</th>
<th>LD CT Slope (mL)</th>
<th>ULD CT Intercept (mL)</th>
<th>ULD CT Slope (mL)</th>
<th>Model-based Iterative Reconstruction CT Intercept (mL)</th>
<th>Model-based Iterative Reconstruction CT Slope (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional ellipsoid</td>
<td>−0.78 (27.9)</td>
<td>1.0 (0.02)</td>
<td>−30.6 (40.5)</td>
<td>1.0 (0.02)</td>
<td>−52.3 (40.7)</td>
<td>1.0 (0.02)</td>
<td>−41.0 (45.0)</td>
<td>1.00 (0.03)</td>
</tr>
<tr>
<td>Mayo ellipsoid</td>
<td>5.8 (23.5)</td>
<td>0.9 (0.01)</td>
<td>−8.1 (26.8)</td>
<td>0.9 (0.02)</td>
<td>−30.9 (32.7)</td>
<td>0.9 (0.02)</td>
<td>−19.2 (34.3)</td>
<td>0.91 (0.02)</td>
</tr>
<tr>
<td>Midsection method</td>
<td>−19.5 (42.0)</td>
<td>1.0 (0.02)</td>
<td>−0.07 (36.0)</td>
<td>1.0 (0.02)</td>
<td>52.9 (46.5)</td>
<td>0.9 (0.03)</td>
<td>−8.4 (40.6)</td>
<td>0.95 (0.02)</td>
</tr>
</tbody>
</table>

Note.—Data in parentheses are standard error. Values in the table are presented as intercept and slope of the linear regression by using each combination of imaging type and volume equation as the dependent variable, and the reference standard of manual planimetry as the independent variable. LD = low dose, TKV = total kidney volume, ULD = ultra LD.
standard of MRI planimetry could be obtained by using less resource-intensive methods. Both dose-reducing CT protocols and volume measurement based on less time-consuming linear measurements yielded accurate and reliable results comparable with this reference standard. Rather than establishing one clearly superior method for measuring TKV, these results demonstrated that there are accurate alternatives to MRI planimetry that can be used depending on the resources that are available to individual clinicians.

Our study provides support for the ongoing use of CT to measure TKV. The CT methods were comparable to MRI and there was no statistically significant difference between LD and ULD CT (regardless of reconstruction technique) performed at a significantly lower radiation dose. If imaging is performed for TKV measurement alone, our ULD protocol yields results comparable to MRI with minimal radiation exposure. Renal clinicians have been hesitant to use CT for so-called screening purposes such as TKV measurements (8) but with a radiation dose similar to a conventional abdominal radiographic series (23), concerns may be eliminated for this ULD CT protocol. This would make ULD CT a viable alternative to MRI in settings where access to that modality is limited.

The degree of TKV measurement variation in our study was consistent with previous reports of TKV measurement (6,15,16). A comprehensive evaluation of ellipsoid methods observed similar high correlation between planimetry and ellipsoid measurements with standard deviations in the range of 13.8%–20.1% (15). Derivation and validation cohorts of the Mayo Clinic imaging classification (6) reported TKV standard deviations that ranged from 5.5% to 10.1%. This range is similar to the RMSE and standard deviation values observed in our study, and it was associated with a low rate of misclassification with this commonly used method (6).

We compared multiple TKV measurement techniques, and the performance of these measurement equations provided support for their use at both CT and MRI. Although our sample size precluded statistical comparisons between the methods, the Mayo ellipsoid tended to have the best performance in terms of accuracy and variability, which further supports the use of this already commonly used method. A barrier to the adoption of TKV measurements is the time required for the manual planimetry method (7,10,11); similar to prior publications, the interpreting radiologists performed ellipsoid measurements in a fraction of the time required for planimetry.

TKV measurements demonstrated excellent interrater reproducibility. The two interpreting radiologists were general radiologists without specialized training in measurement of polycystic kidneys, which is different than previous reports (6,15) wherein radiologists underwent dedicated training in ADPKD measurement. Therefore, our findings are more generalizable to radiologists who practice in diverse settings outside of specialized ADPKD centers.

Our study had limitations. The sample size was small, and the convenience sampling method we used to facilitate participant identification in a general nephrology clinic in which participants are a minority subpopulation limited generalizability. It would have been ideal to have each radiologist measure TKV on images more than once to calculate intraobserver reliability, but this was not feasible because of time constraints. Similarly, this was the reason that only two readers were used. Regarding imaging, our particular model-based iterative reconstruction technology is not available in all centers; however, because our results indicated that ULD CT with or without model-based iterative reconstruction was similar, this technology was not a necessity. A limitation of MRI was that, because of time constraints, the MRI protocol was limited to only two planes with reformatting of the axial data set to measure on the sagittal plane. The lack of a sagittal MRI examination may have potentially introduced error into the ellipsoid methods. A final limitation was that time data for planimetry measurements was only available for one reader.

In conclusion, the results of our study demonstrated that total kidney volume (TKV) measurements comparable to the resource-intensive standard of MRI planimetry can be obtained by using alternate methods that may be more feasible in everyday clinical practice. With results comparable to MRI, the dose-minimizing ultra-low-dose (ULD) CT protocol represents a viable alternative in settings where access to MRI is limited. Similarly, ellipsoid volume measurement equations can be applied to these imaging techniques and yield results comparable to more time-consuming manual planimetry. A readily available and less resource-intensive TKV measurement method such as the combination of ULD CT interpreted with the Mayo ellipsoid equation may improve access to TKV measurement and therefore enable more widespread clinical adoption of this important tool in autosomal dominant polycystic kidney disease management. Ongoing research in this area will be valuable and would include further refinement of CT methods to minimize radiation exposure, efforts to automate or reduce the time requirements needed to produce these measurements, and ongoing work that correlates the results of these imaging tests to long-term clinical outcomes.

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Author contributions: Guarantors of integrity of entire study, M.U.B., C.J.H., A.L.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agree to ensure any questions related to the work are appropriately resolved, all authors; literature research, M.U.B., C.J.H., T.W.Y.; clinical studies, M.U.B., H.S., A.L.; statistical analysis, M.U.B., A.R., A.L.; and manuscript editing, M.U.B., C.J.H., D.M.V., A.L.

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References
1. Spithoven EM, Kramer A, Meijer E, et al. Renal replacement therapy for autosomal dominant polycystic kidney disease (ADPKD) in Europe: prevalence and sur-