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Correlation between CT-estimated tumor volume, pathologic tumor volume, and final pathologic specimen weight in children with Wilms' tumor

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Abstract *Objective:* To evaluate the relationship of Wilms' tumor (WT) volume to weight, and evaluate computed tomography (CT) scan-derived final pathologic specimen weight estimation models.
Methods: We retrospectively reviewed WT patients from 2003 to 2011 who had a pre-operative CT scan, final pathologic specimen weight, and tumor dimensions. A partial nephrectomy tumor cohort ($n = 12$) was used derive WT density. A radical nephrectomy cohort ($n = 45$) was used to develop a simplified estimation equation of final pathologic specimen weight, and analysis of all known estimation models was performed.
Results: Fifty-two patients were identified. WT volume and weight were not equivalent ($p = 0.0410$). WT density was 1.3091 g/cm^3. WT volume and final pathologic specimen weight were not significant ($p = 0.0007$). Our model ($p = 0.9983$) and CT estimated ellipsoidal volume ($p = 0.0741$) were able to estimate final pathologic specimen weight in all tumors. However, CT-estimated ellipsoidal volume failed to estimate final pathologic specimen weight in specimens $<$ 250 g ($p = 0.0066$).
Conclusion: Pathologic WT volume is not equivalent to final pathologic specimen weight. Final pathologic specimen weight can be estimated from a pre-operative CT scan, which suggests that it may be used to improve pre-operative surgical planning and to reduce treatment morbidity.

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Introduction

In 1963, Garcia et al. [1] published a Wilms' tumor (WT) staging system that included *tumor volume* to assess for its prognostic value, like nearly all other solid tumors. In tumors with volume $> 550\ cm^3$, they reported a dismal overall survival of 0% [1]. Ten years later, Cassady et al. [2] published a sentinel article on WT outcomes. They used the staging system of Garcia et al. [1], but substituted *pathologic specimen weight* for tumor volume as a variable for stage I disease. At a specimen weight $<$ 550 g, they demonstrated improved survival compared with larger tumors and compared with prior studies, including Garcia et al. [2]. These studies first raised the potential value of WT size as a prognostic indicator in this subset of WT patients. Today, final pathologic specimen weight has been proposed to guide adjuvant therapy in very low-risk WT patients (stage I, favorable histology, age $\leq$ 2 years, tumor $<$ 550 g) [3–6].

Tumor weight and tumor volume have been used interchangeably in many studies looking at prognostics of WT size [1,2,4–7]. However, there has been no published research on the actual relationship between WT pathologic volume, WT pathologic weight, and final pathologic specimen weight. Additionally, several studies have shown that computed tomography (CT)-derived tumor volume may accurately predict final pathologic specimen weight. The aim of this study was to evaluate the relationship of pathologic WT volume and pathologic WT weight to the final pathologic specimen weight, and to evaluate the accuracy of CT-derived tumor volume to predict final pathologic specimen weight. We hypothesize that pathologic WT volume and weight are not equivalent to the final pathologic specimen weight and that tumor volume derived from preoperative CT scan provides an accurate estimate of final pathologic weight.

Materials and methods

After institutional review board approval was obtained (COMIRB# 11-0238), we conducted a retrospective review of patients with a primary diagnosis of WT (International Classification of Diseases 9th edition code 189.0) treated from 2003 to 2011 at the Children's Hospital Colorado (Aurora, CO, USA). Patients were excluded if they did not have pathologic confirmation of WT, pre-operative CT scan images, final pathologic specimen weight, or final pathologic tumor dimensions. Patients were then divided into radical nephrectomy and partial nephrectomy cohorts. Seventeen patients were excluded (Fig. 1). In the radical nephrectomy cohort, six patients were excluded owing to surgically unresectable disease and associated concerns regarding potential inclusion of other organs that were removed at the time of nephrectomy in the pathologic specimen weight.

In patients who met the inclusion and exclusion criteria, age, gender, mortality, surgical date, CT scan date, and pathologic specimen details (stage, histology, final pathologic specimen weight, final pathologic specimen dimensions, and final pathologic tumor dimensions) were collected as data points from the medical record. In the total nephrectomy cohort, the pathologic specimen weight included normal renal parenchyma and associated perinephric tissue removed at the time of nephrectomy in every instance.

In calculating WT volume based on CT scan and pathologic measurements, we assumed that the natural shape of WT most closely resembled that of an ellipsoid. This formula also allows for accurate estimation of smaller WT, which are typically more spherical in shape. The geometric formula for the volume of an ellipsoid that we utilized is:

$$\text{Vol of Ellipsoid } (cm^3) = (4/3)\pi(D/2)(L/2)\ (W/2)$$

A database was originated and analyzed with Excel 2010 (Microsoft, Seattle, WA, USA). *P*-values $<$ 0.05 were considered statistically significant.

Analysis of pathologic WT volume and WT weight

The partial nephrectomy cohort was used for this analysis. We assumed that partial nephrectomy specimens allow for an accurate estimation of both WT volume and WT weight owing to the lack of substantial additional tissue in the specimen. WT volume was defined as the volume of the tumor only and was derived from tumor dimensions listed in the pathology report. WT weight was defined as the weight of the tumor only and was obtained from the final pathologic specimen weight listed in the pathology report. The relationship between mass and volume of a substance depends on the density of the substance (Density = Mass/Volume). Using simple linear regression, we derived an estimate of WT density. Statistical significance was tested via a comparison of means using a two-tailed, paired Student's *t* test.

Final specimen weight estimated from CT scan

The radical nephrectomy cohort was used to derive tumor volume estimation from the pre-operative CT scans. These were individually reviewed and measurements recorded using the standard measuring tool provided in the picture archiving and communication software (PACS) at our institution. Tumor depth (D) and width (W), in centimeters, were obtained on axial CT images where the tumor appeared to be the largest in size relative to other slices. Tumor length (L) (cranial–caudal dimension) was similarly obtained on sagittal CT images (Fig. 2). In those scans that did not include sagittal reconstruction, the CT scan slice width was used to estimate the length (L) from the axial images, starting at the most cranial and ending at the most caudal extent of the tumor. Review of our measurements was confirmed by a board-certified pediatric radiologist (KLH) who was blinded to the pathologic measurements.

As previously described, CT-estimated tumor volume was derived from the geometric formula of an ellipsoid. To most accurately estimate final pathologic weight, a linear regression model was used to account for both the additional mass that accompanies the WT specimen and the density of the entire specimen. Mathematical substitution and a reduction of constants were performed to derive a simpler version of the model used to estimate final pathologic weight.