Prediction of Cervical Endplate Size: One Size Does Not Fit All

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When selecting optimal implants for spinal surgery, surgeons generally attempt to match the patient’s specific anatomy with the most appropriate implants. Whether implanting allografts, cages, or disk replacements in the cervical interbody space, surgeons attempt to appropriately match the vertebral endplate footprint to the implant footprint. It is important to maximize endplate coverage with the implant to avoid implant subsidence and endplate fracture, especially in patients with osteopenia. Given the same force, a larger surface area of implant-to-endplate contact produces less pressure on the endplate. In addition, the bone density of the endplates are greater in the periphery over the apophyses, and an implant with a larger footprint is more likely to contact and engage the apophyses.1,2 These 2 factors demonstrate the biomechanical advantages to choosing implants that maximize endplate coverage.

In anterior cervical diskectomy and fusion (ACDF) and cervical total disk replacements (C-TDR), subsidence rates range from 14.3% to 47.9% depending

Abstract

Significant variations exist in the footprint size of cervical vertebral endplates. In anterior cervical spine surgery, an implant that maximizes coverage of the endplate and contacts the apophyses may reduce subsidence and decrease risk of endplate fracture. The ability to accurately predict a patient’s vertebral endplate size may be helpful for surgeons to preoperatively choose the optimal implant for the patient’s specific anatomy. The purpose of this study was to (1) demonstrate the range of vertebral endplate sizes between individual patients and cervical levels and (2) determine if vertebral endplate size can be predicted based on patient characteristics and vertebral level. Fifty cervical computed tomography scans of patients 18 to 65 years old were selected for analysis. Superior vertebral endplate sizes of C3-C7 were measured medial-laterally and anteriorly-posteriorly. The medial-laterally measurement was taken from the midbody coronal view at the flat central region of the superior endplate, and the anteriorly-posteriorly measurement was taken at the midbody axial view from the front to back edge of the vertebral body. Age, height, weight, gender, and race were recorded for all patients. One-way analysis of variance, linear regressions, and multivariate regressions were performed. Patient height, age, gender, and race accounted for 51% to 71% of the variance between individuals, and endplate size increased by 1 mm in width and 0.6 mm in depth for each progressively more caudal vertebral level. Vertebral endplate size could be reliably calculated based on patient height, age, gender, and vertebral level. These data may be useful to assist surgeons in preoperative planning for patient-specific implant selection. [Orthopedics. 2016; 39(3):e526-e531.]
Subsidence can lead to loss of distraction-induced stability from ligamentotaxis, increased flexion range of motion, segmental kyphosis, and loss of indirect neural decompression with subsequent foraminal stenosis and recurrent radiculopathy. Previous studies have shown that the use of grafts covering less than 25% of the cross-sectional area of the endplate leads to graft fractures and a high failure rate in interbody fusions.

Although it is biomechanically optimal to closely match the endplate footprint with the interbody implant footprint, many surgeons routinely use the same implant size regardless of the patient’s size or the level of operation. In addition, many implant producers only offer a small range of implant footprint size options. For example, Nuvasive (San Diego, California) offers only a single allograft size, and Stryker (Kalamazoo, Michigan) offers only a single footprint size for each of their cage models. Although larger companies such as Medtronic (Minneapolis, Minnesota) may offer several implant sizes, many hospitals only keep 1 size per model type in stock, and other sizes must be special ordered.

The medical field is gradually moving toward more patient-specific implants and treatments. Multiple studies have shown that customized implants in total knee and hip arthroplasty improve patient outcomes, and more individualized implants should be considered for ACDF and C-TDR as well. A prior study by Stone et al found that meniscal dimensions could be predicted by gender, height, and body mass index (BMI). The current authors hypothesized that cervical vertebral endplate size also can be predicted by these factors. The purpose of this study was to demonstrate the range of vertebral endplate sizes between patients and cervical levels, and to determine whether vertebral endplate size could be predicted based on patient gender, height, and BMI, as well as vertebral level. The ability to accurately predict a patient’s vertebral endplate size may be helpful to surgeons in choosing the optimal implant for a patient’s specific anatomy. In addition, the demonstration of significant variation in endplate size may motivate implant manufacturers to offer more sizes of endplate implants.

**MATERIALS AND METHODS**

Fifty cervical computed tomography (CT) scans (25 men and 25 women) from patients 18 to 65 years old were collected for analysis. All images were obtained from the hospital’s imaging database. The images were taken to assess trauma during a 1-year period (June 2013 to June 2014). Patients were selected in reverse chronological order, except for the final 10 women, who were selected to ensure that the male and female groups were age-matched. Recent images were selected to obtain the highest quality images and to avoid differences in CT technology. The study was performed under an institutional review board-approved protocol and was compliant with Health Insurance Portability and Accountability Act (HIPAA) guidelines; informed consent was waived. Patients with cervical fractures or prior cervical spine surgery were excluded.

Computed tomography scans (Siemens, Munich, Germany) were all acquired in an axial plane using a standardized protocol, with postacquisition reconstructed coronal and sagittal planes. All images were reviewed on a PACS workstation (General Electric Healthcare, Little Chalfont, United Kingdom) using IMPAX software (AGFA Healthcare, Mortsel, Belgium).

Vertebral endplate sizes of C3-C7 were measured medially-laterally and anteroposteriorly. The mediolateral (ML) measurement was taken from the coronal view center-body slice at the flat central region of the superior endplate, and the anteroposterior (AP) measurement was taken at the midbody axial view from the front to back edge of the vertebral body.

To determine variance between individuals, ML and AP measurements were separately averaged across vertebral bodies C3 through C7 for each individual. Student t tests, linear regressions, and 1-way analysis of variance (ANOVA) were performed to assess the correlation between the summed values and gender, age, height, BMI, and race as appropriate. The variables that correlated significantly then were used in multivariate linear regression models to determine the predictive value of each variable while accounting for confounding interactions between variables. A multivariate regression was performed.
at each cervical level to yield a set of formulas that would determine endplate size based on patient factors as well as cervical level.

To display the variance between vertebral levels, ML and AP measurements were averaged separately across all individuals for each vertebral level. A best-fit model was determined to display how endplate size changed with vertebral level. In addition, the greatest difference between vertebrae was recorded for each individual and then averaged across all individuals. The greatest difference was usually found between C3 and C7, but in some cases, the greatest difference was between C4 and C7 or between C3 and C6.

Finally, to determine intraobserver reliability of the measurements, repeat measurements were taken by the original observer for one-fourth of the patients. The difference and relative uncertainty was calculated for each pair of measurements and then averaged across all repeated measurements.

**RESULTS**

**Patient Data**

The average age of the patient population was 40.6 years, and men and women were age-matched. The average height of patients was 170.3 cm, and the average BMI was 30.3 kg/m². Patient demographics are listed in Table 1.

**Correlations**

The averaged ML and AP measures of vertebral body size correlated significantly with height ($P<.01$, $R^2=0.27-0.41$) and gender ($P<.01$, $R^2=0.31$), and the averaged AP measurements correlated significantly with age ($P≤.004$, $R^2=0.15$). The $R^2$ indicates the percentage of the variance of the dependent variable [endplate size] that can be explained by the independent variable [height, gender, age].) The correlation between averaged ML measurements and age showed a trend toward significance ($P=.10$, $R^2=0.05$), as did the correlation between averaged AP measurements and race ($P=.08$, $R^2=0.14$). Only Caucasian and African American races had enough statistical power to reach significance in this study. No significant correlation was found between BMI and endplate size, or between race and ML measurements. Larger vertebral endplates correlated with taller, older, male, and African American patients. The results of the linear regression are summarized in Table 2.

**Multivariate Regression**

Height, age, and gender were used in multivariate linear regressions to predict vertebral body size (ML and AP) at each cervical level (Table 3), and race was used in the AP regressions. This determines the effect of each dependent variable while controlling for confounding between patient variables. Depending on the level, the resulting ML equations were able to predict 34% to 51% of the variance between patients ($R^2=0.34-0.51$), and the AP equations were able to predict 51% to 71% of the variance between patients ($R^2=0.51-0.72$). The majority of the resulting coefficients (35 of 42) were statistically significant ($P≤.05$), and the majority of the remaining coefficients (5 of 7) showed trends toward significance ($P≤.15$). To demonstrate the lack of significance of some of the coe-
Multivariate Regressions

| Vertebral Level | Measure Type | Formula (size in mm) | Height in cm, Age in years, Gender: Male = 1, Female = -1 | $P>|t|$ | Height | Age | Gender | Race | $R^2$ |
|-------|-------------|----------------------|----------------------------------------------------------|----------|--------|-----|--------|-------|--------|
| 3     | ML          | $ML_{3}=0.074 \times \text{Height}+0.028 \times \text{Age}+0.03 \times \text{Gender}+1.37$ | <.001   | .02   | .84  | .000 | .47  |
| 4     | ML          | $ML_{4}=0.050 \times \text{Height}+0.004 \times \text{Age}+0.14 \times \text{Gender}+6.56$ | .004    | .08   | .44  | .000 | .06  |
| 4     | AP          | $AP_{4}=0.02 \times \text{Height}+0.04 \times \text{Age}+0.9 \times \text{Gender}+1.6[African American]+0.3[Caucasian]+8.8$ | .13     | .005  | .0001 | .000 | .66  |
| 5     | ML          | $ML_{5}=0.040 \times \text{Height}+0.025 \times \text{Age}+0.31 \times \text{Gender}+8.84$ | .02     | .05   | .08  | .004 | .38  |
| 5     | AP          | $AP_{5}=0.03 \times \text{Height}+0.06 \times \text{Age}+0.8 \times \text{Gender}+1.5[African American]+0.6[Caucasian]+8.2$ | .06     | .001  | .002  | .004 | .58  |
| 6     | ML          | $ML_{6}=0.035 \times \text{Height}+0.022 \times \text{Age}+0.41 \times \text{Gender}+10.79$ | .05     | .12   | .04  | .34  |
| 6     | AP          | $AP_{6}=0.03 \times \text{Height}+0.05 \times \text{Age}+0.5 \times \text{Gender}+1.2[African American]+0.4[Caucasian]+9.1$ | .15     | .001  | .02   | .03  | .51  |
| 7     | ML          | $ML_{7}=0.062 \times \text{Height}+0.027 \times \text{Age}+0.58 \times \text{Gender}+7.51$ | .003    | .001  | .02   | .006 | .65  |
| 7     | AP          | $AP_{7}=0.04 \times \text{Height}+0.06 \times \text{Age}+0.9 \times \text{Gender}+1.4[African American]+0.3[Caucasian]+7.5$ | .05     | .0008 | .0004 | .006 | .65  |
| Averaged | ML       | $ML_{AVG}=0.052 \times \text{Height}+0.025 \times \text{Age}+0.6 \times \text{Gender}+7.0$ | .004    | .02   | .05   | .51  |
| Averaged | AP       | $AP_{AVG}=0.03 \times \text{Height}+0.05 \times \text{Age}+0.8 \times \text{Gender}+1.4[African American]+0.3[Caucasian]+8.5$ | .05     | .0002 | .0001 | .000 | .71  |

Abbreviations: AP, anteroposterior measurement; ML, mediolateral measurement.
*Only African American and Caucasian races were displayed as there were not enough patients within other races to reach significance.

Coefficients was likely due to the small sample size, a multivariate regression to predict the ML and AP values averaged across all levels also was performed (Table 3). This analysis showed patient height, age, and gender were able to predict 51% of the ML variance, and patient height, age, gender, and race predicted 71% of the AP variance; all coefficients were statistically significant ($P<.05$). Measurement error and random anatomical variation likely contributed to the remaining variance. The regressions were able to predict all patient measurements within 3 mm.

The averaged ML and AP equations showed that for every 20 cm of increase in patient height, there was an increase of 1.04 mm in vertebral endplate width (ML) and 0.6 mm in depth (AP). In addition, vertebral endplates in men were wider by an average of 0.6 mm and deeper by 1.6 mm than vertebral endplates in women. For every 20-year increase in patient age, there was a 0.5-mm increase in vertebral endplate width (ML) and a 1.0-mm increase in depth (AP). Finally, endplates in African American patients were 1.4 mm deeper than in Caucasian patients. These combined patient factors resulted in a significant difference in endplate sizes. For example, a 60-year-old African American man who was 6 ft 6 in tall with a C7 predicted endplate size of 22.1×21.3 mm would have an endplate that was 7.6 mm wider and 7.8 mm deeper (280% larger cross-sectional area) than a 20-year-old Caucasian woman who was 5 ft tall with a predicted C3 endplate size of 13.1×12.9 mm.

Variance Between Vertebral Levels

When measurement values were averaged across all patients for each vertebral level, vertebral endplate width and depth (ML and AP) increased with each progressively more caudal vertebral level (Table 4). Mean values for each level were plotted and demonstrated a quadratic curve. A quadratic regression was determined for each measurement type and can be found below.

Equation 1: $ML_X(mm)=11.67+1.01X+0.12X^2$; $R^2=0.99$

Equation 2: $AP_X(mm)=13.5+0.53X+0.15X^2$; $R^2=0.99$

These equations display how the average endplate size increases with vertebral level. Graphs of these equations can be found in Figures 2-3.

The average variance between C3 and C7 within individuals was 4.1 mm for ML measurements and 2.4 mm for AP measurements. This indicates that on average, the vertebral endplate increased by 1.0 mm in width and 0.6 mm in depth for each cervical level (C3-C7) moving caudally.
Intraobserver Reliability

The average difference between the first and second measurements was 0.5 mm, and the range of this difference was 0 to 2.5 mm. The intraclass correlation between the first and second measurements was 0.963, indicating that approximately 3.67% of the sample variability was due to measurement error.

Discussion

Many spine surgeons use a single routine footprint size interbody implant for all of their patients undergoing ACDF or C-TDR. The routine implant typically is a smaller cage that can be implanted easily into most levels in most patients. However, a relatively smaller cage may lead to an implant-to-endplate mismatch in larger patients at more caudal levels. This mismatch may lead to greater pressure on the weaker areas of the endplates and result in subsequent implant settling or graft failure. For example, the standard Medtronic Cornerstone cage is 14x11 mm, which will fit within the vertebral footprint for most patients at most levels. However, in a 6 ft 6 in, 60-year-old C6-C7 patient with a predicted endplate dimension of 19.5x21.1 mm, approximately only one-third of the endplate would be covered by this implant.

This study demonstrated a significant variation in the range of cervical endplate sizes between individuals and between vertebral levels. For example, the area is 4.52 cm² for a man who is 6 ft 8 in tall with C7 superior endplate dimensions of 2.12x2.13 cm, whereas the area is 1.75 cm² for a woman who is 5 ft 1 in tall with C4 superior endplate dimensions of 1.37x1.28 cm. The C7 endplate in the man would have nearly 3 times the area of the C4 endplate in the woman. Even within the same patient, the C7 superior endplate is an average 4.1 mm wider and 2.4 mm deeper than the C3 superior endplate. These examples demonstrate variance among individuals and among cervical levels, attesting to a need for a wider range of interbody implant sizes from device manufacturers.

The current study demonstrated that gender, height, age, race, and vertebral level can be used to reliably predict the endplate sizes of cervical vertebrae (Table 3). This predictive tool may be helpful to surgeons in selecting and ordering implants that are optimal for patients. Although preoperative CT is the best modality for visualizing bony anatomy and therefore measuring endplate size, it is associated with significant radiation exposure and cost, and is not typically ordered preoperatively for anterior cervical surgery. Moreover, magnetic resonance images typically do not include coronal images necessary for accurately measuring the width of the endplate. The current study provides a method for predicting endplate size without additional imaging, thereby avoiding extra cost and radiation. Height, gender, age, and race were found to predict 51% to 71% of the variance in endplate size between individuals, depending on measurement type. On average, endplate width increased by 1 mm per vertebral level and endplate depth increased by 0.6 mm per level.

The main limitations of this study were defining measurement endpoints and measurement error. Although the AP measure-

<table>
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<th>Vertebral Level</th>
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<th>Anteroposterior, cm</th>
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<td></td>
<td>Mean (Range)</td>
<td>SD</td>
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<tr>
<td>C3</td>
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<tr>
<td>C4</td>
<td>1.60 (1.35-1.83)</td>
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<tr>
<td>C5</td>
<td>1.67 (1.41-1.90)</td>
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</tr>
<tr>
<td>C6</td>
<td>1.77 (1.55-2.06)</td>
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</tr>
<tr>
<td>C7</td>
<td>1.93 (1.63-2.42)</td>
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</tr>
<tr>
<td>Total variance within patient</td>
<td>0.41 (0.07-0.73)</td>
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Table 4

Variance Between Vertebral Levels

Figure 2: Graph showing endplate mediolateral (ML) dimension by vertebral level (equation 1: ML = 11.67 + 1.01X + 0.12X²; R² = 0.99).

Figure 3: Graph showing endplate anteroposterior (AP) dimension by vertebral level (equation 2: AP = 13.5 + 0.53X + 0.15X²; R² = 0.99).
ments typically had clear endpoints, the ML measurement endpoints were located at an angle between curved lines, making it difficult to locate on some patients (Figure 1A). Similarly, because the AP diameter measurement was taken at the midbody level to avoid falsely enlarging osteophytes, the equations predicting AP diameter may slightly underestimate the AP diameter of the superior endplate. Nevertheless, the intraclass correlation was high (0.963), indicating the strong precision of the measurements. Another limitation was the study’s sample size, which limited the statistical power of the multivariate regressions. Additional research with larger sample sizes is warranted to fine-tune the accuracy of the predictive equations and to determine the effect of other races. Finally, although height, gender, age, and race accounted for more than half of the variance in endplate size, this still left a significant degree of variance unaccounted for. Other potential sources of variation include level of physical activity and degenerative bone disease. It is also possible that the small sample size limited the correlation of endplate size with these patient characteristics.

This study demonstrates variation in cervical endplate size across individuals and across cervical level, and provides a rapid and simple method for predicting cervical endplate size that could be easily implemented in a preoperative setting. Further investigation is needed to determine the impact of using better fitting cages on clinical outcome.

**Conclusion**

Cervical endplates show considerable variation among individuals. Endplate size could be predicted based on patient height, age, gender, race, and vertebral level. Patient height, age, gender, and race accounted for 51% to 71% of the variance between individuals, depending on the measurement type (ML, AP). Endplate size increased by 0.6 mm to 1.0 mm per vertebral level, depending on measurement type. These data may be useful for developing and implementing more patient-specific implants for anterior cervical surgery.

**References**