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Correlation between the Korean pork grade system and the amount of pork primal cut estimated with AutoFom III

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Abstract

It is impossible to know the amount of pork primal cut by pig carcass grade which is determined only by carcass weight and backfat thickness in the Korean Pig Carcass System. The aim of this study was to investigate the correlation between the pig carcass grade and the amount of pork primal cut estimated with AutoFom III. A total of 419,321 Landrace, Yorkshire, and Duroc (LYD) pigs were graded with the Korean Pig Carcass Grade System. Amounts of belly, neck, loin, tenderloin, spare ribs, shoulder, and ham were estimated with AutoFom III. Regression equations for seven primal cuts according to each grade were derived. There were significant differences among the three carcass grades due to heteroscedasticity variance ($p < 0.0001$). Three regression equations were derived from AutoFom III estimation of primal cuts according to carcass grades. The coefficient of determination of the regression equation was 0.941 for grade 1^+, 0.982 for grade 1, and 0.993 for grade 2. Regression equations obtained from this study are suitable for AutoFom III software, a useful tool for the analysis of each pig carcass grade in the Korean Pig Carcass Grade System. The high reliability of predicting the amount of primal cut with AutoFom III is advantageous for the management of slaughterhouses to optimize their product sorting in Korea.

Keywords: Pig carcass grade, AutoFom III, Regression, Primal cuts, Heteroscedasticity

INTRODUCTION

With increasing national income in Korea, the consumption of meat per capita has increased. Because of that, quality control of meat produced is necessary. The Animal Products Grading Service in Korea has been established in 1989. The grading system has led to many changes in the production, distribution, and consumption of livestock products [1]. The Korean pig carcass system is divided into grade 1^+, grade 1 and grade 2 according to carcass weight and back fat thickness (Table 1). Meat quality is judged by subjective marbling level, meat color, fat color, degree of maturity, and texture of whole pig carcass. It has contributed to the development of the livestock industry which has changed from live

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Availability of data and material
Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions
Conceptualization: Park Y, Ko E, Kim J, Choi J.
Data curation: Park Y, Ko E, Kim J.
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Ethics approval and consent to participate
This article does not require IRB/IACUC approval because there are no human and animal participants.

Table 1. Korean pig carcass grade system

Primary carcass grade	Carcass weight (kg)	Backfat thickness (mm)
1+	83–92	17–24
1	80–82	15–27
	83–92	15–16
	83–92	25–27
	93–97	15–27
2	Neither 1+ nor 1	

Korean Ministry of Agriculture, Food and Rural Affairs Notification 2014-4 [2].

animals to meat products, causing conversion from warm carcass to cold carcass distribution. It has also prevented meat quality degradation, increased the reliability of distribution, and provided reasonable price formation. Data from the grading system are also helpful for the development of breeding and rearing technology. In Korea, there is a large difference in market price for each pork cut [3]. Thus, it is important to evaluate the amount of each part. However, the Korean grading system of pork does not know the weight of each pork primal cut until primal cuts are separated because the grade of pork is only evaluated based on carcass quality such as carcass weight and backfat thickness.

There are several no-destructive techniques for analyzing pig carcasses worldwide, including dual-energy x-ray absorptiometry [4], magnetic resonance imaging [5], computed tomography [6], infrared reflectance spectroscopy [7], and ultrasound imaging [8]. Dual-energy x-ray absorptiometry, magnetic resonance imaging, and computed tomography are more accurate than ultrasound imaging [9]. However, ultrasound imaging has advantages of being applicable to any carcass size with a reasonable price, no radiation, and real time measurement [8,9]. These techniques are important for performance testing, grading, and final selection or payment of meat-producing animals.

On-line grading of pig carcasses by ultrasound technology is widely used in European livestock industry. It is a non-invasive and fully automated technology that enables a rapid feedback to slaughter houses on lean meat percentage, primal yields, and specific traits of individual carcasses. Frontmatec Smoerum A/S (formerly known as Carometec A/S, Smoerum, Denmark) launched an ultrasound-based classification system called AutoFom III in 2009. It is used for grading pig carcass in more than 14 countries. Janiszewski et al. [10] have reported that AutoFom III shows very high accuracy for analyzing loin, ham, and belly contents of pig carcass, with coefficients for determining belly-muscle thickness and the percentage of meat in ham of 0.98 and 0.93 in regression equations, respectively. When weights of pork primal cuts were compared to predicted values by AutoFom III, cross-validated prediction accuracies of calibration models were high (0.77–0.86) [11].

The price of pork in pig farms is determined by the pork carcass grade based on carcass weight and backfat thickness. However, pork is sold by primal cuts. Prices of pork primal cuts are different in the market. It is impossible to accurately estimate the amount of pork primal cut with the current Korean Pig Carcass Grade System. To determine an appropriate pork price, the amount of pork primal cuts needs to be predicted according to each grade. Therefore, the objective of this study was to investigate the correlation between pig carcass grade and the amount of pork primal cut estimated by AutoFom III to provide a means to predict the amount of pig primal cut according to each grade.

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MATERIALS AND METHODS

Animals

Pigs used in this estimation test were Landrace x Yorkshire, F1 x Duroc (LYD) crossbreds and were bred with the artificial insemination and the feed provided by Dodram pig farmers cooperative. All pigs from farms having contracts with Dodram were transported to the Dodram LPC in Anseong, Gyeonggi Province, Korea from January 2018 to December 2018. Pigs were slaughtered according to the Livestock Hygiene Control Act. A total of 419,321 heads except for non-grade carcasses in the Korean Pig Carcass Grade System were used in this experiment.

AutoFom III analysis

After hair removal of pig carcasses, an AutoFom III (Frontmatec Smoerum A/S, Smørum, Denmark) equipment was used prior to evisceration of carcasses. AutoFom III equipment has 16 ultrasound transducers. These transducers are excited in turn with repeated frequency of approximately 5 kHz. Scanning of the carcass generates 48 ultrasound images with information on skin, fat, and lean measures. How to use AutoFom III was described in detail in our previous study [11]. Using AutoFom III, amounts of seven pork parts (belly, neck bone-out, tenderloin, spare ribs, shoulder bone-out, and ham bone-out) were estimated.

Grading of pig carcass

Pig carcasses were graded with the Korean Pig Carcass Grade System (Table 1). The pig carcass weight was measured with an electronic scale and expressed as an integer in kg unit. The left half carcass was used to measure the backfat thickness. The backfat thickness between the last thoracic vertebra and the first lumbar vertebra and that between the 11th and 12th thoracic vertebrae were measured with a ruler. The average of the two values was then calculated and used for analysis. A total of 419,321 heads were graded in this experiment.

Statistical analysis

The significance of testing of each grade was investigated by a *t*-test of heteroscedasticity variance. Excess kurtosis and skewness were calculated to investigate distribution characteristics of seven carcass parts. Regression equation was obtained with the weight of the carcass as the dependent variable and as the weight of seven carcass parts. Coefficients of determination and multiple correlation were calculated. Data for each grade were analyzed using the following multiple linear regression model:

$$y_{i} = \mu + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \beta_5 x_{i5} + \beta_6 x_{i6} + \beta_7 x_{i7}$$

where μ was the intercept, β was the slope for the independent variable x_{ij} which was the weight of carcass part estimated by AutoFomm III, X_{i1} was the belly, x_{i2} was the neck bone-out, x_{i3} was the spare rib, x_{i4} was the loin bone-out, x_{i5} was the tenderloin, x_{i6} was the shoulder, and x_{i7} was the ham bone-out. All statistical analyses were performed using SPSS software (version 21.0, SPSS, Chicago, IL, USA).

RESULTS AND DISCUSSION

The Korean grade evaluation of pork is only based on carcass quality and meat quality for the whole pig carcass after slaughtering. The carcass quality is determined by carcass weight and backfat thickness (Table 1). The meat quality is determined by subjective marbling level, meat color, fat color, degrees of maturity, and texture. Therefore, the weight of pork primal cut is not known with the Korean pork grade system until the primal cut is separated. Pork price is set on different standards between producers and consumers. It is determined by the carcass grade into the producer and by various primal and commercial cut into the consumer [3,12]. In addition to the pig carcass grade system, it is necessary to estimate the amount of primal cut for determining the pork price. Non-invasive methods have been used to determine the cutting yield of pig carcasses in European countries and North America since the early 2000s [6,13–16]. AutoFom I shows a smaller residual root mean squares error than the European Union standard when measuring the lean meat percentage (ham, loin, and shoulder) of pig carcasses [17]. In addition, AutoFom I shows a high prediction accuracy in residual root mean squares error and regression coefficient for weights of untrimmed primal cuts of pigs [18–20]. AutoFom III is an image analysis software version after modifying and improving AutoFom I. Our previous study has verified that the prediction with AutoFom III for Korean slaughter pigs has a high accuracy [11]. The present study estimated the amount of pork primal cut using AutoFom III and investigated the correlation between the amount of pork primal cut and each carcass grade.

A total of 419,321 pig carcasses were graded: grade 1^+ for 145,872 heads (34.8%), grade 1 for 157,833 heads (37.6%), and grade 2 for 115,616 heads (27.6%). Table 2 shows carcass weight and backfat thickness of each carcass grade. As a result of F-test and White's-test to investigate the distribution of the carcass weight and the backfat thickness for each grade, the distribution of both data showed heteroscedasticity. There were significant differences in carcass weight and backfat thickness among the three grades by t-test of heteroscedasticity variance ($p < 0.0001$). The lower the grade, the larger the standard deviation value of carcass weight and backfat thickness (Table 2). In other words, the standard deviation of carcass weight or backfat thickness was smaller for a high-quality meat.

To find out the amount of pork primal cut, weights of seven primal cuts (belly, neck, loin, tenderloin, spare ribs, shoulder, and ham) were estimated using AutoFom III. All weights of seven primal cuts showed significant differences among the three grades (Table 3). The higher the grade is, the smaller the standard deviation is. The weight was higher in the order of ham, belly, and shoulder for all three grades (Table 3). The ratio of belly weight, which is the most expensive cut in Korea, to carcass weight was investigated among the grades. There were significant differences in the ratio of belly weight to carcass weight among the grades ($p < 0.001$), with grade 2 being the highest and grade 1^+ being the lowest (grade 2: 14.1 ± 0.62%, grade 1: 14.0. ± 0.49%, grade 1^+: 13.9 ± 0.45% as mean ± standard deviation). This result shows that the higher the grade is, the smeller the ratio of belly is. Therefore, it is considered that the current Korean pig carcass grade system needs supplementary means.

Excess kurtosis and skewness were calculated to investigate distribution characteristics. Weights of seven primal cuts were estimated with AutoFom III. Excess kurtosis of belly, neck, spare ribs,

Table 2. Pig carcass weight and backfat thickness according to the Grading System for Pig Products in Korea

	Grade 1^+	Grade 1	Grade 2	p-value[1)]
Carcass weight (kg)	87.6 ± 2.64[c]	87.9 ± 5.27[a]	87.7 ± 8.98[b]	0.000
Backfat thickness (mm)	21.2 ± 2.06[c]	27.8 ± 3.90[a]	23.2 ± 7.33[b]	0.000

Each value is presented as mean ± SD.

Population numbers for Grades 1^+, 1, and 2 are 145,872, 157,833, and 115,616, respectively.

[1)] p-value is obtained by t-test of heteroscedasticity variance.

[a–c] Different superscripts in the same row differ significantly in the analysis of heteroscedasticity variance.

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Table 3. Weights of seven carcass primal cuts estimated with AutoFom III (unit: kg)

	Grade 1+	Grade 1	Grade 2	p-value[1)]
Belly	12.14 ± 0.544[c]	12.27 ± 0.894[b]	12.55 ± 1.528[a]	0.000
Neck bone-out	4.58 ± 0.199[a]	4.47 ± 0.318[b]	4.40 ± 0.462[c]	0.000
Loin bone-out	5.68 ± 0.495[a]	5.63 ± 0.633[b]	5.48 ± 0.800[c]	0.000
Tenderloin	0.97 ± 0.055[a]	0.96 ± 0.078[b]	0.95 ± 0.106[c]	0.000
Spare ribs	3.64 ± 0.114[b]	3.65 ± 0.205[a]	3.62 ± 0.322[c]	0.000
Shoulder	8.13 ± 0.281[a]	8.12 ± 0.479[b]	8.04 ± 0.717[c]	0.002
Ham bone-out	17.04 ± 0.790[a]	16.98 ± 1.189[b]	16.71 ± 1.667[c]	0.000

Each value is presented as mean ± SD.

Population numbers for Grades 1+, 1, and 2 are 145,872, 157,833, and 115,616, respectively.

1) *p*-value is obtained by *t*-test of heteroscedasticity variance.

a–c Different superscripts in the same row differ significantly in the analysis of heteroscedasticity variance.

and shoulder showed a platykuric distribution with negative values (k < 0, Table 4). Excess kurtosis of loin, tenderloin and ham showed negative or positive values depending on the grade. Loin with grade 2 and tenderloin and ham with Grades 1 and 2 had negative excess kurtosis (k < 0), indicating a platykuric distribution. Besides loin, tenderloin, and ham with grade 1+, loin of grade 2 also had positive values (k > 0), indicating a leptokurtic distribution (Table 4). Belly and spare ribs had negative skewness that skewed to the left, whereas loin had positive skewness that skewed to the right (Table 4). Neck, tenderloin, shoulder, and ham showed negative or positive skewness depending on the grade. All seven primal cuts had skewness. However, loin, tenderloin, spare ribs, and shoulder were approximate in mean, median, and mode. Thus, they were close to symmetry (Tables 3 and 4).

To investigate the relationship between pig carcass grade and pork primal cut, regression analysis was carried out. Multiple regression analysis was performed with carcass weight as a dependent variable and each primal cut as independent variables. Intercept and independent variables are shown in Table 5. Substituting the intercept and the slope in Table 5, the regression equation for each grade is shown below:

$$\text{Grade } 1^{+}: y = 0.28 + 2.59x_1 + 14.40x_2 - 24.33x_3 - 7.10x_4 - 46.56x_5 + 10.56x_6 + 4.66x_7$$
$$\text{Grade } 1: y = -3.56 + 3.00x_1 + 17.25x_2 - 29.12x_3 - 8.07x_4 - 56.56x_5 + 11.15x_6 + 5.48x_7$$
$$\text{Grade } 2: y = -4.96 + 3.32x_1 + 17.14x_2 - 32.19x_3 - 8.27x_4 - 64.88x_5 + 12.19x_6 + 6.06x_7$$

Coefficients of determination and multiple correlation for each grade were higher for the lower grade (Table 6). The prediction accuracy with AutoFom III was higher in the present study than that in our previous study [11]. This difference of accuracy could be due to the following two reasons: i) difference in the number of pork primal cuts (11 primal cuts in the previous study and 7 primal cuts in the present study) estimated with AutoFom III. AutoFom III was less accurate for pork primal cuts with less amounts [11]; ii) difference in the number of samples (419,321 heads in this study and 162 heads in the previous study). A high prediction accuracy of AutoFom III was shown for pork belly muscle thickness and ham lean meat percentage (r^2 = 0.98 and r^2 = 0.93, respectively) [10]. In Spain, when AutoFom III was used to predict subcutaneous fat thickness of ham, the final quality of dry-cured ham was improved [21].

The consumption and price of pork primal cuts are higher in the order of belly, neck, and shoulder in Korea [22,23]. The price of pork belly, which is the most preferred primal cut of Koreans, is more than four times per kg of primal cut than the price of ham, which is the unfavorable primal

Table 4. Distribution characteristics of seven carcass primal cuts analyzed by AutoFom III (unit: kg)

	Median	Mode	Min	Max	Excess kurtosis	Skewness
Belly						
Grade 1+	12.12	12.16	10.66	13.64	−0.224	0.099
Grade 1	12.24	11.66	9.66	15.26	−0.871	0.106
Grade 2	12.81	10.90	8.50	16.74	−0.951	0.105
Neck bone-out						
Grade 1+	4.48	4.46	3.14	5.14	−0.113	−0.141
Grade 1	4.44	4.24	2.32	5.36	−0.712	0.095
Grade 2	4.34	4.16	2.78	5.96	−0.444	0.357
Loin bone-out						
Grade 1+	5.70	5.70	1.58	7.98	0.336	−0.243
Grade 1	5.64	5.72	0.24	7.94	−0.003	−0.126
Grade 2	5.46	5.48	1.16	8.42	0.065	−0.004
Tenderloin						
Grade 1+	0.98	0.98	0.50	1.18	0.528	−0.282
Grade 1	0.96	0.94	0.36	1.22	−0.180	−0.043
Grade 2	0.94	0.90	0.28	1.32	−0.108	0.198
Spare ribs						
Grade 1+	3.64	3.64	3.12	4.26	−0.570	0.004
Grade 1	3.62	3.44	2.94	4.48	−1.074	0.168
Grade 2	3.58	3.32	2.56	4.76	−0.654	0.369
Shoulder						
Grade 1+	8.12	8.12	6.54	9.18	−0.361	−0.073
Grade 1	8.08	7.70	5.56	9.66	−0.910	0.135
Grade 2	7.94	7.48	5.76	10.36	−0.554	0.381
Ham bone-out						
Grade 1+	17.06	17.00	11.32	19.82	0.097	−0.204
Grade 1	16.92	16.48	7.80	20.58	−0.499	0.038
Grade 2	16.50	16.02	9.72	22.44	−0.319	0.304

Population numbers for Grades 1+, 1, and 2 are 145,872, 157,833, and 115,616, respectively.

Table 5. Intercepts and slopes of seven carcass parts in regression function

	Grade 1+	Grade 1	Grade 2
Intercept	0.28	−3.56	−4.96
Linear regression slope			
Belly (X_1)	2.59	3.00	3.32
Neck bone-out (X_2)	14.40	17.25	17.14
Spare ribs (X_3)	−24.33	−29.12	−32.19
Loin bone-out (X_4)	−7.10	−8.07	−8.27
Tenderloin (X_5)	−46.56	−56.56	−64.88
Shoulder (X_6)	10.56	11.15	12.19
Ham bone-out (X_7)	4.66	5.48	6.06

Population numbers for Grades 1+, 1, and 2 are 145,872, 157,833, and 115,616, respectively.

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Table 6. Coefficients of determination and multiple correlation of animal products according to the grading system

	Grade 1+	Grade 1	Grade 2
Coefficient of determination	0.941	0.982	0.993
Adjusted coefficient of determination	0.941	0.982	0.991
Coefficient of multiple correlation	0.991	0.993	0.996

Population numbers for Grades 1+, 1, and 2 are 145,872, 157,833, and 115,616, respectively.

cut. Therefore, it is necessary to consider the price of pigs by measuring the amount of pork primal cut. In this study, distribution characteristics of data for each Korean grade of pork carcasses and their seven primal cuts estimated with AutoFom III were investigated in order to be clear about correlation between pork carcass grade and pork primal cuts. Regression equations with high reliability were derived for the relationship between each grade and each of seven primal cuts (belly, neck, loin, tenderloin, spare ribs, shoulder, and ham). In conclusion, these regression equations based on the AutoForm III software will be a useful tool for the analysis of specific grades of pig carcasses. The high reliability prediction of primal cuts is advantageous for the management of slaughterhouses to optimize their product sorting prior to carcasses entering the cold room. Results of this study can be used as a base to suggest the optimal price of pigs in the market and the direction of pig breeding in the pig farming industry.

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