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Roentgenographic Procedure for Selecting Proximal Femur Allograft for Use in Revision Arthroplasty

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Abstract: A roentgenographic scoring system was developed to help orthopaedic surgeons and bone banks estimate the quality of bone stock in proximal femoral allografts intended to use in revision arthroplasty. This system scores a standardized anteroposterior roentgenograph of the proximal femur using four indices representing morphological features of cancellous and cortical bone known to be clinically associated with bone strength. The indices were combined to give a weighted score, which was thought to reflect the ability of a bone to carry *in vivo* loads. Thirty bones were evaluated for bone mineral density using dual-photon absorptiometry. They were then sent to another institution and evaluated using the newly devised roentgenographic scoring system. The results showed that the bone score roentgenographic method is a reasonable technique for selecting allograft femurs for transplantation. This roentgenographic technique and scoring system has now been packaged into kits and is available to orthopaedic surgeons and bone banks for evaluating bone stock quality in proximal femoral allografts intended for transplantation. **Key words:** allograft, arthroplasty, roentgenograph, bone, femur, revision.

The demand for allograft bone used in orthopaedic surgeries in the United States has exhibited a marked increase over the past decade. In 1982 total hip revision alone accounted for approximately 7% of all allograft bone used,[22] but this percentage increased to an estimated 39% by 1987.[16] Factors influencing the success of allograft bone used in procedures such as revision arthroplasty include initial load carrying properties, incorporation and remodeling potential of the bone–graft, and factors associated with preservation, storage, and sterilization.[25] Because proximal donor femurs used in allograft surgery typically serve to buttress prosthetic devices, act as struts, and fill in void spaces,[12] surgeons agree that the success of procedures requiring allograft tissue are often contingent on the ability of the allograft to carry *in vivo* loads.[9,25] It is important to ensure that proximal femurs obtained for use as allograft material have the structural and material properties necessary to carry *in vivo* loads adequately, that is to say femurs with good quality bone stock.

The term "bone stock" is used in this study to indicate the relative amount and distribution of cortical and cancellous bone in the proximal femur. The term "good quality bone stock" is used to indicate that the bone has various morphological characteristics that are correlated with mechanical properties that

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orthopaedic surgeons typically consider to be satisfactory for use in allograft surgery.

Bone banks attempt to eliminate femurs with poor quality bone stock by procuring femurs only from donors under the age of 45 (Table 1).[5] The consequence of this practice is the potential loss of good quality bone from suitable older donors and results in a financial burden with femurs of poor quality bone stock are procured from donors younger than 45 years old. Prospective donors could be screened for characteristics associated with good quality bone stock by using techniques for determining bone mineral density (BMD), such as quantitative computed tomography (CT), dual-photon absorptiometry (DPA), or neutron activation analysis.[10] However, these techniques are expensive and are not available

Table 1. Current Donor Criteria

A. Age: 15–45
Bone and related soft tissues (tendons, ligaments, and fascia).
Age 15 is chosen as a lower limit to avoid the collection of grafts with open epiphyses. If the donor is below the age of 19, an anteroposterior radiograph of the knee must be obtained prior to procurement to document that the epiphysis is closed. Age 45 is chosen as an upper limit to avoid collection of grafts with any deterioration of cartilage surfaces or loss of elasticity of tissue due to normal aging changes.

B. Time Constraints
The potential donor must be identified, permission obtained, and blood and tissues gathered within 24 hours from the time of death (providing the body has been refrigerated within 3 hours of death). In cases where the body has not been refrigerated, all procedures must be completed within 12 hours of death. If the body is sent to the morgue prior to the recovery, it should be wrapped tightly in a body bag.

C. General Health Criteria
Basic information must be gathered in order for a donor to be considered for bone and tissue procurement. That information is as follows:
- Cause of death
- Time of death
- Past medical history
- History of present illness
- Current medical status (include laboratory data when available)

1. Cause of Death: It is not permissible to proceed with the procurement process without clear knowlege of why the patient died or was declared brain dead. Failure to determine cause of death prior to procurement will rule the patient out as a donor.
2. Time of Death: Because of the time constraints outlined above, the time of death must be known and documented. Reliable eyewitness reports regarding the last known contact with the donor may be accepted as long as they are truly reliable.
3. History of Present Illness:
   - No septicemia
   - No active infection including meningitis, encephalitis, tuberculosis, typhus, measles, mumps, rubella, chicken pox, herpes II (genital herpes), or other viral/fungal/bacterial disease
   - No active unexplained immune system disorder
   - No jaundice, open skin lesions, unexplained rashes, or purulent wounds
4. Current Medical Status: (including laboratory data)
   - No elevated WBC count (except where related to brain trauma, postoperative elevation, trauma or massive soft tissue injury)
   - No elevated ESR (unexplained by injury)
   - No positive VDRL, HIV, HBsAg, HTLV-1, HBcAb, HAAb, cultures, or ANA
   - No high fever unexplained by CNS injury (101°F)
   - No potential systemic infectious conditions (septic IV site, septic decubitii, etc.)
5. Past Medical History: Disease processes or conditions that contraindicate tissue donation are:
   - Malignancy
   - AIDS, AIDS related complex
   - Hepatitis, syphilis, leprosy
   - Transfusions: No history of over 10 units (5,000 mL) of blood, plasma, or platelets. If the patient has received 10 units or less of blood, a pretransfused sample (2 mL) is required for HIV and hepatitis screening
   - Slow viral disease (Epstein Barr, Croutefield Jacob's disease [CJD])
   - Autoimmune diseases (rheumatoid arthritis, myasthenia gravis, lupus)
   - Connective tissue disease (lupus)
   - Neurological and/or demyelinating diseases (multiple sclerosis, muscular dystrophy, amyotrophic lateral sclerosis)
   - Unexplained dementia (includes senile dementia and cerebral arteriosclerosis as they may be indistinguishable from CJD)
   - Unexplained jaundice
   - Use of pituitary growth hormone
   - Recent (within 4 weeks) immunizations against measles, rubella, mumps, polio, yellow fever, or rabies
6. Past Medical History: Disease processes or conditions that must be evaluated on a case by case basis include:
   - Disease states of unknown etiology (includes but is not limited to Alzheimer's disease)
   - Exposure to toxic chemicals/metals (lead, mercury, Agent Orange)
   - Chronic long-term steroid use (excluding anabolic steroids)

WBC, white blood cell; ESR, erythrocyte sedimentation rate; HIV, human immunodeficiency virus; HTLV, human T-cell lymphotropic virus; ANA, antinuclear antibody, CNS, central nervous system; AIDS, acquired immunodeficiency syndrome; VDRL, venereal disease research lab test; HBsAg, hepatitis B surface antigen; HBcAb, antibody to HBcHg; HAAb, antibody to hepatitis A.

to most orthopaedic surgeons or hospitals participating in donor retrieval programs. Bone banks need an inexpensive method for screening proximal femurs for bone stock quality prior to procurement. The method should also be versatile and inexpensive so that the orthopaedic surgeon could assess allograft bone for potential transplantation during the preoperative planning prior to revision arthroplasty. This screening method should accommodate a broad age range of potential donors, ultimately resulting in an increase in the yield and quality of allograft femurs available for transplantation.

The objective of this study was to develop a roentgenographic screening method using clinically established morphological characteristics. This was accomplished by using four morphologic indices to score a standardized anteroposterior (AP) roentgenogram of the proximal femur. The indices used were the Singh index,[30] cortical shaft index,[6] calcar isthmus to canal isthmus (CC) ratio,[6] and calcar width.[15] These indices were combined to give a weighted score. This score was felt to correspond to the presence or absence of morphological features that have been shown to correlate with mechanical properties that reflect the capacity of the proximal femur to carry *in vivo* loads adequately. Using this roentgenographic scoring system, it was further hypothesized that femurs with good quality bone stock could be readily distinguished from those with poor quality bone stock. In order to test this hypothesis, DPA was used to independently determine whether or not the bone scores correlated to actual BMD.

The Singh index is a roentgenographic bone grading system used to assess the amount of osteopenia present in the proximal femur as demonstrated by the presence or absence of trabecular arches seen in AP roentgenograms (Figs. 1–6).[30] The Singh index was used in this study because it gives a general indication of the relative amount and distribution of cancellous bone that may be available for use as allograft material in revision arthroplasty. In addition, low Singh grades have been correlated to a decrease in the weight-to-volume ratio of the bone ash of the proximal femur[3] and to an increase in the incidence of femoral neck fracture,[15] as well as to a loss of individual trabeculae as shown on iliac biopsy.[19] Consequently, the Singh grade serves to suggest that the quality and quantity of bone stock in a given

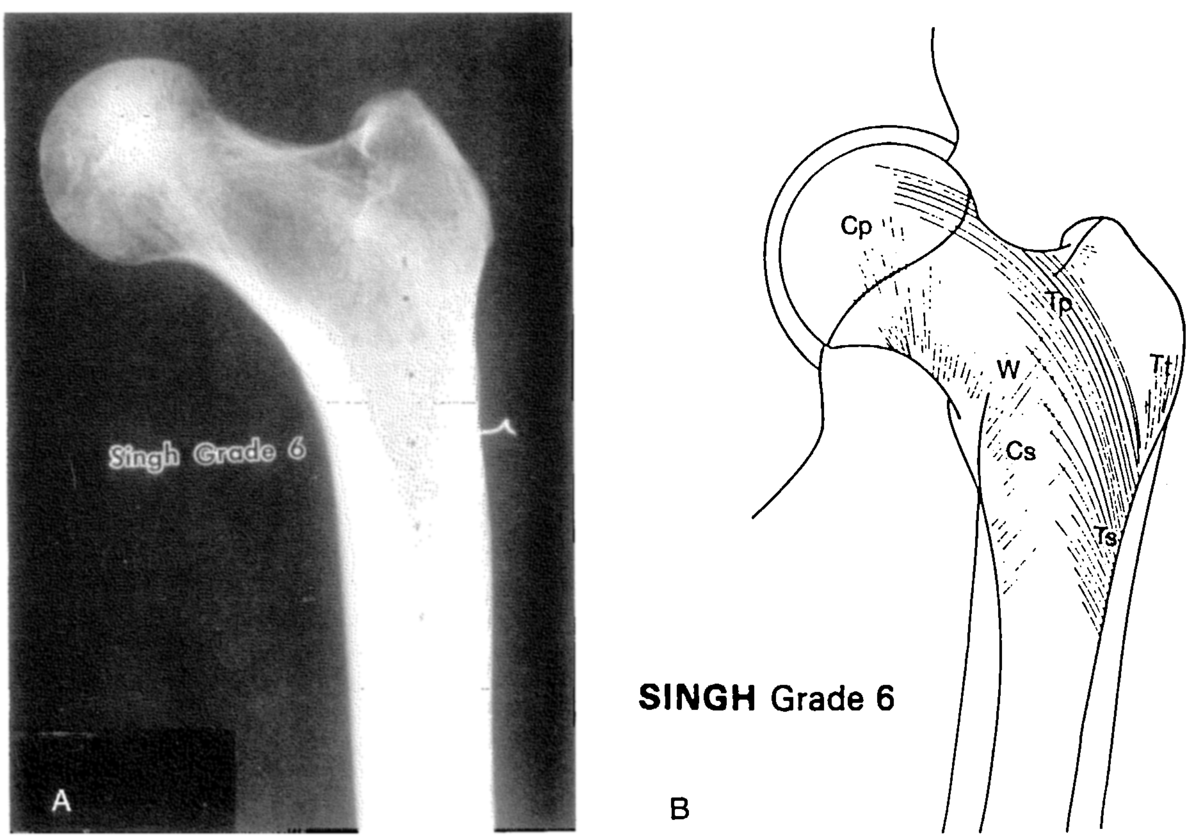


Fig. 1. (A) Roentgenograph representing Singh grade 6 with (B) corresponding diagram showing all normal groups of trabeculae, which include two sets of compression (Cp, Cs) and three sets of tensile (Tp, Ts, Tt) trabeculae. Ward's triangle (W).

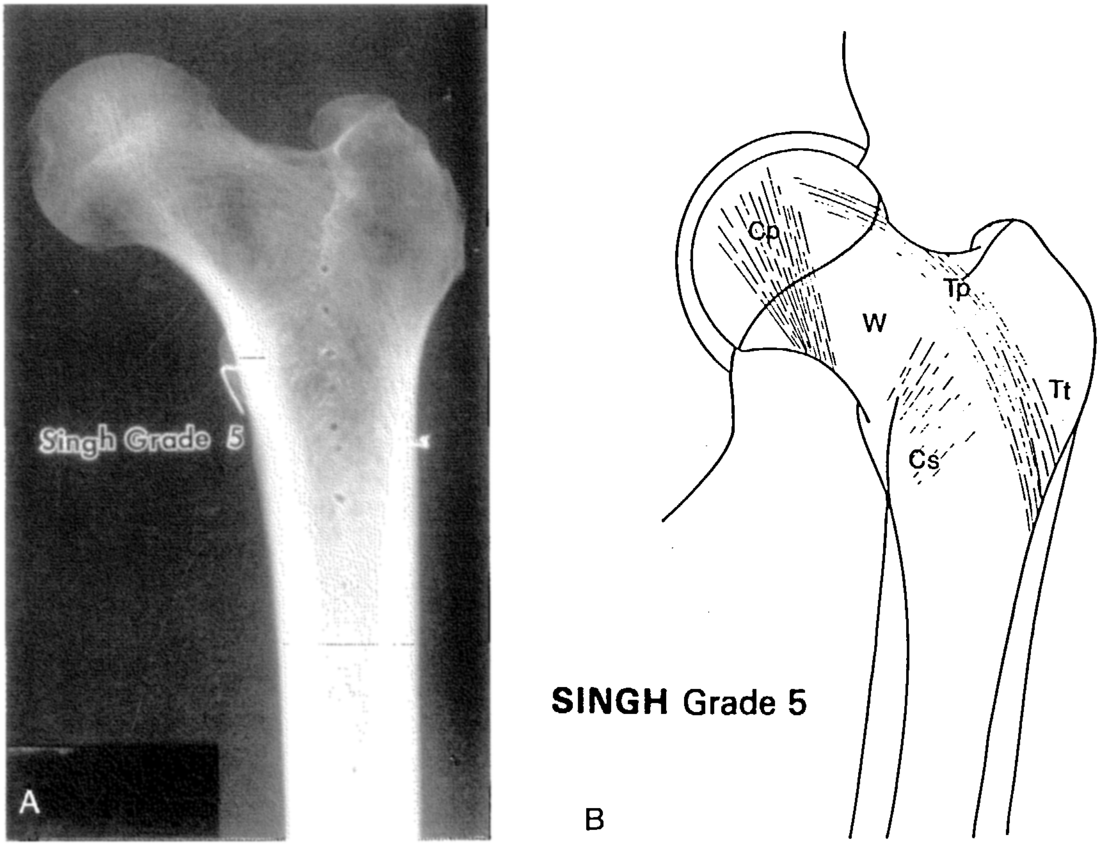


Fig. 2. (A) Roentgenograph representing Singh grade 5 with (B) corresponding diagram showing an enlarged Ward's triangle (W) and fading of the secondary compressive trabeculae (Cs). The accentuation of primary compressive (Cp) and tensile trabeculae (Tp) are a roentgenographic characteristic of this grade. Note the loss of the greater trochanter trabeculae group (Tt).

femur may, depending on the grade, be unsatisfactory for use as an allograft in revision arthroplasty.

The CC ratio and cortical shaft index are two roentgenographic morphologic indices that have been shown to correlate with clinical success in total hip arthroplasty.[8] These two indices have been used to classify bones into types A, B, and C (Fig. 7).[8] Patients with type A proximal femurs have been shown to have excellent long-term clinical results after total hip arthroplasty. Patients with type B and C proximal femurs have a higher incidence of clinical complications including implant failure.[6] Consequently, these indices correlate with structural features that are associated with good quality bone stock required for implant load transfer and implant stability. This A, B, C classification scheme has also been correlated to the quality of bone stock in terms of bone histomorphometry analysis findings, including cortical porosity, osteoid volume and surface area, bone–osteoblast interface, and osteoblast number.[8]

The calcar width is the measurement of the width of the clinical calcar area and should not be confused with the true calcar femorale, which cannot be seen on AP projections of the femur.[13] The clinical calcar is actually the medial band of bone just above the lesser trochanter visible on the AP roentgenogram. It stands to reason that the larger this band appears the more bone present and thus better bone stock. A femur with a calcar width greater than 5 mm has been shown to have a decreased risk for femoral neck fracture[15] and an increased weight-to-volume ratio of bone ash of the femoral head.[3]

In summary, it is hypothesized that each of the indices described above could be scored on AP roentgenograms of proximal femora and that these scores could be combined to give a weighted score that would correlate closely to actual BMD, and thus serve as an objective criterion for prescreening potential donor femora for use as allograft tissue.

Materials and Methods

Mineral density of 30 randomly chosen femora from men and women aged 24–61 was measured using DPA (Model DP3, Lunar Corporation, Madi-

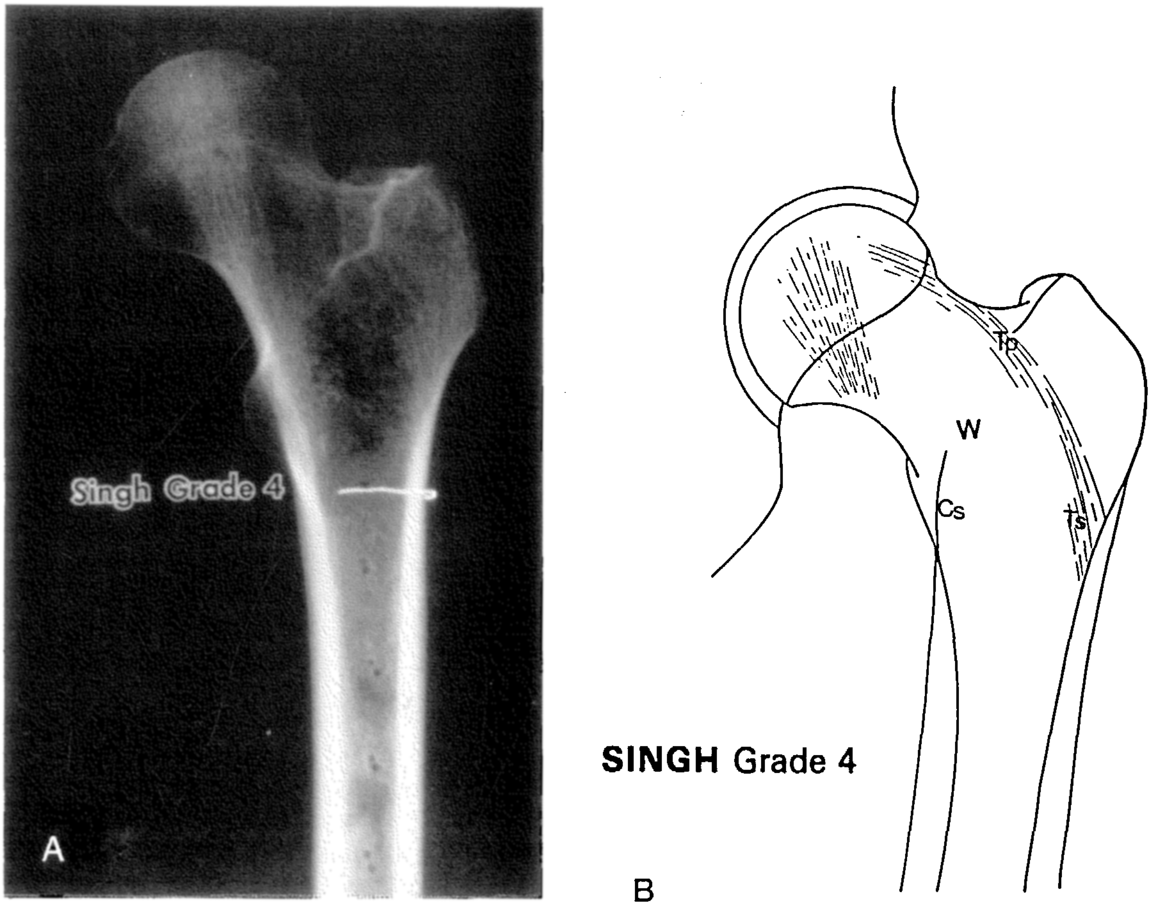


Fig. 3. (A) Roentgenograph representing Singh grade 4 with (B) corresponding diagram showing an enlarged Ward's triangle (W), the absence of the secondary compressive group (Cs), and the beginning of discontinuity between the primary (Tp) and secondary (Ts) tensile groups.

son, WI). The bones were placed with the posterior aspect flat on the scanner table and were scanned in an AP projection. This technique is exactly the same as that normally used in scanning a patient in the clinical setting. The regions of interest included the femoral neck, Ward's triangle, and the greater trochanter of each bone (Fig. 8). Bone mineral density was reported in g/cm^2. The reproducibility of the above technique has been reported at a level of 3%, an accuracy of 2–4%, and precision of 1%.[33]

The scan values for each femur were compared to normal data from sex-, race-, height-, and weight-matched femora of normal individuals, and the average BMD value for normal subjects aged 20–40 years was calculated. This average BMD value was referred to as the "percent young normal"[20]; these values are standards that were available as part of the DPA system. The percent young normal value was calculated for each area analyzed on each bone in the study. The values for the three areas on each bone were averaged resulting in 1 average percent young normal per bone (Table 2). Percent young normal is a good indicator of a patient's fracture risk and osteoporosis status. Studies have shown that percent young normal values less than 80% represent a bone with a significantly high risk of femoral neck fracture.[2] In this study, the interval between 80% and 90% is considered to be an intermediate zone that could represent early signs of osteoporosis and may be indicative of compromised bone stock. Therefore, 90% young normal was the value chosen in this study as the point delineating acceptable and unacceptable bones for transplantation.

After DPA analysis the bones were sent to another institution for the roentgenography portion of the study. In an effort to imitate *in vivo* conditions, each bone was radiographed in a $\frac{1}{4}$ inch thick (0.64 cm) Plexiglass tank (67.5 × 28.6 × 27.8 cm) under 15 cm of water that simulated soft tissue. The method of femur orientation was based on that described by Ruff[27,28] (Fig. 9). The film cassette size was 26.5 × 32.5 cm and the distance from the cassette to the x-

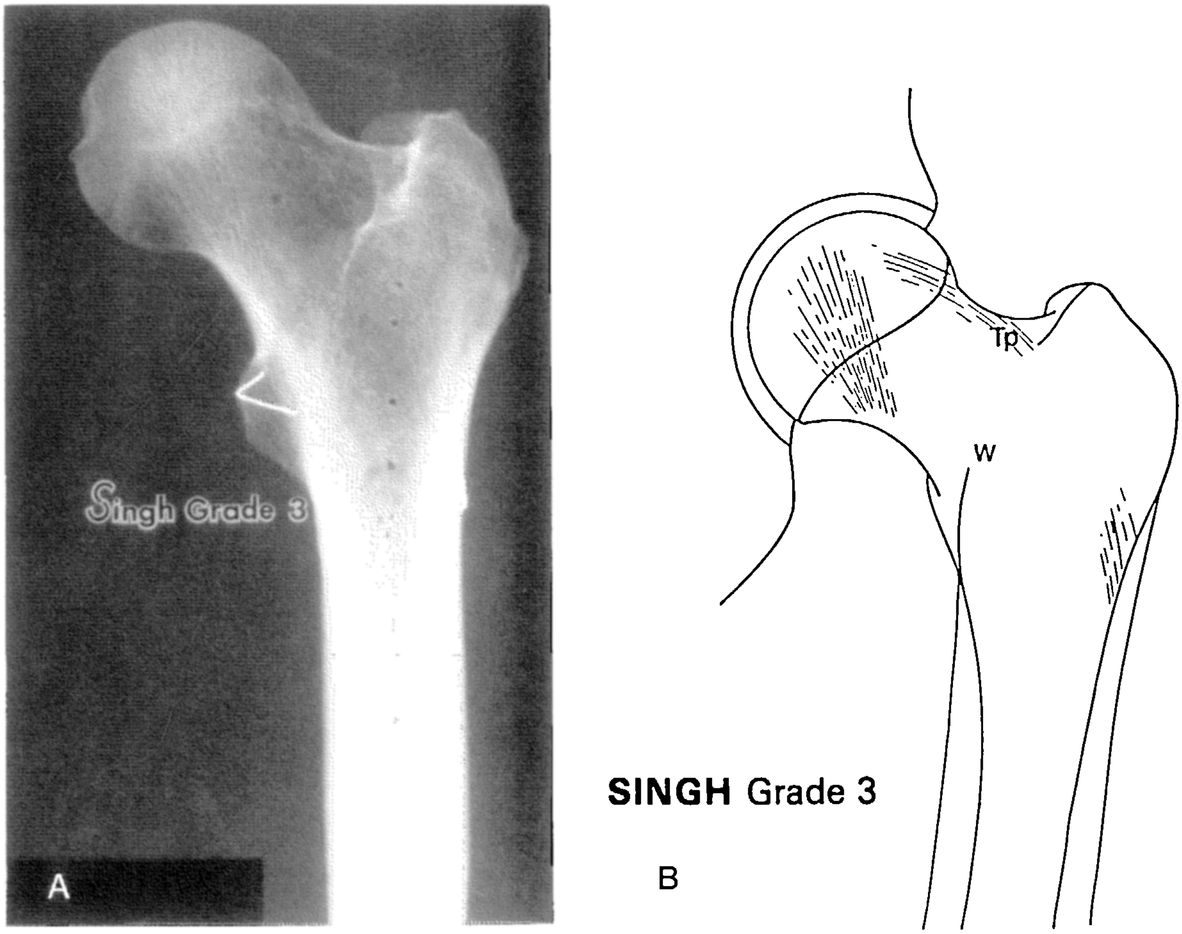


Fig. 4. (A) Roentgenograph representing Singh grade 3 with (B) corresponding diagram showing the break in continuity of the primary tensile trabeculae (Tp) and the large Ward's triangle (W), all characteristic of this grade.

ray tube was 73.66 cm (29 in). The cassette was placed immediately beneath the Plexiglas tank. A Phillips M100 (Shelton, CT) x-ray machine was used at the settings 75 kV, 4 ms, and 40 mA with Kodak Lanex regular film (Rochester, NY) in a bucky. These settings were chosen because they produced an optimal roentgenographic appearance of the proximal femur as determined by the graylevel separation seen on an aluminum stepwedge placed beside it (Fig. 10). The stepwedge had 13 steps progressing in 1-mm increments, the first step being 5 mm high. Because this stepwedge provided good graylevel contrast, graylevel differences could be easily ascertained and thus, good quality roentgenographs obtained. According to pilot studies, this technique provided optimal visualization of the trabecular arches and decreased observer variability when conducting Singh grading (Fig. 11).

The weighted scoring was established as follows (Table 3). Bones received 3 points for Singh grades 6 or 5, 2 points for grade 4, 1 point for grades 3 or 2, and 0 points for grade 1. Singh grade 4 was isolated and scored differently from grades 5 and 3 for two reasons: (1) although grade 4 is the first grade to herald the existence of what may be considered clinically significant osteoporosis, in terms of fracture fixation it is considered to be within the range of normal and (2) grades 3, 2, and 1 are clinically considered to show reduced bone strength and may be pathologic or osteoporotic, whereas grades 6 and 5 are unequivocally considered to be clinically normal.[17] Therefore, grades 6 and 5 were scored similarly and grades 3 and 2 were scored similarly, but grade 4 was isolated since it alone represents the pivotal grade between poor quality and good quality bone.

For the CC ratio and cortical shaft index, the following points were assigned respectively: bones with values corresponding to type A bone received 3 points, type B bones received 2 points, and type C bones received 1 point. The overall bone scores, when totaled, ranged between 0 and 9. Type A bone

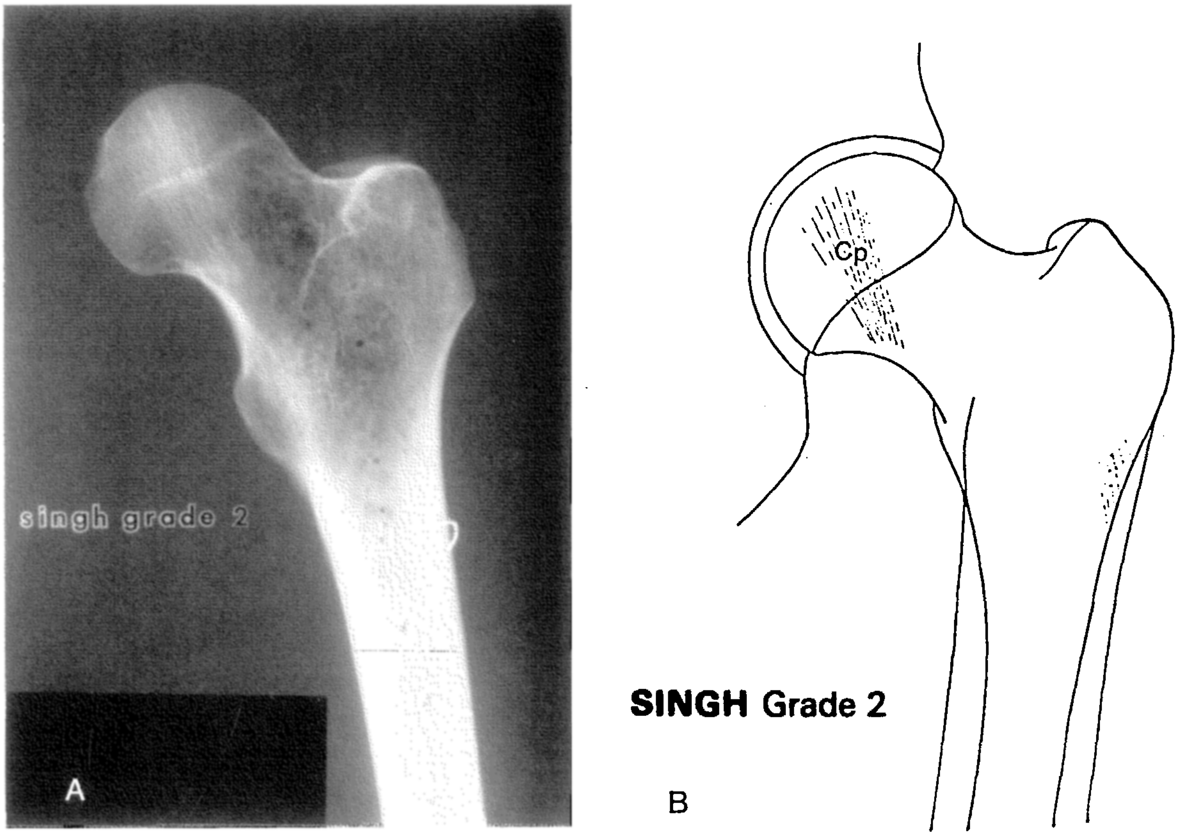


Fig. 5. (A) Roentgenograph representing Singh grade 2 with (B) corresponding diagram showing that except for the primary compressive group (Cp), all remaining trabeculae have faded.

with a Singh grade of 5 or 6 was judged to have characteristics consistent with good quality bone stock. These bones were represented by scores of 9.

Because a thick calcar is another characteristic shown to be a clinically favorable trait of bone stock, bones with clinical calcar thickness greater than 5 mm received an extra bonus point. An optimal bone for transplant would, therefore, have a bone score of 10. Reasoning that bones with scores of 8 and 9 probably would have good quality bone stock, as they represent bones in the upper $\frac{1}{3}$ of bone quality, these bones were also designated as optimal for collection and transplantation. For bones scoring 7 and 6 caution was advised to use further evaluation by conducting DPA before use in transplantation. Bones scoring less than 5 were considered to have bone stock quality below optimal and were not recommended for transplantation.

Results

Table 2 presents a tabulation of the results. Bones 1–7 had Singh grades of 5, were type A bone according to both the CC ratio and cortical shaft index, and had calcar widths greater than 5 mm. For those reasons, these bones received radiographic bone scores of 10. Bone mineral densities obtained by DPA also placed bones 1–7 well above 90% young normal.

Bones 8 and 9 were both type A bone by the CC ratio and cortical shaft index and had calcar widths greater than 5 mm. These bones scored a Singh grade of 4, which reduced the overall bone score to 9, a score still considered to represent bone stock that is satisfactory for transplantation. Although the radiographic scoring for the bones was identical and both bones had percent young normal values above 90%, bone 8 had a percent young normal value considerably higher than bone 9 (121.3% vs. 90.4%, respectively).

Interestingly, bone 10 had type A bone by the cortical shaft index, but type B bone by the CC ratio. Bone 10 also scored high on the Singh index and the calcar width, giving it a bone score of 9. The bone was recommended as being acceptable for transplantation by both roentgenographic bone score and DPA criteria.

Bones 11 and 15 were type A bones with moderate Singh grades, giving them bone scores of 8 and therefore designating them as acceptable transplant mate-

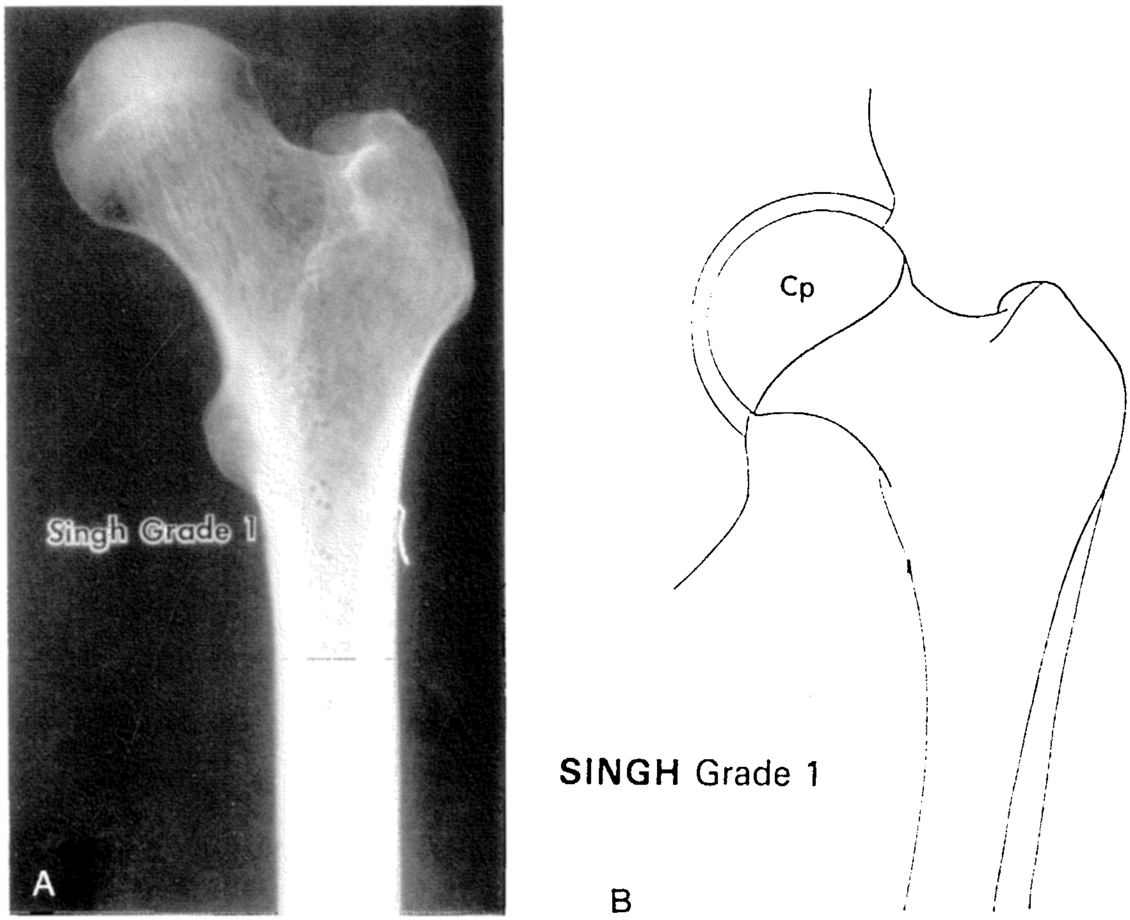
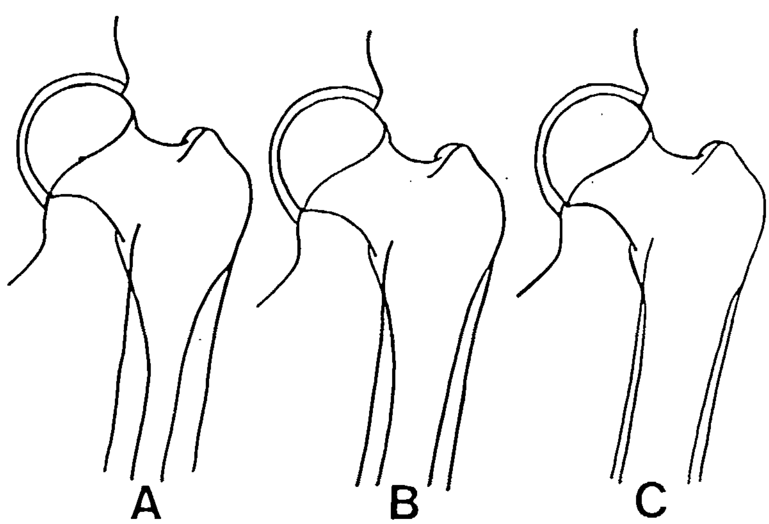


Fig. 6. (A) Roentgenograph representing Singh grade 1 with (B) corresponding diagram showing that only remnants of the primary compression groups (Cp) can be observed. The remaining trabecular groups can no longer be seen.

Fig. 7. Three types of bone as classified by Dorr et al.[8] Type A bone has thick cortices and a funnel appearance on roentgenograph. Type B bone has thinner cortices and has therefore lost some of its funnel-shaped appearance. Type C bone has thin cortices with an enlarged cortical shaft and a tunnel-like appearance.



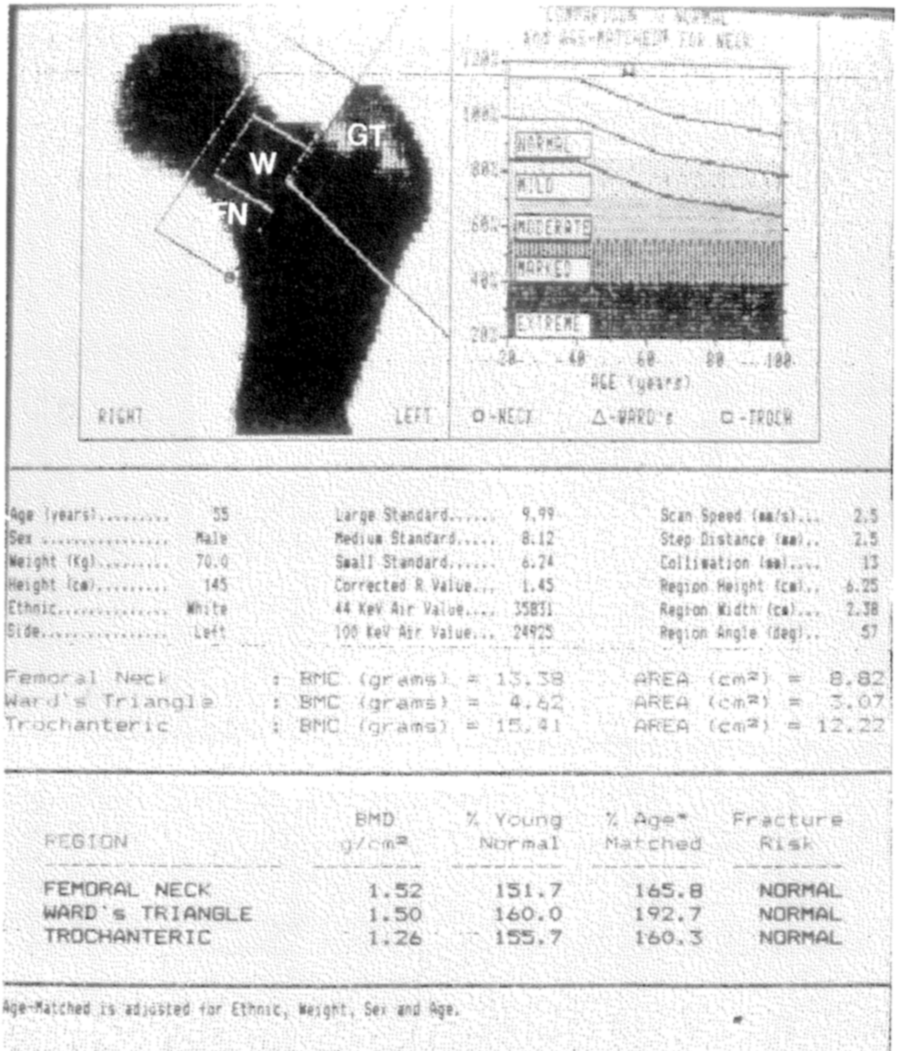


Fig. 8. Sample computer printout of bone analyzed using dual-photon absorptiometry with bone mineral density values and corresponding percent young normal values. The actual grades and dual-photon absorptiometry information for each femur used in this study are included. The percent young normal represents comparisons to normal subjects aged 20–40 years. The femoral neck (FN), Ward's triangle (W), and the greater trochanter (GT) were the regions analyzed.

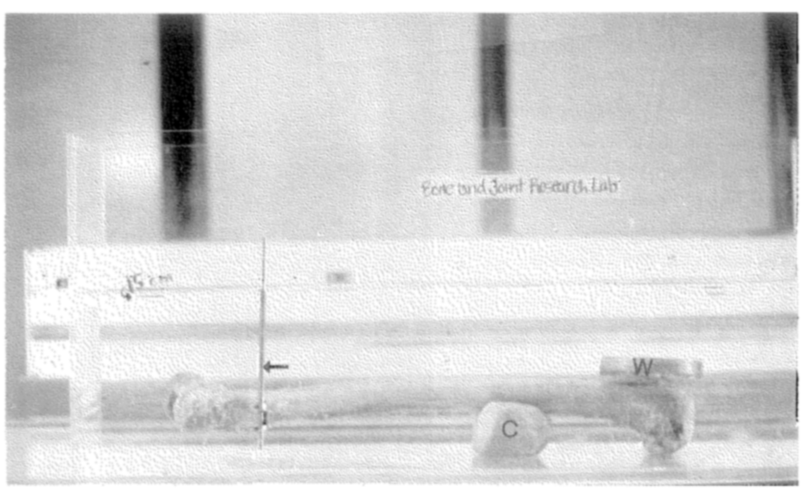


Fig. 9. Femur placed under 15 cm of water to simulate soft tissue. The bone is in the anteroposterior position with weight (W) placed on the bone to assure the condyles remain flat during radiographing. Modeling clay (C) assures the femur is held level. Alignment device (arrow) was used to keep the shaft of the femur parallel to the table.

Table 2. Donor, Radiographic, and Dual-photon Absorptiometry Data

Bone No.	Donor Bone Information		Radiographic Data					Dual-photon Absorptiometry Data			
								Percent Young Normal			
	Age	Sex	Singh Grade	Bone Type by CC Ratio	Bone Type by Cortical Shaft Index	Calcar Width (mm)	Bone Score	FN (%)	WT (%)	Troch. (%)	Average (%)
1	41	M	5	A	A	9	10	122.9	120.8	133.3	125.7
2	43	M	5	A	A	6	10	132.5	132.7	140.0	135.1
3	51	M	5	A	A	7	10	104.2	83.4	132.9	106.8
4	56	F	5	A	A	7	10	111.7	100.7	131.9	114.8
5	51	M	5	A	A	8	10	105.7	92.1	121.4	106.4
6	41	M	5	A	A	10	10	131.6	131.9	143.6	135.6
7	56	F	5	A	A	7	10	114.6	101.9	137.5	118.0
8	50	M	4	A	A	10	9	119.7	103.6	140.7	121.3
9	52	M	4	A	A	7	9	89.4	66.2	115.6	90.4
10	33	M	5	B	A	6	9	94.7	85.6	103.3	94.5
11	30	M	3	A	A	10	8	147.1	148.7	156.7	150.8
12	50	M	4	B	A	7	8	124.0	124.7	145.3	131.3
13	32	F	5	C	A	7	8	116.3	102.5	119.0	112.6
14	43	M	5	C	A	7	8	128.0	111.6	137.3	125.6
15	30	M	3	A	A	9	8	151.7	160.0	155.7	155.8
16	32	F	5	C	A	6	8	104.4	100.6	116.4	107.1
17	61	M	3	A	A	5	7	73.2	62.8	85.6	73.9
18	24	M	5	C	A	5	7	123.8	128.6	140.5	131.0
19	51	M	5	C−	A	7	7	105.7	95.9	115.5	105.7
20	61	M	3	A	A	5	7	82.0	68.5	85.9	78.8
21	33	M	5	C−	B	6	7	88.7	80.2	99.3	89.4
22	24	M	5	C	A	4	7	124.5	131.1	128.6	128.1
23	29	M	6	C−	A	7	7	235.3	129.4	142.1	135.6
24	54	M	5	C−	B	6	6	95.6	71.1	100.0	88.9
25	29	M	6	C−	B	7	6	151.4	150.9	150.4	150.9
26	51	M	5	C−	B	7	6	101.8	82.4	135.7	106.6
27	54	M	5	C−	B	5	5	87.1	72.2	97.2	85.5
28	52	M	5	C−	C	6	5	85.0	60.6	99.0	81.5
29	32	M	2	C−	B	4	4	99.6	95.0	96.0	96.9
30	32	M	2	C−	B	4	3	104.1	101.7	92.2	99.3

Percent young normal represents comparisons to normal subjects aged 20–40 years. FN, femoral neck; WT, Ward's triangle region; Troch, greater trochanter region; CC ratio, calcar isthmus to canal isthmus.

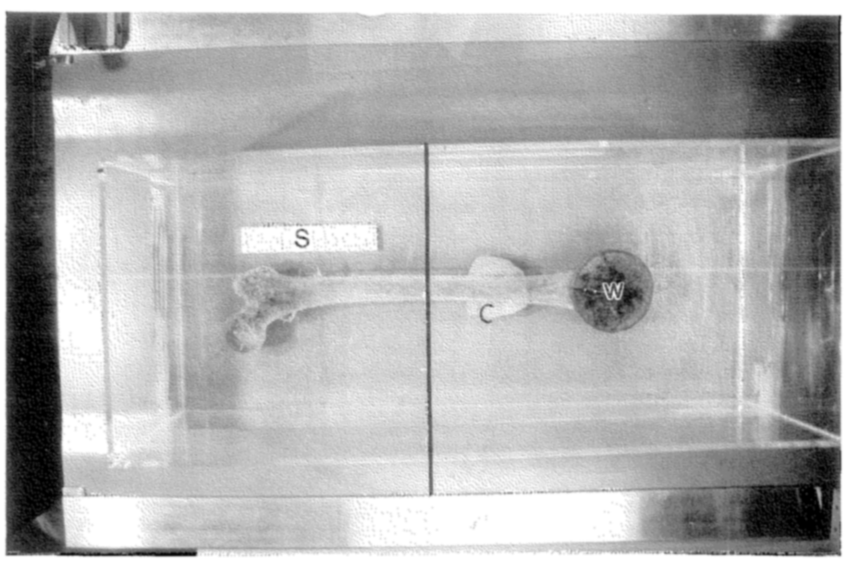


Fig. 10. Top view of tank on x-ray table showing placement of the high-resolution aluminum stepwedge (S). Only the proximal femur (region left of line) was radiographed for analysis and grading. Modeling clay (C), weight (W).

Fig. 11. Roentgenogram from pilot studies with high-resolution aluminum stepwedge (S) placed under thigh near the proximal femur. Note the distinct graylevel changes apparent on the stepwedge. First step (1), last step (13).

rial. These bones were also deemed acceptable by DPA criteria, with high percent young normal values of 150.8% and 155.8%, respectively.

Bones 13, 14, and 16 had Singh grades of 5, thick calcars (>7 mm), and type A bone by the cortical shaft index; however, they were rated as type C bone by the CC ratio. Using the bone scoring system, all received scores of 8, which is sufficient for being selected for transplantable material. This corresponded well with the percent young normal data, as these bones had values ranging from 107.1% to 125.6%.

When analyzing the data for the four bones that were rated as poor using the bone scoring system, bones 27 and 28 also had percent young normal values below 90%. Bones 27 and 28 had high Singh grades, were worse than type C bone by the CC ratio, and had type B or C bone by the cortical shaft index. Bone 28 received a bonus point for a thick calcar, but the overall bone score was still not high enough to place it in an acceptable category.

Closer examination of the two bones with low bone scores but acceptable percent young normal values (29 and 30) showed that both of these bones had low Singh grades, thin calcars, type C or worse bone by the CC ratio, and type B bone by the cortical shaft index. It is interesting to note that despite such obviously poor morphological features, these bones still managed to rate high enough for transplantation by DPA standards. In the good and bad categories these were the only two bones in which the bone score and DPA data were contradictory.

Bones that fell in the intermediate or "caution" zone by the bone score had DPA data ranging from as low as 73.9% young normal to as high as 150.9% young normal. This suggests that some bones may require further assessment prior to processing for transplantation.

Statistical analysis showed that the bone score and DPA are positively correlated ($r = 0.332$). This correlation coefficient is significantly greater than zero with 95% confidence (the P value lies between .025 and .05). While this does not indicate a strong relationship between the two measures, the positive correlation coefficient indicates that if the bone score is

Table 3. Four Radiographic Indices Used, Corresponding Scores, and Weighted Assessment Technique

Singh Grade	Singh Grade Points	CC Ratio	CC Ratio Points	Cortical Shaft Index	Cortical Shaft Index Points	Calcar Width	Calcar Width Points
1	0	worse than type C bone	0	worse than type C bone	0	≤0.5 mm	0
2, 3	1	type C bone	1	type C bone	1	>0.5 mm	1
4	2	type B bone	2	type B bone	2	>0.5 mm	1
5, 6	3	type A bone	3	type A bone	3	>0.5 mm	1
		Total Score	≤5 points	6–7 points	≥8 points		
			Bad Quality Bone Stock DISCARD	USE CAUTION Further Analysis Needed	Good Quality Bone Stock KEEP		

After the bones are graded, a final score is assigned to determine if the bone tissue should be collected. Total score = Singh grade points + CC ratio points + cortical shaft index points + calcar width points. CC ratio, calcar isthmus to canal isthmus.

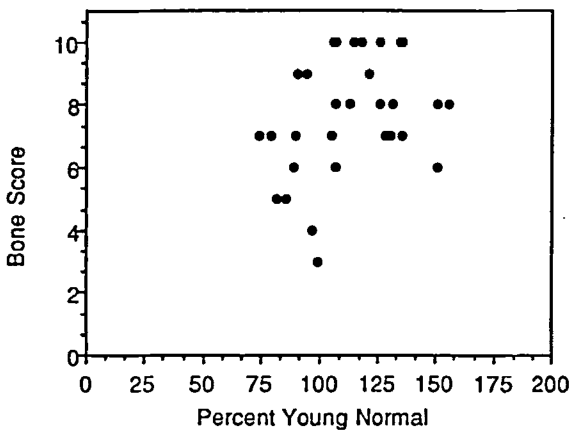


Fig. 12. Scatterplot of bone scores versus average percent young normal values. Relationship between average percent young normal values calculated using dual-photon absorptiometry and bone scores.

high, DPA is also likely to be high. A scatterplot of the bone score and DPA (Fig. 12) shows the relationship between the two measures.

Using the bone score to determine the suitability of a donor bone for transplant could result in two possible errors: (1) when the bone score concludes that a bone is suitable when in fact it is unsuitable because it has suboptimal bone mineral content (when DPA is less than 90% young normal) and (2) when the bone score concludes a bone is unsuitable when in fact it is suitable, meaning that a potentially good donor bone was discarded when it could have been used for transplant.

The probabilities of making these errors should be evaluated as part of the decision as to whether the bone score could replace DPA. The true probabilities are unknown but can be estimated from the sample data. In the sample of 30 bones, 24 were designated to be suitable by DPA and 6 were designated unsuitable. To compute an estimate of the probability of making the first error, we look at the proportion of unsuitable bones declared to be suitable by the bone score:

P[bone score concludes suitable when bone is really unsuitable (by DPA)] = 0/6 = 0%.

This figure of 0% is an estimate of the true probability that the bone score would designate an unsuitable bone to be suitable. A 95% confidence upper bound on this estimate is .393.[23] In other words, one could conclude with 95% confidence that the true proportion of unsuitable bones found to be suitable using the bone score is between 0% and 39.3%. The large length of this interval is due to the small sample size of unsuitable bones[6] found in this study.

Table 4. Summary of Bone Score and Dual-photon Absorptiometry Data Used for Statistical Analysis

Bone Score	Good (>90% YN)	Bad (<90% YN)	Total
8–10	16	0	16
6–7	6	4	10
0–5	2	2	4
Total	24	6	30

YN, young normal.

To compute an estimate of the probability of making the second error, we look at the proportion of suitable bones declared to be unsuitable by the bone score:

P[bone score concludes unsuitable when bone is really suitable (by DPA)] = 2/24 = 8.33%.

This figure of 8.33% is an estimate of the true probability that the bone score would designate a suitable bone to be unsuitable. A 95% confidence interval on this estimate is (.0103, .2700).[23] In other words, one could conclude with 95% confidence that the true proportion of suitable bones found to be unsuitable using the bone score lies between 1.03% and 27.00%. Table 4 summarizes the data in a two-way contingency table for the statistical analyses described above.

Discussion

The aim of this study was to test the hypothesis that a standardized roentgenographic technique and weighted scoring system, using characteristics of bone morphology,[3,6–8,15,19,30] could, with reasonable accuracy, predict the quality of the bone stock in the proximal femur as determined by BMDs measured using DPA.[20,21,26] This hypothesis was supported by the results presented. Using this new bone scoring system we identified 67% (16 of 24) of the bones with percent young normal values greater than 90% to be suitable for transplant, 8.3% (2 of 24) to be unsuitable for transplant, and the remaining 25% (6 of 24) to be in a "caution" zone. Of the six bones whose percent young normal values were less than 90%, the bone scoring system showed that none were considered suitable for transplant, (2 of 6) were labeled unsuitable for transplant, and the remaining (4 of 6) fell in the "caution" zone. We acknowledged that it is better to err on the side of caution, with the exclusion of "potentially good" bones rather than the inclusion of "bad" bones. However, it should be kept in mind that the "good" bones that were excluded by BMD standards actually had radiographically poor morphological features, and for this reason alone could be considered unacceptable allograft tissue. Consequently, the method described for prescreening donors bones allows for the relaxation of strict donor age standards that could potentially result in a substantial increase in the overall yield of usable tissue harvested by bone banks.

"Bone quality" continues to be a nebulous concept to most surgeons using allograft tissue. In an attempt to clarify this, Stulberg et al.[31] recently reported that bone histomorphometric standards would be the ideal method for assessing bone quality. However, their method of assessment would not be a feasible screening tool when harvesting allograft bone tissue because of the time and sophisticated facilities needed to conduct these histologic analyses. In contrast, the bone scoring method described in this study was designed to enable harvest teams to obtain increased amounts of allograft tissue with increased efficiency (in terms of both cost and time). It is suggested that allograft tissue obtained by the roentgenographic bone scoring method would also increase the likelihood that good quality bone is obtained because all four of the indices used are considered to correlate strongly to a bone's ability to carry *in vivo* loads[3,6,8,15,30] Additionally, the CC ratio and cortical shaft index have been shown to predict good to excellent clinical results in joint arthroplasty,[6,8] and the CC ratio has been shown to correlate with favorable histomorphologic features.[6] A number of authors have also shown significant correlation between measures of femoral neck BMD and the mechanical strength of this region.[1,4,18,29,32] Consequently, the positive correlation between DPA data (considered by some to be the clinical gold standard for BMD) and the weighted bone scores further supports the suggestion of an increased probability in obtaining good quality bone, in addition to increased bulk amount of bone, when using the roentgenographic bone scoring method.

It is interesting to note that a 32-year-old donor (bone 29) who met all the standard donor criteria established by the American Association of Tissue Banks (Table 1) was considered to have poor quality bone stock using the roentgenographic bone scoring system, but had adequate BMD according to DPA analysis (Table 2). A 56-year-old donor (bone 7), although ineligible for transplantation according to current donor criteria, was determined to have good quality bone stock as reflected by a high bone score and correspondingly high BMD values (Table 2). These results suggest that age limitations used by many bone banks to screen their donors may not assure good quality bone stock in proximal femora.

This study also raises an important question for prescreening donor femora: which of the bone grading systems (DPA or roentgenographic bone score) used in this study is actually more reflective of a bone's ability to carry *in vivo* loads? The DPA method of assessment appears limited at this time because it examines only the neck and greater trochanteric region of the femur. The advantages of the roentgenographic bone scoring technique are that it takes into account the cortical bone morphology of the proximal femur as well as the trabecular portion of the head and neck areas while estimating the relative amount and distribution of cortical and cancellous tissues. Furthermore, DPA devices like the one used in this study are currently expensive and investigational, requiring trained technicians.[20,21,26] It is therefore highly unlikely that DPA devices will be standard equipment at most hospitals in the near future or that bone retrieval teams and orthopaedic surgeons will be experienced in the application of this technology.

In contrast, using imaging equipment that is standard in hospitals, the roentgenographic scoring technique provides a simple method for the screening of donor bones before harvest or before surgery. It is suggested that this method will help keep pace with the burgeoning demand for transplantable bone tissue[11,14,24,34,35] while assuring good quality bone stock for the surgeon and patient.

Kits containing the materials necessary to utilize the roentgenographic scoring method at the actual retrieval site are now available. These kits were distributed to bone retrieval teams in 1989 and 1990 and are now being used in over 30 hospitals across the United States. The age limitation for bone tissue donation in certain institutions has been increased to 65 years, and the bone kit is being used at these institutions to evaluate femora of all donors between the ages of 45 and 65 years who otherwise meet all of the American Association of Tissue Banks' criteria for donation. In a recent 10-month period, the use of the described method has resulted in a 60% increase in the total donor yield of acceptable allograft tissue.

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