ORIGINAL ARTICLE

Test-Retest Reliability of Isokinetic Knee Extension and Flexion

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ABSTRACT. Sole G, Hamrén J, Milosavljevic S, Nicholson H, Sullivan SJ. Test-retest reliability of isokinetic knee extension and flexion. Arch Phys Med Rehabil 2007;88:626-31.

Objective: To assess reliability of isokinetic peak torque and work for knee flexion and extension.

Design: Single-group test-retest.

Setting: University laboratory.

Participants: Eleven men and 7 women (mean age, 21y).

Interventions: Not applicable.

Main Outcome Measure: Peak torque and work for concentric and eccentric knee extension and flexion were recorded at 60°/s for 3 trials on 2 occasions. Intraclass correlation coefficient model 3,1 ($ICC_{3,1}$), standard error (SE) of measurements, and smallest real differences were calculated for the maximum and for the mean peak torque and work of the 3 repetitions.

Results: Relative reliability was "very high" for peak torque and work (ICC range, >.90). The SE measurements ranged between 5% and 10% of the initial values for both peak torque and work. The smallest change that indicates a real improvement for a single subject (smallest real differences) ranged from 12% to 25% for peak torque and work variables and from 25% to 30% for the peak torque ratios.

Conclusions: Isokinetic concentric and eccentric knee extensor and flexor strength variables are reliable when measured by the same examiner in asymptomatic subjects.

Key Words: Exercise therapy; Knee injuries; Rehabilitation; Reproducibility of results; Thigh; Treatment outcome.

ISOKINETIC DYNAMOMETRY IS A method commonly used in the assessment of muscle performance and pathology, both in research and in clinical practice.[1] To be clinically meaningful, the assessment procedure must be reliable and sensitive enough to assess whether a finding indicates impairment, and to evaluate outcomes of therapeutic intervention. Values must be defined so as to provide guidance in deciding whether an observed change on reassessment is within the boundaries of assessment error or whether there has been a true change.

Most studies of the test-retest reliability of isokinetic knee strength[2-7] have reported only *relative* reliability, such as the intraclass correlation coefficient (ICC). These statistics indicate the degree of the relationship between 2 or more measures,[8] but they do not provide clinical guidance for assessing real changes.[9,10] *Absolute* reliability reflects the magnitude of the differences between 2 measures.[11] Examples of these statistics are the standard error (SE) of measurement and the smallest real difference.[9,12,13] To be clinically useful, an assessment procedure must have a small measurement error to detect a real change. A retest difference in a subject with a value smaller than the SE of measurement is likely to be the result of "measurement noise" and is unlikely to be detected reliably in practice; a difference greater than the smallest real difference is 95% likely to be a real difference. A retest difference that lies between the SE of measurement and smallest real difference is less certain (between 68% and 95%), whether or not there is a real difference.[11] It has been suggested that the SE of measurement can be used to indicate the limit for the smallest change that indicates a real improvement for groups of subjects, whereas for a single person, any retest measurement should exceed the smallest real difference to indicate a real change.[9]

Previous reports[13-15] have suggested "high" to "very high" relative reliability for peak torque and work for the knee extensors and flexors. Absolute reliability has been documented in only a few studies related to isokinetic parameters of knee muscles.[16,17] These studies determined the SE of measurement for peak torque of knee flexors and extensor during concentric reciprocal movements, ranging between 2.4 and 18.0Nm or 4.8% and 12.4% of the means.[15-17] The absolute reliability of eccentric knee extensor and flexor contractions has not been determined, thus the smallest change necessary to indicate a real change is unknown.

Clinicians often use ratios of quadriceps and hamstring muscle peak torques to determine risk of injury or whether an athlete can safely return to a sport. Two ratios have been described, namely, the *conventional* ratio (Hc:Qc), which calculates the ratio between *concentric* hamstring peak torque to concentric quadriceps peak torque, and the *dynamic control* ratio (He:Qc), which calculates the ratio between *eccentric* hamstring peak torque and concentric quadriceps peak torque.[1,18] To our knowledge, however, both the relative and the absolute reliability of these ratios have not been determined.

Our objectives in this study were to determine the relative and absolute test-retest reliability of: (1) peak torque and the work for isokinetic concentric and eccentric knee extension and for concentric and eccentric flexion in uninjured subjects, and (2) of the Hc:Qc and He:Qc ratios.

METHODS

Subjects were included in the study if they participated in elite, subelite, or recreational running-related sports at least twice weekly and, at the time of testing, were participating fully in their planned sports training and/or competition. Ex-

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clusion criteria included having sustained a lower limb, pelvic, or back injury in the past 6 months that prevented them from participating in their training for more than 1 week, or if they had any neurologic or systemic disease affecting a lower limb. They were asked not to do any strenuous exercise in the 48 hours preceding each testing day. Subjects underwent a musculoskeletal screening examination before the study to confirm their eligibility. All subjects read and signed an informed consent document approved by the University of Otago Human Ethics Committee.

Instrumentation

We used the Kinetic Communicator (KinCom) 500H isokinetic dynamometer and the KinCom system software[a] to determine the peak torque and the work performed during the knee extension and flexion movements. The dynamometer was calibrated according to the manufacturer's instructions before the testing. The system reliability of the KinCom dynamometer has been shown to be high, with ICCs of .99, .99, and .95 for the functions of lever arm position, lever arm velocity, and force measurement, respectively.[19]

Procedures

The same test procedure was performed on 2 separate occasions (day 1, day 2), 7 days apart. This time period between tests was used in previous studies of the reliability of isokinetic parameters.[20] Furthermore, subject-linked variability is more likely to be controlled if testing is conducted on the same weekday relative to their respective sports programs. The tests were conducted during the same time of the day in order to reduce the effect of diurnal variation influences.

We tested only the dominant leg, defined as the preferred kicking leg. Subjects were seated in a comfortable position with the backrest angled at 100° to the seat. Self-adhesive (Velcro) straps were placed across the thigh, the pelvis, and chest to minimize body movements and to optimally isolate the movement to the knee joint.[1,21] Subjects folded their arms across their chest and were not permitted to hold on to the equipment during the test. The mechanical axis of the dynamometer was aligned with the knee's axis of rotation, with the lateral femoral epicondyle used as the bony landmark. The shin pad was placed 2cm above the medial malleoli and the length of the lever arm was recorded. The weight of the leg was recorded and gravity adjustment was made using the computer software. The range of movement was from 0° (anatomic 0) to 85° of knee flexion.

Subjects performed 10 consecutive submaximal and 2 maximal concentric and eccentric contractions as a specific warm-up and also to become familiar with the movement. There was a 1-minute break between the warm-up and the testing.

Three concentric and eccentric maximum knee extensions were performed at 60°/s.[22] Each concentric contraction was followed by an eccentric contraction,[23-25] with a 15-second rest between the contractions.[23,26] Subjects were instructed to extend the knee against the shin pad during concentric extensions and to resist the lever during eccentric extension. The dynamometer was then set for knee flexion and the same procedures were followed during the specific warm-up and data collection. Subjects were instructed to flex the knee during concentric flexion and to resist the dynamometer during eccentric flexion.

To reduce examiner variability, the same investigator (GS) conducted the tests for all subjects on both occasions. Subjects were told to abort the test if they felt any discomfort or pain. During the test, all subjects were given visual feedback from the system's monitor. They were also verbally encouraged by the investigator to give their maximal effort.

Measures

Two variables were extracted for each of the direction (flexion, extension) and contraction types (concentric, eccentric): peak torque measured in newton meters, and work measured in joules. The peak torque is the single highest torque output recorded throughout the range of motion of each repetition.[27] Work is defined as the output of mechanical energy and is represented by the area under the torque versus angular displacement curve.[27] It is thus a "whole curve" parameter, rather than a "peak" or "single-point" parameter.[28] In addition to presenting absolute measures of peak torque and work, these variables were normalized to body weight (in kilograms); this method has been used when comparing different groups of subjects[24,29] and in determining outcomes of rehabilitation regimens.[22]

Statistical Analysis

From each set of 3 repetitions, we determined the means and maxima of the variables for each participant. Mean peak torque data were used to calculate the Hc:Qc and He:Qc. Group data are presented as mean ± standard deviation (SD). We used paired *t* tests to examine the differences between test and retest values. The significance level was set at P equal to .05. Data were analyzed using the $ICC_{3,1}$ with 95% confidence intervals (CIs) to determine relative reliability across the 2 test sessions for the respective movement directions and for the conventional and functional ratios.

Absolute reliability was determined with the SE of measurement and smallest real difference. These were calculated with the following formulas:[8,12,30] SE of measurement $= SD\sqrt{(1-ICC)}$, where SD is the mean SD of day 1 and day 2 to represent total measurement variability[8,15]; and smallest real difference $= 1.96\times\sqrt{2}\times$(SE of measurement). The SE of measurement and smallest real difference were also expressed as a percentage of the group mean for both test sessions for each of the variables.[9,15]

We calculated differences between day 1 and day 2 for all variables for each participant. The agreements between measurements of day 1 and day 2 were verified qualitatively using Bland and Altman plots.[31] All statistics were performed using SPSS.[b]

RESULTS

Twenty healthy subjects (13 men, 7 women) volunteered for this study. Two men (aged 22y and 35y) did not attend the second session because of a soccer-related injury and a work commitment, respectively, and were excluded from the study. The mean age ± SD for the 11 men was 20±1 years and for the women it was 22±3 years. The mean body mass index ± SD for the men was 23.0±2.5kg/m^2 and for the women was 22.3±2.6kg/m^2. Two of the men were experienced in resistance training but none of the subjects was familiar with isokinetic dynamometry.

Table 1 shows the means and SDs of the peak torque and work measures. There were statistically significant differences ($P<.05$) between the values of day 1 and day 2 for maximal and mean peak torque and work of concentric extensor contractions. Table 2 shows the ICC values and their 95% CIs for all measurements. All peak torque and work measures had an ICC greater than .90 and thus were classified as "very high," with the exception of work for the maximal concentric flexion (ICC=.88).[32]

The ICC for Hc:Qc was "low," but was "high" for the He:Qc. The means ± SDs of the Hc:Qc on day 1 and day 2 were 62.84%±9.15% and 62.52%±0.41%, respectively. For the

Table 1: Summary of Isokinetic Peak Torque and Work at 60°/s on 2 Occasions (N=18)

Test Measurement	Peak Torque (Nm)			Work (J)		
	Day 1 Mean ± SD	Day 2 Mean ± SD	*P*	Day 1 Mean ± SD	Day 2 Mean ± SD	*P*
Concentric extensor contraction						
Maximal*	121.39±30.53	132.11±31.45	.009	115.56±26.37	125.50±26.53	.005
Mean†	114.08±29.08	123.31±28.69	.004	110.53±26.50	119.08±27.46	.002
Concentric flexor contractions						
Maximal*	77.39±20.62	81.28±21.91	.158	86.5±21.33	92.61±26.06	.112
Mean†	71.18±18.82	76.71±20.03	.189	82.20±19.85	87.73±23.70	.056
Eccentric extensor contractions						
Maximal*	182.28±50.25	181.06±43.35	.989	162.28±37.31	162.44±33.88	.988
Mean†	172.49±48.44	169.70±43.05	.726	155.67±38.24	155.44±36.12	.944
Eccentric flexor contractions						
Maximal*	94.44±26.25	94.00±27.43	.616	105.00±29.90	107.83±31.98	.472
Mean†	86.77±23.56	88.98±27.87	.785	97.82±28.81	102.06±31.55	.250

*Maximum of 3 repetitions; †mean of 3 repetitions.

He:Qc, means were 76.27±13.66 on day 1 and 72.37±13.51 on day 2. The reliability statistics of these parameters are shown in table 2.

Bland-Altman[31] plots for mean peak torque of concentric and eccentric extension and flexion contractions (fig 1) illustrated a random relationship between the individual differences and the averages of the 2 testing sessions. The bias represents the average difference between day 1 and day 2 for the subjects, with a negative figure indicating that day 2 had a higher value than day 1. There were similar findings for plots of work (not illustrated here).

DISCUSSION

Our subjects formed a heterogeneous group with regard to sex, experience with strength testing and training, and sports backgrounds and were a reflection of patients most commonly seen by clinicians at the community level. The men were generally stronger than the women, as is apparent from the Bland-Altman plots (see fig 1). No other systematic differences existed between the sexes, however, thus we pooled the reliability statistics for the men and the women.

Correlations from .50 to .69 have been described as being "moderate," those from .70 to .89 as being "high," and from 0.9 and above as being "very high."[32] The ICC values for peak torque that we found can thus be described as being "very high" and in agreement with results of earlier studies with healthy, uninjured subjects.[6,16] Phillips et al[6] found slightly higher ICC values for the extensor and flexor maximal peak torque of 3 contractions (.98 for both directions). Harding et al[16] also found high ICC values (.95) and lower SE of measurement (2.40−5.46Nm) scores for peak torque when testing concentric knee flexion and extension. These 2 studies[6,16] used reciprocal movements, that is, concentric extension followed by concentric flexion, and Harding[16] used the average score of 6 contractions as opposed to 3. The SEs of measurement of the concentric contractions that we found were similar to those found by Pincivero et al,[17] ranging between 6% and 10% of the average scores.

Table 2: Reliability of Isokinetic Concentric and Eccentric Knee Measurements (N=18)

Test Measurement	Peak Torque					Work				
	ICC (95% CI)	SEM (Nm)	SEM%	SRD (Nm)	SRD%	ICC (95% CI)	SEM (J)	SEM	SRD (J)	SRD%
Concentric extension contractions										
Maximal*	.93 (.81−.97)	8.21	6.48	22.75	17.95	.94 (.83−.98)	6.50	5.39	18.01	14.94
Mean†	.95 (.85−.98)	6.45	5.44	17.88	15.07	.96 (.88−.98)	5.12	4.45	14.19	12.34
Concentric flexion contractions										
Maximal*	.93 (.80−.97)	5.57	7.02	15.45	19.47	.88 (.69−.96)	8.20	9.16	22.73	25.38
Mean†	.94 (.83−.98)	4.74	6.41	13.14	17.78	.91 (.76−.97)	6.55	7.73	18.15	21.42
Eccentric extension contractions										
Maximal*	.93 (.81−.97)	12.24	6.74	33.92	18.67	.95 (.87−.98)	7.87	4.84	21.81	13.43
Mean†	.94 (.85−.98)	11.20	6.54	31.04	18.14	.96 (.90−.98)	6.86	4.37	19.01	12.12
Eccentric flexion contractions										
Maximal*	.94 (.85−.98)	6.48	6.88	17.97	19.07	.94 (.84−.98)	7.46	7.00	2.69	19.41
Mean†	.92 (.79−.97)	7.20	8.20	19.19	22.72	.93 (.80−.97)	7.82	7.83	21.66	21.70
Hamstring to quadriceps peak torque ratios										
Hc:Qc	.43 (.00−.77)	6.91	11.02	19.15	3.55					
He:Qc	.73 (.28−.90)	7.61	1.24	21.09	28.38					

Abbreviations: SEM, standard error of measurement; SEM%, SEM as percentage of group average; SRD, smallest real difference; SRD%, SRD as percentage of group average.
*Maximum of 3 repetitions; †mean of 3 repetitions.

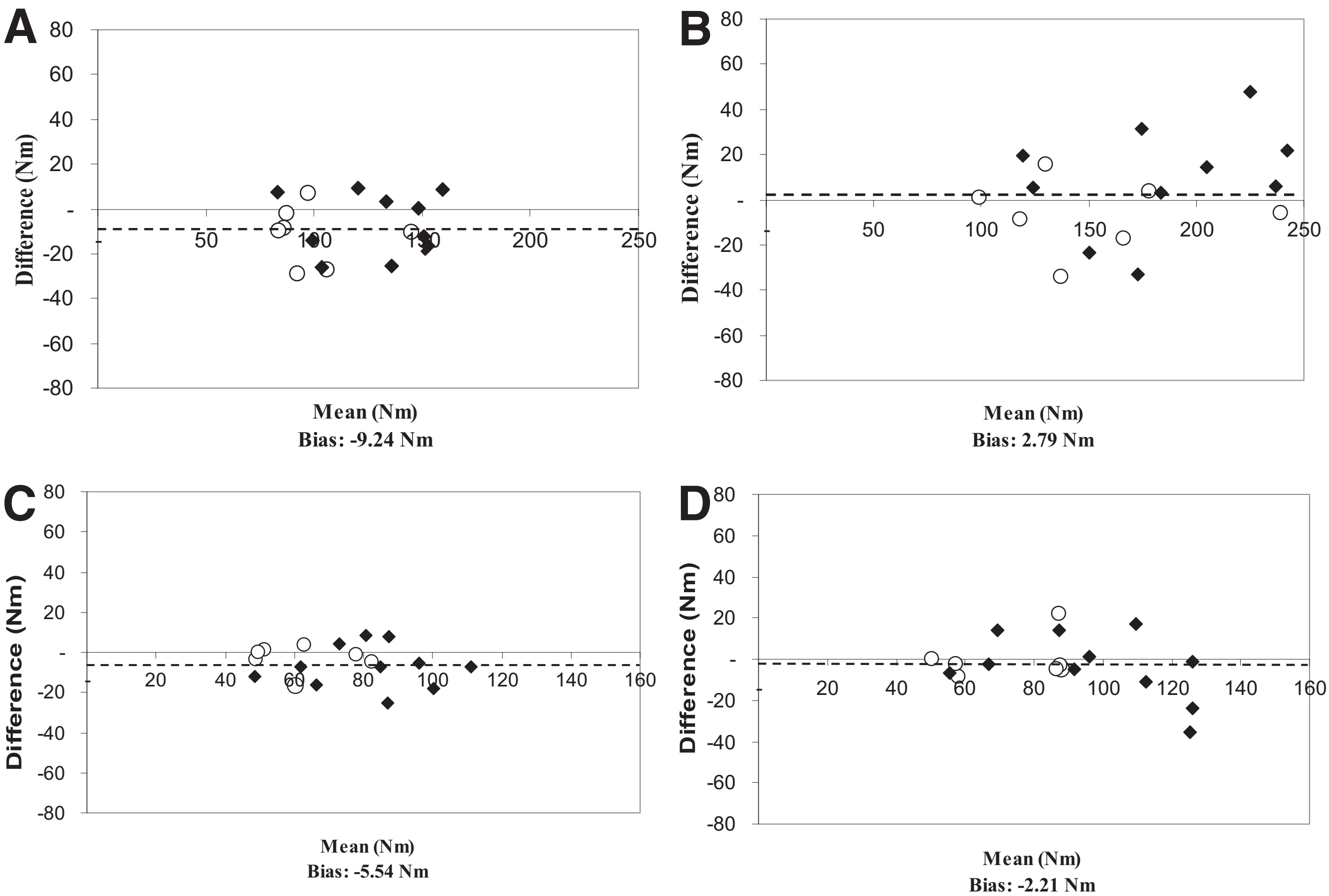

Fig 1. The differences between day 1 and day 2 sessions plotted against the means of the 2 test sessions for the peak torque of the men (◆) and the women (○): (A) concentric extensor contractions; (B) eccentric extensor contractions; (C) concentric flexor contractions; and (D) eccentric flexor contractions.

When interpreting changes in variables on reassessment after an intervention, clinicians must decide whether a true change has occurred or whether the changes reflect measurement noise or assessment error. If the change is less than the SE of measurement (and percentage of SE of measurement), it is most likely that the change reflects measurement noise and is unlikely to be of clinical significance. Based on the percentage of SE of measurement we found in this study, differences less than 8% and 10% for peak torque and work, respectively, should be considered to be measurement noise and most likely to be meaningless. Alternatively, the magnitude of a retest difference that is less than the SE of measurement and percentage of SE of measurement cannot be reliably determined. A retest difference that lies between the SE of measurement and smallest real difference is less certain (between 68% and 95%), whether or not there is a real difference.[11] For concentric extension, concentric flexion, and eccentric extension peak torque differences between 8% and 20%, a clinical decision about whether a real change has occurred would be needed, taking into account all aspects of patient assessment (eg, prior familiarity with testing procedures). For eccentric flexion peak torque and all work measures, this would apply for differences up to 25%. Based on the percentage of smallest real difference in this study, a general guideline would be that a change of 15% to 20% is necessary for peak torque of concentric and eccentric extension and concentric flexion, and up to 23% for eccentric flexion peak torque to be 95% confident that there has been real change. For work measures, this difference is 12% to 15% for concentric and eccentric extension, but is 19% to 25% for concentric and eccentric flexion.

Reliability of eccentric flexion contractions has not been previously reported and our findings indicate that these also have a "very high" reliability for peak torque and work measures. There were no statistically significant differences for the group means of eccentric extensor and flexor peak torque and work between the 2 occasions. This differed from the differences found for peak torque and work for concentric extensor contractions. Subjects often reported that they found the eccentric contractions more difficult to perform than the concentric contractions in both movement directions. Eccentric contractions thus may require more skill and motor control. The increased group means of the variables for the concentric extensor contractions may indicate a learning effect for these among some of the subjects.

For both peak torque and work measures, the ICCs of mean variables (ICC range, .91−.96) were slightly higher than for the maximal variables (ICC range, .88−.95), with the exception of eccentric flexion contractions. There was a similar pattern for SE of measurement and percentage of SE of measurement, but these differences were very small. Because of the small differences in reliability, clinicians and researchers can choose to use either the maximum score of a set of repetitions or the mean of the set.

The reliability of the hamstring to quadriceps ratios has not, to our knowledge, been reported elsewhere. In this group of subjects, the Hc:Qc had "low" relative test-retest reliability with an ICC of .43. For the He:Qc, the ICC of .73 can be classified as "high" relative reliability. The 95% CIs for both ratios, however, are wide and the smallest real differences indicate that a difference of 28% and 30% for the He:Qc and Hc:Qc, respectively, is needed to be 95% confident that there has been a real change. Individual changes in extension and flexion of individual subjects from day 1 to day 2 were not equal, which would explain the low reliability of the ratios. These ratios thus cannot be considered in isolation when the outcomes of isokinetic tests of knee flexors and extensors in people who are active in sports are assessed.

Reliability of measurement can be affected by instrument, data processing, examiner and subject-linked variability, test procedure, and protocol errors.[1] The reliability of the KinCom operating system has been shown to be excellent, with ICCs of .99 for force recorded at the strain gauge.[19] When calibrated, the accuracy of the force measuring system was within 3% of an applied actual load.[19] The KinCom 500H alignment of the mechanical axis of the dynamometer to the knee is performed manually and depends on visual placement of the seat relative to the dynamometer. The precise placement is not documented for subjects, thus it can affect intersession reliability. Variability between sessions may be smaller than our findings for dynamometers where placement is adjusted mechanically and where this can be individually recorded.

To reduce examiner variability in this study, 1 experienced examiner conducted all procedures and gave standardized instructions and verbal encouragement. Protocol-linked errors were kept to a minimum by following standardized procedures in regard to warm-up, stabilization, seating, and alignment of the dynamometer and lever. Various factors can affect subject-linked variability. It has been suggested that a prior familiarization session may decrease learning effects.[3] In an earlier study,[3] however, lower ICCs than what we found were found for eccentric and concentric knee contractions at 60°/s despite a pretrial familiarization session. Further, an investigation on the reliability of isokinetic isometric elbow flexion did not show a decrease in variability on 5 consecutive days.[33] In clinical practice and in the screening of athletes, it is unlikely that a familiarization session would be held because of time commitments and financial costs. We thus made the decision not to include an additional familiarization session before day 1.

Study Limitations

This study included only healthy, young adults who participate in running-related sports at various levels. In a group of men and women with hemiparesis after stroke, the percentage of smallest real difference ranged from 26% to 33% for knee extension and from 39% to 55% for concentric flexion.[9] Similarly, variability is likely to be greater in subjects with musculoskeletal injuries than in the subjects in this study.[15] In the absence of reports of absolute and relative reliability in subjects with specific impairments, a decision about a minimal acceptable level of change still must be based mainly on clinical reasoning.

CONCLUSIONS

With the Kin-Com 500H isokinetic dynamometer, the relative reliability for all knee flexion and extension variables at a velocity of 60°/s was very high and was high for the He:Qc, but low for the Hc:Qc. In uninjured subjects, the smallest change that can indicate a real improvement (smallest real difference) ranges from 13 to 34Nm (15%−23%) for peak torque and from 14 to 23J (12%−25%) for work variables. The peak torque ratios are less sensitive in detecting a real change, with the smallest necessary change ranging from 25% to 30% of the initial value.

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Suppliers

a. Chattecx Corp, 4717 Adams Rd, PO Box 489, Hixson, TN 37343.
b. Version 10.1; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.