Report on the Max II/Quark RMR/Deltatrac Comparisons

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1. Introduction

Over the years, the most reliable machine for measuring the resting metabolic rate (RMR) has been the Deltatrac II system by Sensormedics. This device is relatively user friendly, consistently accurate, and fairly durable. Unfortunately, Sensormedics was bought out and the new company chose not to continue to provide support or service for the Deltatrac. Most of the Deltatrac carts are currently in good shape, but some have recently become problematic. Because the lifespan Deltatrac system is finite, a new machine is required to begin the transition before the current systems deemed unusable. The main factors to consider in a new RMR machine are accuracy, consistency, reliability, ease of use, physical size, technical support availability, and total cost of ownership.

Two possible replacements were tested against the Deltatrac: the Max II by AEI Technologies and the Quark RMR by Cosmed, Inc. Seven volunteers were tested on each machine back-to-back-to-back on two separate days at the same time of day (tests were performed at 0800, 1000, and 1300, CDT). Each participant was given a rest period of thirty minutes and then performed a thirty minute test on each of the three machines. The testing order for each participant was randomly selected for the first day and then shifted for the second day. This was done to reduce the effects of any variables over time. The participants were asked to fast overnight to ensure consistent testing parameters. Participant results were measured against the Deltatrac data and consistency of the two tests.

After the human subject testing was completed, three ethanol burns were performed on each machine to determine CO_2 recovery and Respiratory Quotient (RQ) accuracy. For the ethanol burns, five mL of ethanol was burned to depletion under standard conditions. With these results the reliability of the machines was tested to measure a known recovery and RQ. This is considered to be the gold standard for quality control in RMR testing and calibration.

2. System Specifications

Max II by AEI Technologies (from company website)

OXYGEN ANALYZER (Paramagnetic):
Range 0 - 100% Oxygen, accuracy, linearity and repeatability are better than 0.03% of Oxygen from 10% - 21% Oxygen. Stability is better than 0.01% of Oxygen per hour. A 4-1/2 digit front panel display has a resolution of 0.01% Oxygen, front panel controls with vernier dials are provided for low and high calibration. Sample flow rate is 100 ml. one (1) minute. In order to protect the analyzer measuring cells, 5µ filters are employed.

CARBON DIOXIDE ANALYZER (Infrared):
Range 0 - 10% CO_2, accuracy, linearity and repeatability are better than ±0.03% of CO_2 over the physiological range. Stability better than ±0.1% of CO_2 over 24 hours, 3-1/2 digit front panel display has a resolution of 0.01% of CO_2, front panel controls with vernier dials are provided for low and high calibration.

VOLUME AND FLOW:
Range of flow from 0-15 liters per second, volume accuracy is better than ±1.0% typical from resting ventilation levels to Ve's over 200 l/min. Flow stability better than ±0.01% full scale. Verification of accuracy can be done without recalibration.

SOFTWARE:
Off-line data may be entered either during or after tests. All data can be exported to any Windows compatible spreadsheet or statistics program. Breath-by-breath or averaged data may be viewed during or after test in either tabular or graphic form. Averages may be viewed over any interval from 1 second to 99 seconds. Data from external equipment may be integrated with basic data.

“MAX-II” CART:
Size - 30”W x 24”D x 55”H - 4 Casters 2 of which are locking, a Power Distribution Strip, Bracket, Two Calibration Cylinders and Two Regulators.

Independent Validation:
Validation studies, performed by renowned physiologists, have shown the performance of the MAX-II to be comparable to simultaneous measurements made with Douglas Bags and a Tissot Spirometer (the gold standard).

Quark RMR by Cosmed, Inc. (from company website)

Analyzers Oxygen (O2) Carbon dioxide (CO2)
Type Paramagnetic NDIR
Range 0-100 % 0-10 %
Accuracy ± 0.03% ± 0.03%
Response time <120ms <120 ms
Warm-up time 0 min 5 min

Flowmeter
Type Bi-directional digital turbine (Ø 18 mm)
Range 0-50l/min
Accuracy ±2%
Resistance <0.7 cmH2O/l/sec @ 3 l/sec

Hardware
Dimensions & weight (Quark RMR unit) 17 x 30 x 45 cm/8 Kg
Dimensions & weight (Canopy) 16l/0.6 Kg

Standard Packaging Includes
Quark RMR unit, Canopy, RMR flowmeter, RMR disposable masks, antibacterial filters, PC software RMR, calibration syringe, Polar® HR monitor (receiver & transmitter), power supply cable, USB cable, user manual

Electrical requirements
Quark RMR unit 110-240V ±10%; 50/60Hz
Internal emergency battery 12V; 1,2 Ah

PC configuration required
PC Pentium or higher, Windows XP, 64 Mb RAM, USB or RS 232 , CD reader, 20 Mb space free on HD, Monitor VGA, SVGA, XGA

Safety & Quality Standards
Quark RMR is in compliance with the European Directive 93/42/CEE concerning medical devices.
Equipment complies with MDD (93/42 EEC) and FDA 510 (k)

3.Comparison with Deltatrac II

Several graphical comparisons were made to show the consistencies and differences between the Deltatrac and the possible replacements. Figures 1-3 show the day-to-day consistency of each machine. The thin line in each graph is the linear reference; the darker line is the actual line of best fit, with the equation in the upper right corner. The closer the slope is to 1 and the y-intercept is to 0, the better the consistency of the machine day-to-day. The raw data used can be seen in Appendix A.

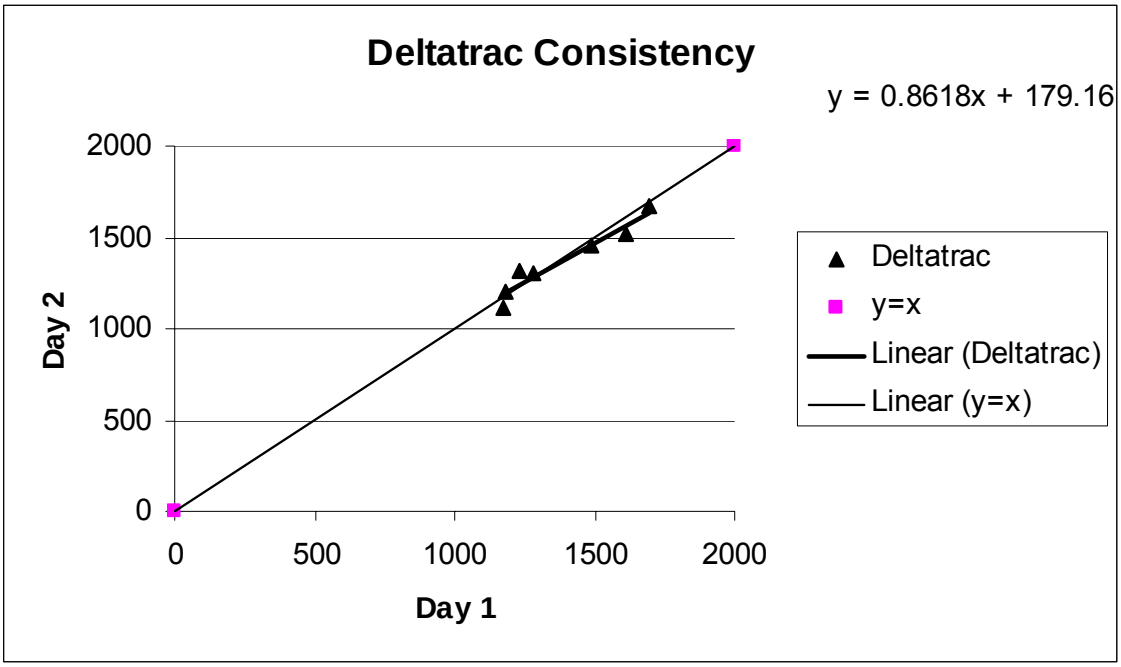

Figure 1: Consistency of the Deltatrac from day-to-day.

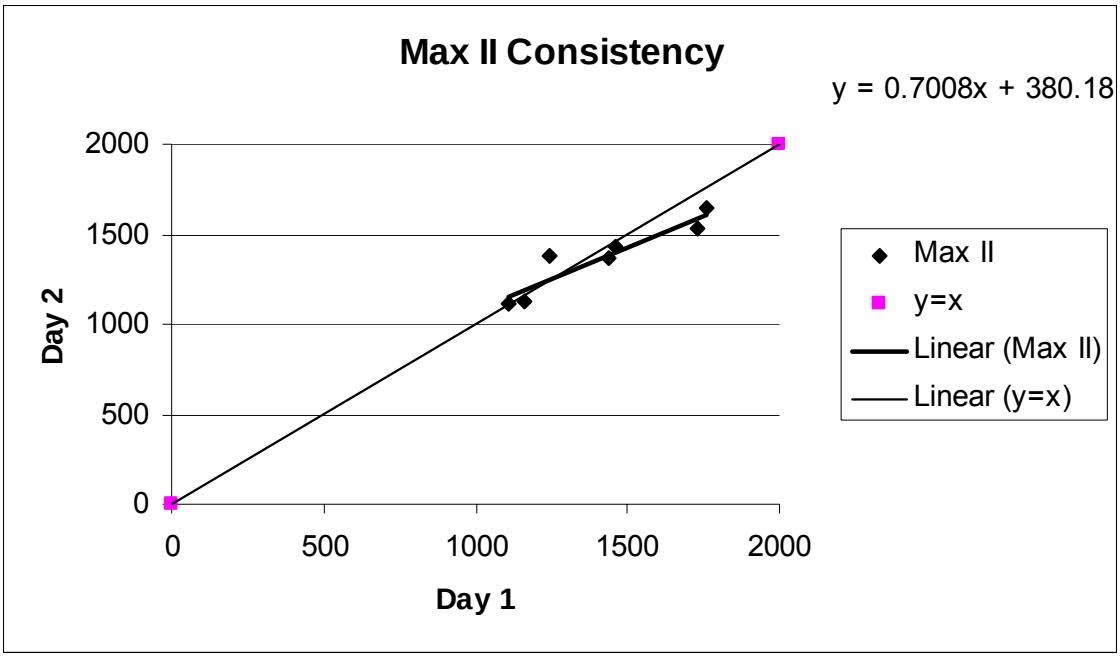

Figure 2: Consistency of the Max II from day-to-day.

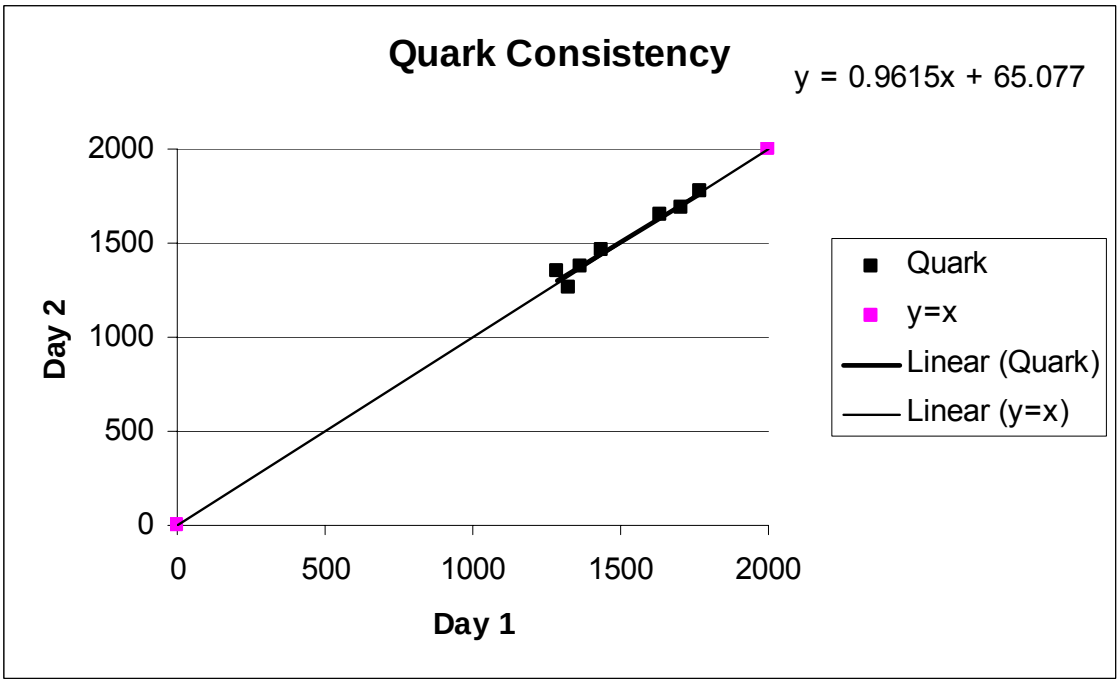

Figure 3: Consistency of the Quark RMR from day-to-day.

The Quark RMR displayed the most consistent data over the two day test period. The Deltatrac had the next best slope, followed by the Max II. None of the tests was more than 250 kcal off from day-to-day.

Next, the Resting Energy Expenditure (REE) for both the Max II and Quark RMR were compared to the Deltatrac. From these values, the average percent difference for each participant was determined and plotted in Figure 4 below. This graph shows that the Max II had a lower deviation from the Deltatrac values than the Quark for all but two tests, one of those being almost the same value.

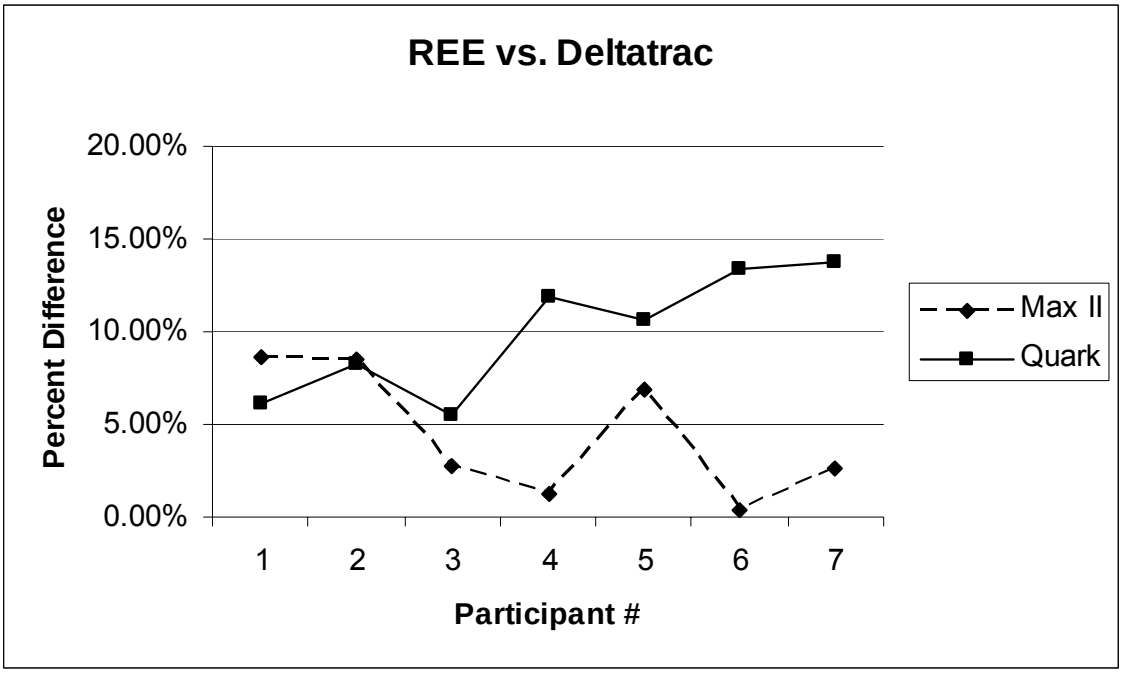

Figure 4: Average Resting Energy Expenditure percent difference with respect to Deltatrac.

The data suggests that the Max II will more accurately produce tests with similar values to the Deltatrac. Figures 5 and 6 show the relationships in another way by comparing the average REE from the Max II and Quark against the Deltatrac's average REE. The Max II's linear equation is very close to a perfect 1:1. While the Quark has a good slope close to one, the line is offset from the ideal line by over 200 kcal.

The data was later analyzed using the Bland-Altman (B-A) formula:
(A – T)/(avg(A,T))
where A is the actual (or in this case, the average of the Max II or the Quark) and T is the theoretical (average of the Deltatrac). The Bland-Altman test is used to determine the variance from the mean over a range of data to determine if accuracy is increased or decreased within a sub-range, such as the lower or upper values displayed on the X-axis. Figure 7 shows the Max II B-A, and Figure 8 shows the Quark B-A. The data does not show how accuracy changes over the range because the range is too small (only about 500 kcal). A larger energy expenditure range is required to make this determination. However, the graphs do show that the Max II is more accurate with respect to the Deltatrac while the Quark produced more consistent measurements.

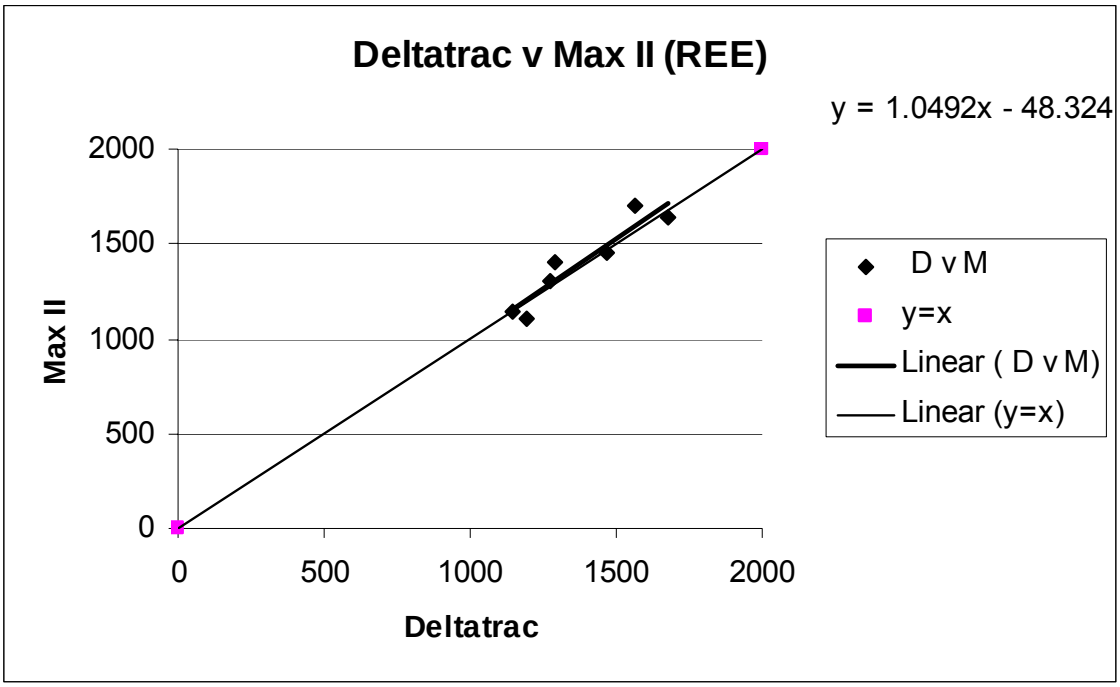

Figure 5: Consistency of the average REE values of the Max II with the Deltatrac.

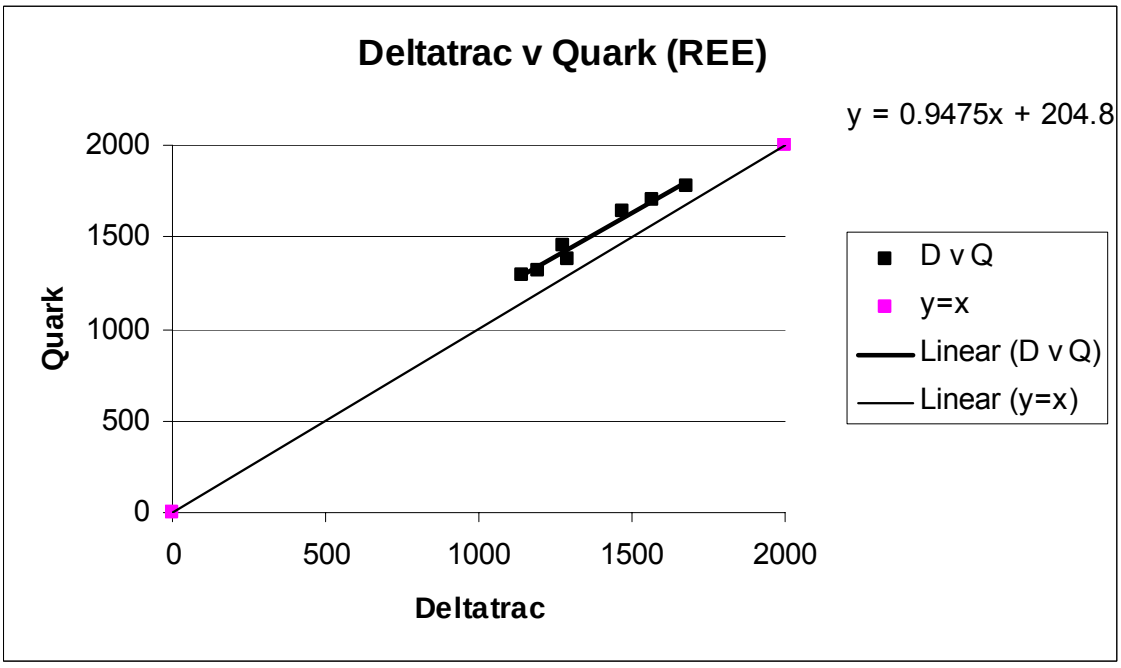

Figure 6: Consistency of the average REE values of the Quark RMR with the Deltatrac.

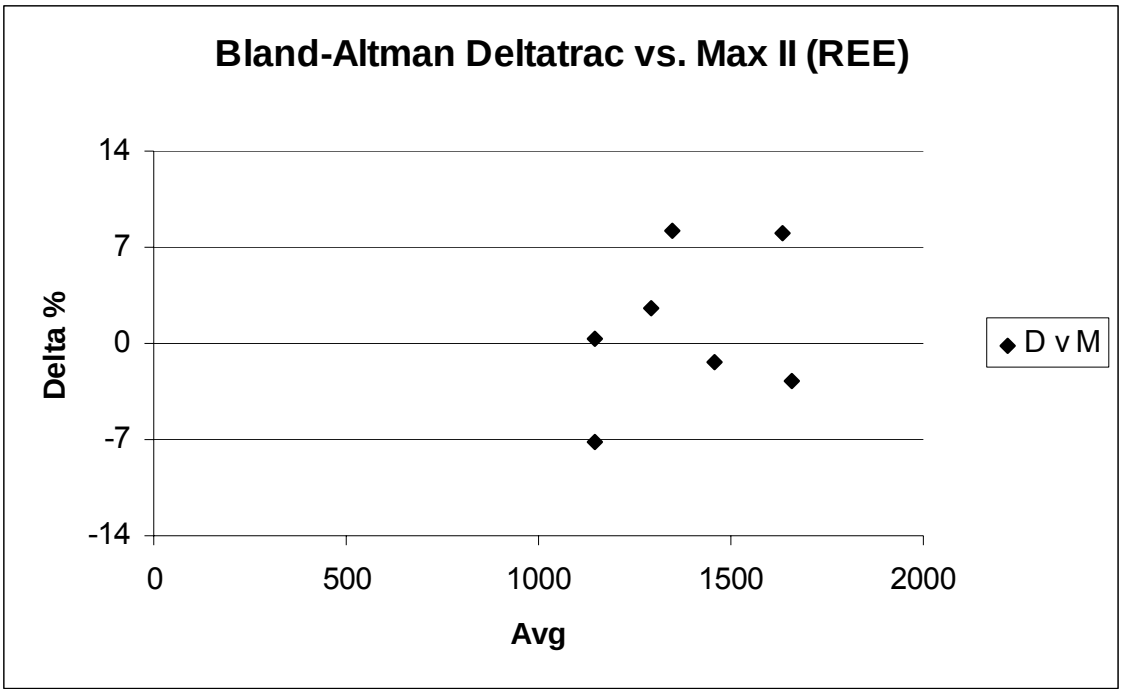

Figure 7: Bland-Altman comparison of the Deltatrac with the Max II.

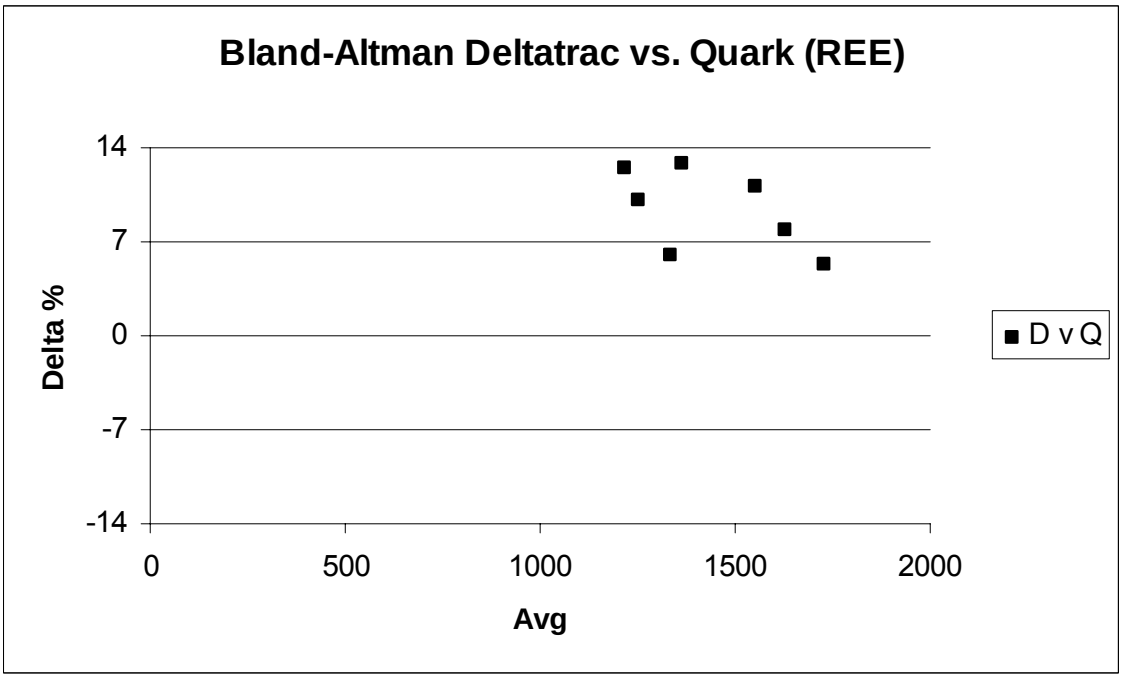

Figure 8: Bland-Altman comparison of the Deltatrac with the Quark RMR.

4. Flow and RQ test

RQ and flow were tested by an ethanol burn. This test is based on the following:

- Oxidation of ethanol: $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
- The theoretical RQ of ethanol is: VCO2/VO2 = 2/3 = 0.667
- The molecular weight of ethanol = 46.069 g and the molecular weight of gases in STPD conditions is 22.4L.

Therefore, when the volume of the amount of ethanol oxidized is known, it is possible to calculate the theoretical amount of O_2 used and CO_2 produced. Five mL of 100% pure ethanol was burned in a conical shaped glass cap until all of ethanol was consumed. This volume of ethanol should theoretically yield a total CO_2 volume of 3820 mL. This is a standard calibration procedure for ethanol burns. Six tests were performed for the MAX-II and Deltatrac and three tests were performed for the Quark-RMR (the company needed the equipment back before 6 burns could be performed)

Figure 10 shows the percent recovery of each test with respect to the theoretical result of CO_2 recovery; Figure 11 shows the same for the RQ. The raw data used in these calculations is included in Appendix B.

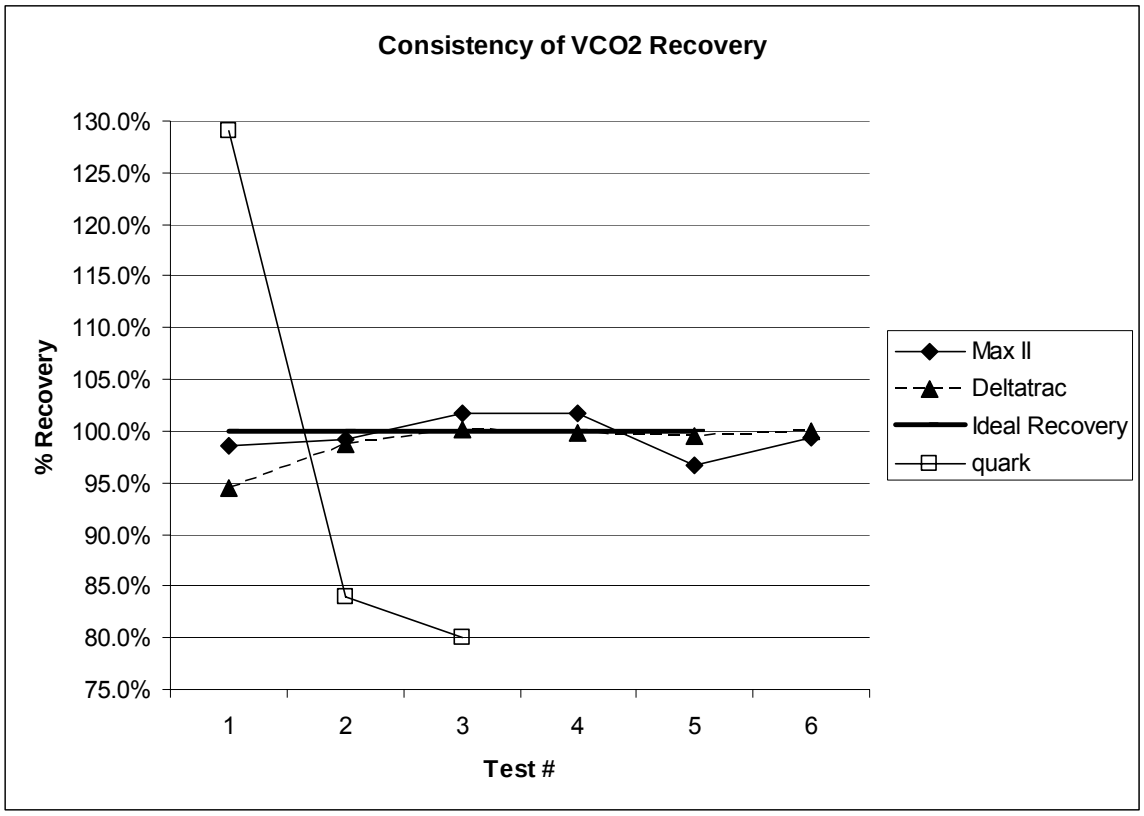

Figure 10: Percent of CO_2 Recovery versus a known quantity of 3820 mL.

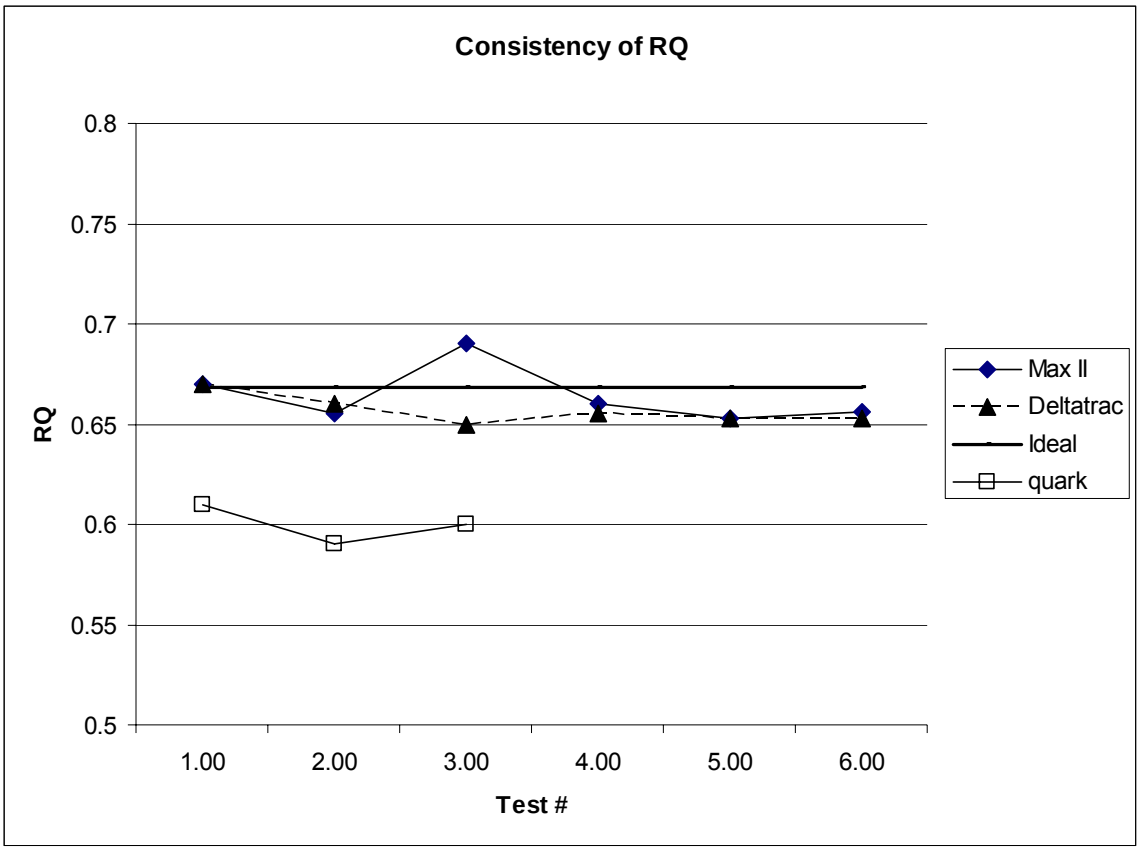

Figure 11: RQ values for the three machines for each test.

Both graphs above show that the Max II and Deltatrac had stable, accurate burns. The Quark, however, did not provide a good test in any of the three trials. The data was so unacceptable that the representative from Cosmed was contacted, who sent over data of previous validation tests performed at various testing sights yielding results closer to the theoretical values.

4. Subjective Analysis

Max II

Pros

- User friendly
- Preferred by nurses in feedback sessions
- Easy calibration with auto calibration feature
- Easily navigated software
- Patient reports help with data analysis
- Few in-test adjustments
- Extra dryers
- Flexible test times
- Pre-patient data menu
- 1 second averaging
- Analog display panel
- Can delete bad data in-test
- Numerous auxiliary inputs
- Can perform research grade exercise testing w/ minimal change

Cons

- Bulky*
- Noisy
- More connections/tubing
- No reference air during test*
- Two calibration gasses**

*being worked on by the company

**could be considered as a pro or a con

Quark

Pros

- Compact
- Durable
- Simple calibration
- Preset test protocols
- Saves patient data
- Allows for adjustment before data collection
- Less connections/tubing
- Quiet
- Discounted price
- FDA approved
- Can be used on ventilated patient
- References room air during test
- Can filter data in software for analysis
- Has built-in air pressure and temperature gauges
- Changes can be made post-test if necessary

Cons

- All test adjustments are made on back of module
- Breath-by-breath gas sample
- Less user friendly
- Too much unnecessary data
- Must continuously purchase filters
- One calibration gas**
- Less auxiliary inputs

5. Recommendation

Staff surveys of both machines were conducted generating a variety of input regarding the easy of use, patient comfort, and overall preference. Positive feedback was obtained on both units; however, overall the nurses and staff preferred the Max II to the Quark.

The opinions of the Max II are that it is easier to setup, had easier to use software, and required less in-test monitoring than the Quark. The main perceived drawbacks of the Max II are the cart size and lack of reference air monitoring during the test. Both of these problems are currently being addressed by AEI Technologies.

The Quark received good feedback as well, such as its compact size, ease of use, and simple calibration. However, the flow rate adjustments, and breath-by-breath analysis were found to be problematic.

After consideration of both test data and staff opinions the Max II is recommended for the specific needs to test resting metabolic rates at PBRC. Both machines performed well during testing; however, the Max II was found to be more accurate and had values closer to the Deltatrac, which is being replaced. The Quark by Cosmed is a great machine for measuring resting metabolic rates but that it is better suited for a different setting, such as one which requires the machine to be frequently transported to different locations.

APPENDIX A

Max II-Quark-Deltatrac Test

	Vs Deltatrac		Consistency		
Cart	**RQ**	**EE**	**RQ**	**EE**	**Tot Avg**
Deltatrac			**3.17%**	**3.77%**	**3.47%**
Max II	**2.31%**	**4.43%**	**5.69%**	**5.50%**	**4.48%**
Quark	**9.32%**	**9.92%**	**3.38%**	**1.98%**	**6.15%**

		Day 1		Day 2		Average		vs Deltatrac		Consistency	
H-B		**RQ**	**EE**	**RQ**	**EE**	**RQ**	**EE**	**RQ**	**EE**	**RQ**	**EE**
	Deltatrac	0.8	1277	0.8	1310	0.8	1293.5	0.00%	0.00%	0.00%	2.55%
1372	**Max II**	0.787	1438.44	0.805	1372	0.796	1405.22	0.50%	8.64%	2.26%	4.73%
	Quark	0.76	1367.79	0.738	1377.92	0.749	1372.855	6.38%	6.13%	2.94%	0.74%
	Deltatrac	0.806	1614	0.81	1522	0.808	1568	0.00%	0.00%	0.50%	5.87%
1790	**Max II**	0.799	1759.88	0.85	1641.26	0.8245	1700.57	2.04%	8.45%	6.19%	6.98%
	Quark	0.76	1704.3	0.72	1689	0.74	1696.65	8.42%	8.20%	5.41%	0.90%
	Deltatrac	0.77	1692	0.77	1669	0.77	1680.5	0.00%	0.00%	0.00%	1.37%
1956	**Max II**	0.734	1734	0.745	1535.48	0.7395	1634.74	3.96%	2.72%	1.49%	12.14%
	Quark	0.712	1771	0.69	1775	0.701	1773	8.96%	5.50%	3.14%	0.23%
	Deltatrac	0.8	1485	0.84	1450	0.82	1467.5	0.00%	0.00%	4.88%	2.39%
1879	**Max II**	0.763	1462.16	0.864	1434.78	0.8135	1448.47	0.79%	1.30%	12.42%	1.89%
	Quark	0.74	1635	0.76	1647	0.75	1641	8.54%	11.82%	2.67%	0.73%
	Deltatrac	0.89	1180	0.83	1201	0.86	1190.5	0.00%	0.00%	6.98%	1.76%
1316	**Max II**	0.88	1105.89	0.85	1110	0.865	1107.945	0.58%	6.93%	3.47%	0.37%
	Quark	0.76	1282	0.75	1353	0.755	1317.5	12.21%	10.67%	1.32%	5.39%

	Deltatrac	0.85	1176	0.81	1108	0.83	1142	0.00%	0.00%	4.82%	5.95%
1350	**Max II**	0.775	1159.09	0.816	1132.06	0.7955	1145.575	4.16%	0.31%	5.15%	2.36%
	Quark	0.74	1321.64	0.71	1267	0.725	1294.32	12.65%	13.34%	4.14%	4.22%
	Deltatrac	0.78	1234	0.82	1317	0.8	1275.5	0.00%	0.00%	5.00%	6.51%
1520	**Max II**	0.87	1243.73	0.796	1375	0.833	1309.365	4.12%	2.66%	8.88%	10.03%
	Quark	0.75	1439	0.72	1463	0.735	1451	8.13%	13.76%	4.08%	1.65%

APPENDIX B

Max II												
Test 1		Test 2		Test 3		Test 4		Test 5		Test 6		
RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	avg RQ 0.664
0.67	214	**0.655**	202	**0.69**	211	**0.66**	209	**0.653**	207	**0.656**	216	**std dev 0.0141**
	215		210		220		217		205		216	
	198		212		213		212		201		205	
	187		203		218		212		199		209	
	187		191		207		209		191		206	
	187		189		202		203		189		202	
	185		181		196		201		185		195	
	182		176		192		200		176		191	
	182		176		194		190		175		187	
	182		179		194		192		177		191	
	174		174		181		190		170		179	
	164		168		175		184		168		176	
	162		167		177		175		161		173	
	159		166		172		170		160		172	
	157		163		169		171		157		164	
	154		160		164		166		152		159	
	154		158		165		162		152		154	
	150		150		168		162		150		154	
	146		150		161		156		143		152	
	146		148		157		153		146		149	
	143		145		151		150		142		144	
	140		122						89			
VCO2 sum	**3768.0**		**3790.0**		**3887.0**		**3884.0**		**3695.0**		**3794.0**	**average 99.55%**
% recovery	**98.6%**		**99.2%**		**101.8%**		**101.7%**		**96.7%**		**99.3%**	**SD 1.91%**

Deltatrac II												
Test 1		Test 2		Test 3		Test 4		Test 5		Test 6		
RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	avg RQ	0.66
0.67	201.4	**0.66**	195.6	**0.65**	194.6	**0.66**	187	**0.66**	203.2	**0.653**	195.9	std dev	0.0067
	199		189.3		201.1		197.7		200.3		204.7		
	195.2		193		197.3		197.5		206.2		195.8		
	188.4		190.4		188.7		195		196.8		196.9		
	182.9		177.4		182.3		185		183.4		186.9		
	178.3		180.5		178.5		182.8		180.6		178		
	176.8		172.4		174.9		182.6		171.9		179.2		
	169.3		176.8		167.8		180.1		178.7		174.1		
	167.1		170.9		165.5		169.6		169		171.7		
	159.1		168.8		163.6		161.4		171.7		167.5		
	163.5		162.7		162.6		167.4		167.4		161		
	158.8		165.7		160.6		164.4		167		165.3		
	162.6		161.2		156.2		165.3		159.7		168.5		
	156.1		163.1		160.8		159.1		156.7		161		
	155.6		153.2		159.2		152.4		152.4		156.8		
	150.1		148.8		148.9		154.4		151.9		149.6		
	150.3		152.9		148.1		151.8		145.7		150.2		
	144.9		150.8		144.9		146.6		147.1		147.6		
	144.5		142.1		150.9		146.7		149.8		150.1		
	138.3		140.6		149.4		142.8		145		140.7		
	138.8		141.8		134.9		142.8		138.6		147.6		
	130.4		137.7		134.3		141.1		136.8		135.9		
			138.1		198.7		138.1		124.5		136.6		
VCO2 sum	**3611.4**		**3773.8**		**3823.8**		**3811.6**		**3804.4**		**3821.6**	**average**	**98.81%**
%recovery	**94.5%**		**98.8%**		**100.1%**		**99.8%**		**99.6%**		**100.0%**	**SD**	**2.14%**

Quark						
Test 1		Test 2		Test 3		
RQ (avg)	VCO2	RQ (avg)	VCO2	RQ (avg)	VCO2	
0.61	278.7	**0.59**	168.5	**0.6**	180.94	
	289.0		178.3		186.39	
	277.3		177.2		187.49	
	259.2		174.0		168.94	
	258.9		164.2		162.48	
	259.6		165.3		157.05	
	247.7		160.9		150.52	
	248.7		153.3		147.26	
	245.5		147.9		153.75	
	242.0		142.4		149.44	
	230.1		139.2		146.15	
	230.1		138.0		142.91	
	221.4		136.9		139.63	
	220.1		134.7		136.4	
	213.4		131.5		129.88	
	207.1		127.1		126.61	
	212.5		126.1		123.33	
	204.0		120.6		122.22	
	202.6		120.6		118.94	
	197.4		116.3		114.66	
	186.3		111.9		112.44	
			111.8			
						average
VCO2 sum	**4931.60**	**VCO2 sum**	**3146.78**	**VCO2 sum**	**3057.44**	**97.2%**
% recovery	**129.1**		**82.4**		**80.0**	**std dev**
						27.2%