Oxygen consumption was measured simultaneously from continuous respiratory gas analysis with an open circuit indirect calorimeter (Deltatrac, Datex Instrumentarium, Helsinki, Finland). Each reported value, $mVO_2$, was the mean of 10 successive measurements obtained immediately after determination of cardiac output by the thermodilution technique and blood sampling. The use of the monitor has been validated in previous clinical studies using similar patient groups[9,10]. The monitor is calibrated with a known concentration of oxygen and carbon dioxide prior to the study period according to the manufacturer's instructions. No changes of therapy occurred during the period of evaluation.

### Statistical method

Differences of values obtained between methods were analysed by using Student's t-test for paired samples. The agreement between the two methods used to obtain the same parameter, $VO_2$, was analysed according to the method of Altman and Bland[11]. The differences between paired $VO_2$ measurements by the two methods is the error, and the average error is the bias. Limits of agreement were calculated as bias ± 2 X standard deviation. A $p$ value of $<0.05$ is regarded as statistically significant.

## Results

### Group I

Of the 30 patients, 25 were males and five were females. The mean age was 55.8 ± 10.3 years; mean weight was 65.5 ± 9.4 kg; and mean body surface area was 1.69 ± 0.15 $m^2$. The mean $cVO_2$ determined by the Fick principle was 126 ± 16 $ml.min^{-1}.m^{-2}$ and the mean $mVO_2$ was 129 ± 26 $ml.min^{-1}.m^{-2}$ by respired gas analysis (Table I). The difference was not statistically significant (p=0.49, $t$-test). Bias between the two methods was -3.0 ± 27 $ml.min^{-1}.m^{-2}$. The limits of agreement obtained between the measured and calculated values were from -57 to 51 $ml.min^{-1}.m^{-2}$.

### Group II

The demographic and clinical data of the patients are presented in Table II. The mean APACHE II score for the group was 22 ± 7 and only 5 out of the twenty patients survived. The mean $cVO_2$ was 145 ± 47 $ml.min^{-1}.m^{-2}$ and the mean $mVO_2$ was 163 ± 33 $ml.min^{-1}.m^{-2}$, the difference between the two was not statistically significant (p=0.07, $t$-test) (Table II). The study of the individual paired differences between the measured and the calculated values showed that the magnitudes of the differences were substantial. The bias was -18$ml.min^{-1}.m^{-2}$ with standard deviation of 42 $ml.min^{-1}.m^{-2}$ with the limits of agreement were -101 to 67 $ml.min^{-1}.m^{-2}$ (Table I).

## Discussion

This study compared two different methods of clinical measurement of oxygen consumption applied simultaneously in two distinct groups of patients; after routine cardiopulmonary bypass graft surgery and those in septic shock. We found that in both groups of patients, $mVO_2$ as determined by analysis of respiratory

**Table I**
**Measured and calculated $VO_2$ values in Group I (post-CABG) and Group II (septic) patients**

| | Group I | | Group II | |
|---|---|---|---|---|
| | $cVO_2$ | $mVO_2$ | $cVO_2$ | $mVO_2$ |
| patients (n) | 30 | | 20 | |
| mean ± SD ($ml.min^{-1}.m^{-2}$) | 126 ± 29 | 129 ± 26 | 145 ± 47 | 163 ± 33 |
| bias ($ml.min^{-1}.m^{-2}$) | -3.0 ± 27 | | -18 ± 42 | |
| limits of agreement ($ml.min^{-1}.m^{-2}$) | -57 to 51 | | -101 to 67 | |

**Table II**
**Demographic data and clinical diagnoses of Group II patients**

| Sex | Age | Clinical diagnosis | Positive cultures |
|---|---|---|---|
| F | 81 | Aortoduodenal fistula | blood, tracheal aspirate |
| F | 68 | Empyema gallbladder | blood, bile |
| F | 51 | Ileal perforation | blood, intraabdominal pus |
| M | 63 | Colonic perforation | intraabdominal pus |
| F | 89 | Postgastrectomy anastomotic leakage | blood, intraabdominal pus |
| M | 57 | Perforation of diverticulitis | blood, intraabdominal pus |
| M | 75 | Postcholecystectomy bronchopneumonia | tracheal aspirate |
| M | 66 | Postcolectomy anastomotic leakage | intraabdominal pus |
| F | 20 | Colonic perforation | blood, intraabdominal pus tracheal aspirate |
| F | 36 | Acute pancreatitis | blood, tracheal aspirate |
| F | 66 | Postcholecystectomy bronchopneumonia | tracheal aspirate |
| M | 36 | Fournier's gangrene | blood |
| M | 66 | Postcolectomy bronchopneumonia | tracheal aspirate |
| M | 29 | Fractured pelvis, infected intraabdominal clots | tracheal aspirate, intraabdominal pus |
| M | 29 | Subhepatic abscess | tracheal aspirate, intraabdominal pus |
| M | 73 | Colonic perforation | abdominal drainage |
| F | 53 | Acute pancreatitis | abdominal drainage |
| M | 28 | Acute pancreatitis | intraabdominal pus, blood tracheal aspirate |
| F | 68 | Colonic perforation | intraabdominal pus, blood |
| M | 58 | Colonic perforation | tracheal aspirate, intraabdominal pus |

gases is higher than $cVO_2$, obtained using the reverse Fick method. In addition, the $VO_2$ values, bias and limits of agreement were of greater magnitude in Group II septic patients compared to Group I patients after CABG.

While $cVO_2$ and $mVO_2$ should be identical, various clinical studies that compared the two have consistently reported a difference between paired observations obtained by the two methods of measurement (Table III). This difference was observed in patients populations not unlike those in our present study, *viz.* after routine postcardiopulmonary bypass cardiac surgery as well as in critically ill patients. This difference was postulated to be due mainly to the oxygen consumption of the lungs themselves. Intrapulmonary $VO_2$ is not measured by the reverse Fick method as the pulmonary circulation is bypassed in the calculation of thermodilution-derived cardiac output. Under normal conditions, lung $VO_2$ is less than 5% of the total $VO_2$ however, it may rise to as high as 15% during inflammatory processes involving the lungs[16]. The value of 3 $ml.min^{-1}.m^{-2}$ in Group 1 and 18 $ml.min^{-1}.m^{-2}$ in Group 2 – the difference between $VO_2$ measured by indirect calorimetry and by the reverse Fick method – represented 2.4% and 11.6% of total body $VO_2$ and might be due to intrapulmonary

**Table III**
**Summary of similar studies**

| Study | No. & type of patients | $mVO_2$ | $cVO_2$ | bias |
|---|---|---|---|---|
| 1. Takala *et al*[9] | 20 post-CABG | 294 ± 59 | 247 ± 58 | 49 ± 25 $ml.min^{-1}$ |
| 2. Bizouarn *et al*[12] | 10 post-cardiac | 153 ± 17 | 120 ± 27 | 34 ± 27 $ml.min^{-1}.m^{-2}$ |
| 3. Hanique *et al*[13] | 73 critically ill | 153.9 ± 1.7 | 154.2 ± 2.3 | 0.3 ± 70 $ml.min^{-1}.m^{-2}$ |
| | 98 critically ill | 149.0 ± 1.4 | 146.8 ± 1.5 | 2.2 ± 52 $ml.min^{-1}.m^{-2}$ |
| 4. Brandi *et al*[14] | 26 critically ill | 151 ± 26 | 145 ± 29 | 5.2 ± 8 $ml.min^{-1}.m^{-2}$ |
| 5. Myburgh *et al*[15] | 20 critically ill | 308 ± 64 | 284 ± 72 | 24 ± 47 $ml.min^{-1}$ |

*Results are expressed as mean ± SD*

$VO_2$. Other explanations for these between-method differences may reflect the amount of bronchial blood supply that drains back into the pulmonary veins or coronary blood flow that returns directly into the left ventricle via the Thebesian veins both of which would not be detected by the Fick method. However, left-sided Thebesian flow is only a small fraction of total coronary artery blood flow (<1%) and is thus unlikely to account for any great degree of the observed differences, even if myocardial oxygen consumption is increased. In addition, the cumulative effects of the errors of measurements of the numerous primary variables entering the Fick equation introduce another potential source of error[17,18].

The mean $VO_2$ of 145 $ml.min^{-1}.m^{-2}$ obtained by Fick method and 163 $ml.min^{-1}.m^{-2}$ determined via indirect calorimetry are comparable to the figures obtained in other studies of $VO_2$ in septic patients[19,20]. The higher metabolic state of the septic patients as compared to those patients with uneventful cardiopulmonary bypass is evident from the higher mean oxygen consumption values. This is not unexpected as the septic patients are often in a hypermetabolic state while the patients after uneventful open heart surgery are neither hypermetabolic or hypercatabolic when compared with their baseline state preoperatively[21].

The bias and standard deviation was of a larger magnitude for the group of septic patients (18 ± 42 $ml.min^{-1}.m^{-2}$) as compared to the group of patients who had undergone cardiopulmonary bypass surgery (3.0 ± 27 $ml.min^{-1}.m^{-2}$). As discussed previously, the increase in oxygen usage by the pulmonary tissues might account for the larger bias. This is not unexpected as the latter group of patients is more homogenous and were free from any significant pulmonary pathology preoperatively. The former group had developed septic shock from a variety of infective foci and 10 of the 20 patients had chest infection with positive cultures and a varied degree of pulmonary involvement. The relative nonhomogeneity of this group of patients gave rise to the greater variability in repeated measurements as compared to the more stable group of Group I patients after routine CABG.

We have carried out simultaneous measurements and calculations of $VO_2$ in two distinct groups of patients: after uncomplicated postcoronary artery bypass graft surgery and those in septic shock. Our results demonstrated that these 2 methods of measurement did not provide results which were interchangeable in clinical practice. Measurement of $VO_2$ using analysis of respiratory gases by a metabolic monitor should be preferred because of the better reproducibility as compared to calculated results obtained via the reverse Fick method.

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