Evaluation of Instrumented Force Platform as a Test to Measure Residual Effects of Anesthetics

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Recovery from anesthesia was assessed in a controlled manner in 39 healthy student volunteers, using two psychomotor tests (perceptual speed and tapping board) and an instrumented force platform 1, 3, 5 and 7 h after intravenous injection of 0.3 mg/kg diazepam, 2.0 mg/kg methohexital, 6.0 mg/kg thiopental or saline. Postural stability remained unaltered but the performance on psychomotor tests improved when the tests were repeated after saline injection.

Methohexital did not induce any changes in body sway or psychomotor performance at the time periods tested when compared with saline. Postural stability of subjects receiving thiopental or diazepam was impaired (P < 0.001) for 1 and 7 hours after anesthesia, respectively, when compared with saline. The impairment on performance in the psychomotor tests induced by thiopental or diazepam was of smaller magnitude and for diazepam of shorter duration than balance disturbances measured with the body sway test. Further clinical studies on the use of the instrumented force platform as a fast and easily interpretable guideline for discharge from hospital after different modes of outpatient anesthesia are warranted. (Key words: Anesthesia: outpatient. Anesthetics, intravenous: diazepam; methohexital; thiopental. Recovery: postural stability.)

RAPIDLY INCREASING HOSPITAL expenses have produced a common trend towards outpatient anesthesia and sedation. In the United States, in dental offices alone, more than five million general anesthetics and many more intravenous sedatives are administered each year. Epstein has estimated that up to 40 per cent of today's inpatient surgery can probably be done with safety on an ambulatory basis, resulting in up to 40–50 per cent savings in cost. Consequently, rapid recovery after anesthesia and attempts to find an easily administered, reliable test to be used as a guideline in assessing the length of necessary hospital stay after outpatient anesthesia or sedation are essential.

Measurements of recovery from anesthesia have ranged from assessment of the ability of patients to open their eyes to their ability to drive a car. Simple clinical tests, e.g., Romberg's test or the ability to walk, seem to be inadequate guidelines for safe discharge after outpatient anesthesia, whereas sophisticated equipment, e.g., psychomotor test batteries or driving simulators, are bulky, expensive and too complex to be routinely used in clinical practice.

Stabilometry, or quantitative assessment of human stability, has been applied in aerospace medicine, otolaryngology, evaluation of the interaction of drugs and alcohol, and in studies of the susceptibility of humans to fall. It has also been used in measurements of recovery from anesthesia. Techniques used for measuring postural sway varied from ones in which the signal analysis has been carried out manually from pen recordings to others with relatively complex systems containing tape recorders and computers.

A new force platform has been designed and built, which is instrumented to give immediate results after standing on it. The present study was conducted to evaluate the sensitivity and suitability of this new device as compared with two psychomotor tests to measure recovery after intravenous anesthesia and sedation.

Materials and Methods

SUBJECTS AND TRIAL DESIGN

The study was carried out in 39 young, healthy volunteers. The mean age of the volunteers (± SD) was 23 ± 3.0 years, and their mean weight 65.0 ± 8.0 kg. No subject was taking any medications. The nature and purpose of the study was explained to the subjects, and they signed an appropriate consent form. The study protocol was approved by the University of Iowa Committee on Research Involving Human Subjects.

The subjects were instructed to abstain from any stimulant or depressant beverages from 5:00 P.M. on the day preceding the study, and no food or fluids were allowed for at least 8 h before injection of the drugs. Upon arrival at the laboratory, the subjects were first introduced to the tests, after which they practiced once on each test in a manner similar to that used during the actual test. One hour later they were tested again, to obtain baseline control results before injection of the drugs.

Immediately after the pretreatment results were obtained, the subjects were injected in random order either


<table>
<thead>
<tr>
<th>Body Sway Parameter</th>
<th>Overall Effect for Saline†</th>
<th>Comparison Between Saline and Diazepam‡</th>
<th>Comparison Between Saline and Thiopental‡</th>
<th>Comparison Between Saline and Methohexital‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F (4,32)</td>
<td>P</td>
<td>F (1,35)</td>
<td>P</td>
</tr>
<tr>
<td>Heel-to-heel eyes open</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-ap, total§</td>
<td>1.62</td>
<td>ns</td>
<td>3.61</td>
<td>ns</td>
</tr>
<tr>
<td>-ap, 1.2 to 6.1 Hz†</td>
<td>0.97</td>
<td>&lt;1.50 ns</td>
<td>&lt;1.50 ns</td>
<td>ns</td>
</tr>
<tr>
<td>-ap, 0.4 to 0.81 Hz†</td>
<td>1.26</td>
<td>ns</td>
<td>7.26</td>
<td>ns</td>
</tr>
<tr>
<td>-lat, total§</td>
<td>1.88</td>
<td>0.002*</td>
<td>11.11</td>
<td>ns</td>
</tr>
<tr>
<td>-lat, 1.2 to 6.1 Hz†</td>
<td>1.91</td>
<td>&lt;1.50 ns</td>
<td>7.01</td>
<td>ns</td>
</tr>
<tr>
<td>-ap plus lat, total‡</td>
<td>1.73</td>
<td>0.003*</td>
<td>10.42</td>
<td>ns</td>
</tr>
<tr>
<td>Heel-to-heel eyes closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-ap, total§</td>
<td>1.16</td>
<td>ns</td>
<td>&lt;1.50 ns</td>
<td>ns</td>
</tr>
<tr>
<td>-ap, 1.2 to 6.1 Hz†</td>
<td>1.14</td>
<td>ns</td>
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<tr>
<td>-ap, 0.4 to 0.81 Hz†</td>
<td>1.25</td>
<td>ns</td>
<td>11.28</td>
<td>ns</td>
</tr>
<tr>
<td>-lat, total§</td>
<td>1.39</td>
<td>ns</td>
<td>4.01</td>
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</tr>
<tr>
<td>-lat, 1.2 to 6.1 Hz†</td>
<td>0.74</td>
<td>ns</td>
<td>2.72</td>
<td>ns</td>
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<tr>
<td>-ap plus lat, total‡</td>
<td>0.19</td>
<td>ns</td>
<td>7.74</td>
<td>ns</td>
</tr>
<tr>
<td>Heel-to-toe eyes open</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-ap, total§</td>
<td>0.82</td>
<td>ns</td>
<td>14.47</td>
<td>ns</td>
</tr>
<tr>
<td>-ap, 1.2 to 6.1 Hz†</td>
<td>1.43</td>
<td>ns</td>
<td>&lt;1.50 ns</td>
<td>ns</td>
</tr>
<tr>
<td>-ap, 0.4 to 0.81 Hz†</td>
<td>2.39</td>
<td>ns</td>
<td>7.94</td>
<td>ns</td>
</tr>
<tr>
<td>-lat, total§</td>
<td>4.28</td>
<td>0.007*</td>
<td>24.11</td>
<td>ns</td>
</tr>
<tr>
<td>-lat, 1.2 to 6.1 Hz†</td>
<td>1.16</td>
<td>ns</td>
<td>&lt;1.50 ns</td>
<td>ns</td>
</tr>
<tr>
<td>-ap plus lat, total‡</td>
<td>1.47</td>
<td>ns</td>
<td>30.29</td>
<td>ns</td>
</tr>
</tbody>
</table>

All data (from test times 0, 1, 3, 5, and 7 hours) have been subjected to split-plot analysis of variance for overall effects and to a one-way multivariate analysis of covariance for pairwise overall differences after adjusting to baseline.

† These results indicate that saline did not produce any change in postural sway when compared to the amount of sway before injection except in lateral motion when standing heel to toe.

‡ These results indicate that both diazepam and thiopental (but not methohexital) changed the amount of body sway more than saline.

§ Using frequency independent channels.

†† Using filtered channels.

‡‡ Addition of sways in anteroposterior and lateral directions.

with 0.3 mg/kg diazepam, 2.0 mg/kg methohexital, 6.0 mg/kg thiopental or saline into a large forearm vein through a plastic cannula. The thiopental group consisted of nine subjects, and the other groups of ten subjects each. Each group included five women. The subjects were tested in a double-blind manner 1, 3, 5, and 7 h after injection with the force platform and psychomotor tests. No coffee, tea, cola, or tobacco were allowed during the experiment. The subjects had a standardized snack lunch after the 3-h testing period.

ASSESSMENT OF RESIDUAL EFFECTS

Body Sway

The subjects’ body sway, i.e., the movement of the body’s center of gravity, was automatically measured by the new force platform as sway units. The platform, which provides sufficient data for the instantaneous center of foot pressure to be calculated, consists of two rectangular aluminum plates, each 40.6 cm X 61 cm X 2.54 cm, attached to each other by three piezoelectric force sensors located at the vertices of an equilateral triangle of side d = 33 cm. The device is coupled to a signal processor which electronically determines the time averaged sway in two directions; anteroposterior and lateral and performs a frequency analysis. The apparatus has six channels: one frequency-independent channel and two filtered channels for both anteroposterior and lateral directions. The frequency-independent channels measured the total amount of sway and the two filtered channels measured how much sway occurred in the frequency range of 1.2 to 6.1 Hz and in the range of 0.40 to 0.81 Hz. The authors also added together the amounts of sway in anteroposterior and lateral directions, in order to see whether this parameter would be a more sensitive measure of body sway than either of the directions individually. The scale factor was 26,000 sway units per centimeter of displacement of the center of force in the lateral direction and 36,600 sway units per centimeter.
in the anteroposterior direction over a one minute testing period. We have previously described the apparatus and the testing procedure in detail. **

In this study, body sway was measured when the subjects stood in heel to heel (feet together) and heel to toe (one foot in front of the other) position with eyes open, and in heel to heel position with eyes closed. After completion of one of the standing modifications the subjects were allowed to sit for 30 s before starting the next one. The entire test took an average of six minutes to complete.

**Perceptual Speed**

The speed with which subjects could find well-known symbols in a mass of material was measured. The subjects’ task was to mark every digit in the row as the one circled at the beginning of the row. The test was given for two minutes and the score was the number of correct and incorrect responses.

**Tapping Board**

The subjects were asked to tap with metal stylus, as rapidly as possible, metal target areas at alternate ends of a 55-cm board as previously described. Five 10-s tests were administered with a 10-s rest period following each trial. The score was the total numbers of correct taps made during the five trials.

**Subjective Assessments**

The subjects rated their feelings after each testing period on four visual analogue scales, and their opinion of their psychomotor performance on one scale. The adjective pairs used were: 1) clumsy (0 mm)—well-coordinated (100 mm), 2) mentally slow (0 mm)—quick-witted (100 mm), 3) tired (0 mm)—alert (100 mm), 4) dizzy (0 mm)—clear-headed (100 mm), and 5) impaired psychomotor skills (−50 mm)—improved psychomotor skills (+50 mm).

**Statistics**

The body sway data were transformed using log_{10} to stabilize the variance and induce normality. The other data were treated as untransformed. A split-plot analysis of variance (ANOVA) was used to examine sex and overall effects within treatment. Overall treatment differences were examined using a one-way multivariate analysis of covariance adjusting for baseline differences.


**Fig. 1.** Time averaged sway in frequency independent channel for lateral direction (means ± SE) when standing for 60 s in heel to toe position with eyes open on the force platform before and 1, 3, 5, and 7 h after intravenous injection of 0.3 mg/kg diazepam, 2.0 mg/kg methohexitol, 6.0 mg/kg thiopental or saline. ** Indicates significance P < 0.01 and *** P < 0.001 vs. saline after adjusting to baseline. For explanation of sway units see text. O: Saline. ●: Thiopental. ○: Methohexitol. □: Diazepam.

The overall effect within treatment indicates whether the drug produced any change in performance when compared with the performance before injection, and the overall treatment difference indicates whether one drug changed performance more than another one. Pairwise, comparisons among the four treatments across period, i.e., at 1, 3, 5 and 7 h testing periods, was accomplished using a Bonferroni procedure. P value < 0.05 was considered significant for sex effects. For pairwise comparisons, overall and across period, P < 0.01 was considered significant due to the number of tests involved in the analysis.

**Results**

There were neither systemic sex effects nor drug × time interactions for any treatment or measurement but drug effects were distinct and of long duration depending on the treatment and the test used.

**Body Sway**

When the overall effect was analyzed for saline, no significant changes in postural sway parameters were noticed except in lateral motion when standing heel to toe (table 1). After both diazepam and thiopental significant (P < 0.01–P < 0.001) overall changes in many parameters were measured when compared with body sway changes after saline (table 1). Methohexitol, how-
ever, induced no significant changes in body sway when compared with saline (table 1).

The most sensitive channels to detect the residual drug effects on body sway were the frequency-independent channel for lateral movement and the frequency-dependent channel for 0.40–0.81 Hz (table 1). The magnitude and duration of increased sway in lateral direction for one mode of standing after each treatment is given in figure 1.

Diazepam produced almost a 100 per cent increase in postural sway in lateral direction when standing eyes open one hour after the injection when compared with baseline ($P < 0.001$ vs saline; fig. 1). Postural stability of subjects receiving diazepam was still significantly worse ($P < 0.001$) at 7 h when compared with subjects given saline (fig. 1).

After thiopental, the amount of sway was significantly ($P < 0.001$) increased up to 1 h after anesthesia but equilibrium had returned to baseline at the 3-h testing period (fig. 1).

An example of the sensitivity of the frequency-dependent channels to measure residual sway (the lateral movements after all treatments in the range of 0.40–0.81 Hz) is shown in figure 2. In this frequency range the greatest increase in the sway was noticed 1 h after thiopental injection and stability was still significantly impaired 3 h after diazepam injection.

**Perceptual Speed**

Neither incorrect nor missed correct responses were observed in this test. After saline the number of correct responses increased distinctly at the 1 h testing period, and remained unaltered thereafter (fig. 3). When compared with saline, the performance was significantly impaired for as long as 1 h ($P < 0.01$) and 5 h ($P < 0.001$) after thiopental and diazepam, respectively. The performance after methohexital was similar to that measured after saline (fig. 3).

**Tapping Board**

After saline injections, a slight training effect was noticed, resulting in improved performance when the test was repeated. When compared with saline, the tapping rate was significantly ($P < 0.001$) slower 1 h after both diazepam and thiopental, but at the 3-h testing period and later, the results returned to the level observed after saline injection (fig. 4). No differences were noticed between saline and methohexital.

**Subjective Assessments**

The subjective assessments which were affected most are listed in table 2. The subjects rated themselves as mentally sedated and their performance as impaired for 1–3 h after active drug treatments. These effects disappeared five hours after diazepam injection.

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**Fig. 2.** Time averaged sway in the range of 0.40–0.81 Hz for lateral direction (means ± SE) when standing for 60 s in heel to heel position with eyes open on the force platform before and 1, 3, 5, and 7 h after intravenous injection of 0.3 mg/kg diazepam, 2.0 mg/kg methohexital, 6.0 mg/kg thiopental or saline. ** Indicates significance $P < 0.01$ and *** $P < 0.001$ vs. saline after adjusting to baseline. For explanation of sway units see text. ○: Saline. ●: Thiopental. ●: Methohexital. ■: Diazepam.

**Fig. 3.** The mean numbers of correct responses (± SE) in the perceptual speed test before and 1, 3, 5, and 7 h after intravenous injection of 0.3 mg/kg diazepam, 2.0 mg/kg methohexital, 6.0 mg/kg thiopental or saline. ** Indicates significance $P < 0.01$ and *** $P < 0.001$ vs. saline after adjusting to baseline. ○: Saline. ●: Thiopental. ●: Methohexital. ■: Diazepam.
as an easily administered and fast test in assessing recovery and the length of hospital stay after outpatient anesthesia and sedation.

The same drug doses were used as in earlier studies, in which recovery and residual effects from intravenous anesthesia and sedation were tested with a test battery of clinical and psychomotor tests and with a driving simulator in order to be able to compare the sensitivity of the tests used in the present study with other tests. The doses of thiopental and methohexitol should be equipotent and are those prescribed for minor dental and general surgery. The dosage of diazepam used is also commonly used in outpatient practice.

Terekhov, after reviewing the literature on stabilometry and its applications, concluded that an apparatus designed for clinical use should analyze the data and display the sway parameters in numerical form as soon as the test is completed.

The force platform used in this study was instrumented to give the results immediately after standing, without having to use time consuming manual analysis or tape recording and sophisticated computers to obtain the results. The finding that no training effect was observed when the test was repeated without an extensive practice period is an important advantage in outpatient anesthesia, since the evaluation of practice effects on recovery tests would be difficult to incorporate into clinical routine.


### Table 2. Subjective Assessments on Visual Analogue Scales Before and After Intravenous Administration of Saline, 6 mg/kg Thiopental, 2.0 mg/kg Methohexitol and 0.3 mg/kg Diazepam

<table>
<thead>
<tr>
<th>Parameter Measured</th>
<th>Time</th>
<th>Saline</th>
<th>Thiopental</th>
<th>Methohexitol</th>
<th>Diazepam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mentally slow</td>
<td>Base 1h</td>
<td>38 ± 5</td>
<td>41 ± 7</td>
<td>40 ± 8</td>
<td>38 ± 6</td>
</tr>
<tr>
<td>quick-witted</td>
<td>39 ± 5</td>
<td>42 ± 5</td>
<td>63 ± 8*</td>
<td>67 ± 7*</td>
<td>66 ± 6*</td>
</tr>
<tr>
<td>0 = quick-witted, 100</td>
<td>After 1h</td>
<td>33 ± 4</td>
<td>39 ± 4</td>
<td>53 ± 6*</td>
<td>48 ± 4</td>
</tr>
<tr>
<td>mentally slow</td>
<td>35 ± 4</td>
<td>38 ± 6</td>
<td>37 ± 6</td>
<td>36 ± 5</td>
<td>29 ± 7</td>
</tr>
<tr>
<td>Tired-alert</td>
<td>Base 1h</td>
<td>55 ± 8</td>
<td>42 ± 6</td>
<td>49 ± 9</td>
<td>50 ± 6</td>
</tr>
<tr>
<td>0 = alert, 100 = tired</td>
<td>After 1h</td>
<td>46 ± 7</td>
<td>70 ± 6*</td>
<td>57 ± 8</td>
<td>75 ± 4*</td>
</tr>
<tr>
<td></td>
<td>32 ± 6</td>
<td>53 ± 9</td>
<td>50 ± 7</td>
<td>55 ± 4*</td>
<td>39 ± 7</td>
</tr>
<tr>
<td>Psychomotor</td>
<td>Base 1h</td>
<td>3 ± 3</td>
<td>2 ± 2</td>
<td>6 ± 5</td>
<td>4 ± 5</td>
</tr>
<tr>
<td>performance (±50 = better than normal, 0 = normal, −50 = impaired)</td>
<td>After 1h</td>
<td>3 ± 3</td>
<td>2 ± 2</td>
<td>6 ± 5</td>
<td>4 ± 5</td>
</tr>
<tr>
<td></td>
<td>7 ± 3</td>
<td>3 ± 3</td>
<td>−15 ± 6*</td>
<td>26 ± 7*</td>
<td>1 ± 2</td>
</tr>
<tr>
<td></td>
<td>7 ± 3</td>
<td>3 ± 3</td>
<td>−4 ± 3*</td>
<td>−10 ± 3*</td>
<td>1 ± 2</td>
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<tr>
<td></td>
<td>6 ± 3</td>
<td>5 ± 3</td>
<td>0 ± 2</td>
<td>6 ± 4</td>
<td></td>
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</table>

Means ± of 9 to 10 subjects. * P < 0.01 and † P < 0.001 vs. saline after adjusting to baseline.
Six output variables were used in our platform: one frequency-independent channel and two frequency-dependent channels for each of the two orthogonal directions of sway. The rationale of incorporating both direction sensitivity and frequency sensitivity into the instrument as well as other mechanical and electrical considerations has been discussed previously. For example, cerebellar lesions result in characteristic tremor at 3 Hz, whereas labyrinthine involvements have been shown to elevate sway amplitude in the range of 0.1–1 Hz. The usefulness of the frequency-dependent channels is also illustrated in this study.

The perceptual speed and tapping board tests were selected because they could also be used in clinical practice, and they have been shown to be sensitive in measuring residual effects of inhalational anesthetics and diazepam. This study shows that there is a training effect when either of the tests is repeated and at least two to four practice trials may be needed to achieve a stable performance.

It has been previously shown that driving skills are impaired for at least 8 h after the same doses of the three drugs used in this study, which indicates that the force platform does not measure complete recovery of all psychomotor skills after thiopental and methohexitol, but is sensitive to measure late residual effects of diazepam. Coordination of large muscles, which are required to maintain equilibrium, are impaired to the greatest extent and for the longest time after diazepam administration, which was confirmed by the present results. Eriksen et al. showed postural stability after operation to be distinctly worse for as long as 3 h after brief thiopental anesthesia (6.5 ± 0.3 mg/kg) preceded by meperidine premedication. Meperidine used for preanesthetic medication by Eriksen et al. probably caused a more delayed impairment in postural sway than was measured by us in this study.

Complete mental and psychomotor recovery can only be assessed by a battery of tests. Some tests like flicker fusion and EEG are too sensitive to be of significance in making a clinical decision regarding hospital stay and determining instructions to patients after discharge from the hospital. The results from this series suggest that the instrumented force platform is a potential tool as an easily administered and interpreted test in assessing the length of necessary hospital stay after outpatient anesthesia, as well as in research on the effects of drugs on postural stability. Further clinical studies on its use as a guideline for discharge after different modes of outpatient anesthesia are warranted.

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References

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