A new technique for intraoperative analysis of trunk geometry in adolescent idiopathic scoliosis

Jean-Marc Mac-Thiong, BEng, MSc;*† Hubert Labelle, MD;*† Luc Duong, BEng;† Carl-Eric Aubin, PhD†‡

Adolescent idiopathic scoliosis (AIS) involves a deformity of the spine that is commonly assessed by physicians.[1,2] The external trunk deformity is also recognized as a major concern in AIS, especially for the patient.[3,4] Therefore, many authors advocate that that consideration be given to simultaneous surgical correction of spinal and trunk deformities.[5–7] During posterior instrumentation of the scoliotic spine, the main objective is to restore a well-balanced spine in sagittal, coronal and transverse planes.[8,9] Intraoperatively, surgeons can evaluate the spinal correction by direct visualization of the exposed vertebrae or by such techniques as radiography,[10] stereophotogrammetry,[11] and optoelectronic[12–15] or electromagnetic tracking.[16,17] However, visual evaluation of the scoliotic trunk deformity is difficult since draping sheets cover most of the trunk. In addition, an adequate correction of the spinal deformity does not guarantee successful correction of the trunk deformity.[6] To achieve an overall correction of AIS, it would be useful for the surgeon to have immediate feedback regarding the efficacy of the surgical manoeuvres on the trunk deformity. Mac-Thiong and colleagues[18] recently developed a technique to assess scoliotic trunk geometry in the prone operative position, but they have never used it in a surgical environment. The purpose of this study was to evaluate the feasibility of this technique during surgical correction of AIS. The trunk geometry of a patient undergoing surgical treatment of AIS was quantified at various stages of the procedure.

Case report

A 16-year-old girl scheduled to undergo posterior instrumentation and fusion for AIS was recruited on a voluntary basis at the Scoliosis Clinic of Sainte-Justine Hospital in Montreal. She had a King type III curve with a 60° preoperative Cobb angle and an apex located at the T10 vertebra. The angles of trunk deformity in a forward bending position assessed by a scoliometer were 14° (right hump) at the thoracic level and 12° (left hump) at the lumbar level. The scoliotic curve was surgically reduced with a Colorado 2 Spinal System (Medtronic Sofamor Danek, Memphis, Tenn.) from the T5 to L3 vertebrae followed by fusion of the instrumented area. The postoperative Cobb angle was reduced to 16° (right thoracic curve).

Intraoperative tracking of the trunk was performed using 11 electromagnetic sensors (MotionStar, Ascension Technology, Burlington, Vt.) placed on specific anatomic landmarks (Fig. 1): 1 — C7, 2 — left acromion, 3 — right acromion, 4 — left prominence of thoracic angle of trunk rotation, 5 — right prominence of thoracic angle of trunk rotation, 6 — left prominence of lumbar angle of trunk rotation, 7 — right prominence of lumbar angle of trunk rotation, 8 — left iliac crest, 9 — right iliac crest, 10 — S1, 11 — xiphoid process. The accuracy of the position sensors is 2.5 mm (S. Delorme and R. Leblanc, Université de Montréal: unpublished observations, 1997) and the reproducibility is 0.9 mm[16] in the operative environment (with operating table,

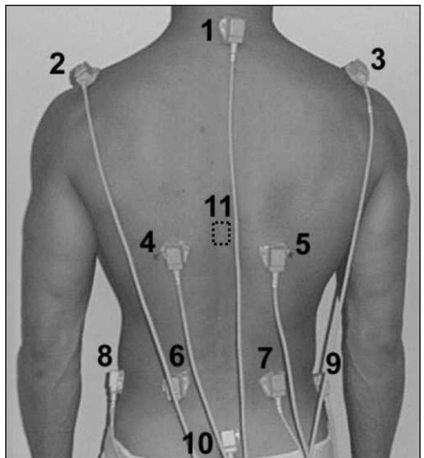

FIG. 1. Anatomic landmarks of the trunk (see text for an explanation of the sensor numbers).

*From the *Faculty of Medicine, Université de Montréal, †Research Centre, Sainte-Justine Mother–Child University Hospital, and ‡Department of Mechanical Engineering, École Polytechnique, Montreal, Que.*

Accepted for publication Aug. 3, 2001.

Correspondence to: *Dr. Hubert Labelle, Division of Orthopedics, Hôpital Sainte-Justine, 3175 Cote Sainte-Catherine, Montreal QC H3T 1C5; fax 514 345-4755, hubert@justine.umontreal.ca*

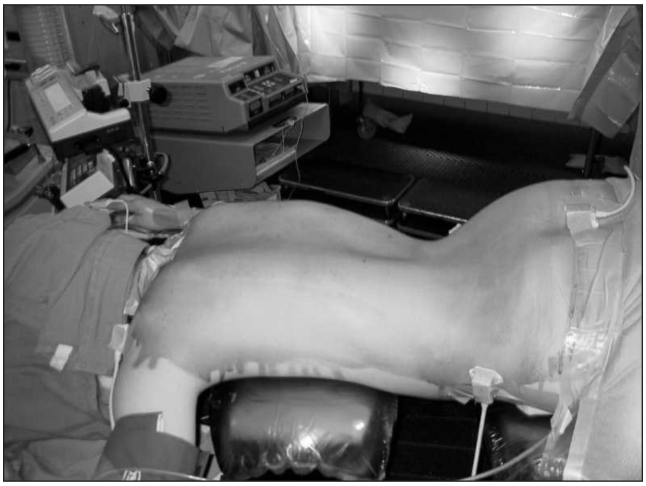

FIG. 2. Placement of the nonsterile sensors.

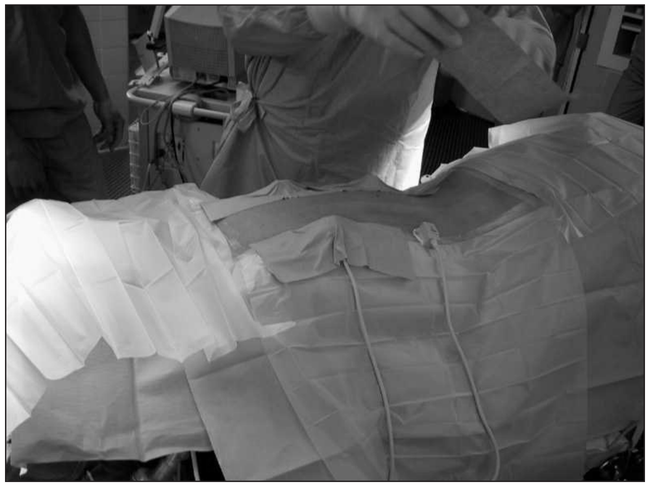

FIG. 3. Placement of the sterile sensors and draping.

lamps, anesthesia equipment, surgical instruments, surgical rods and screws).

Preoperatively, the sensors that were to be placed in the sterile area (4, 5, 6 and 7) were submitted to gas sterilization for 16 hours. On the day of the surgery, the tracking system was brought in the operating room and connected to a portable computer (IBM ThinkPad, IBM, New York) via Ethernet protocol. After positioning the patient on a modified Relton–Hall spine frame, the nonsterile sensors (1, 2, 3, 8, 9, 10 and 11) were placed by the surgical team using double-sided adhesive tape. Waterproof tape was applied on all sensors to secure the fixation before the surgical area was sterilized (Fig. 2). Thereafter, the sterile sensors were installed on the sterilized skin using double-sided adhesive tape and were covered by sterile tape before placing the draping sheets (Fig. 3). The transmitter was placed at the right thoracic level. To prevent magnetic interference, only nonferromagnetic tools and implants (stainless steel or titanium) were used. Furthermore, all tools (including retractors) were cleared from the surgical field during data collection.

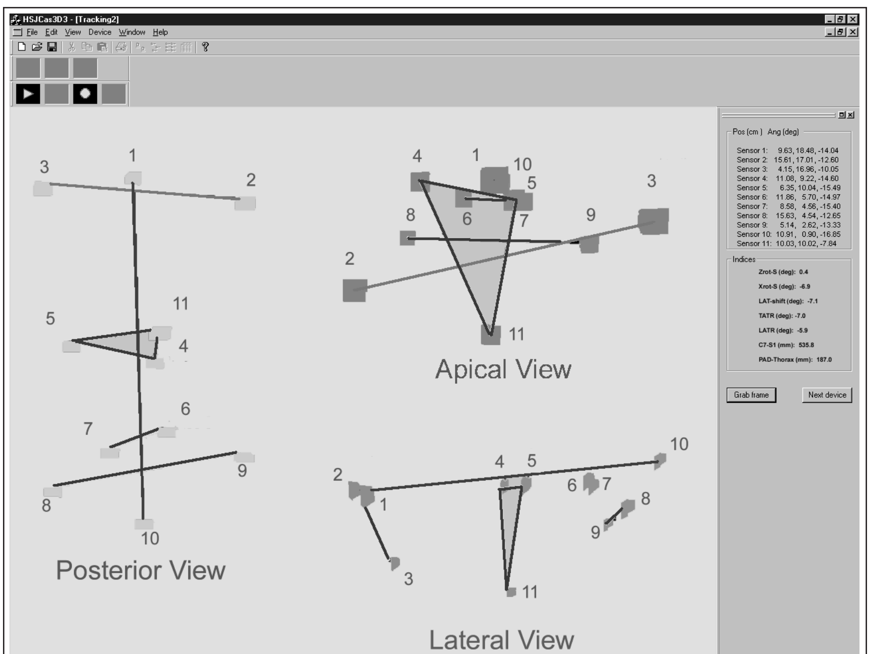

FIG. 4. Computer display of sensor positions, the geometric indices and the schematic representation of the trunk

A first data acquisition (3D position of the 11 sensors) was made after anesthesia and positioning of the patient (stage I). Data acquisitions were also made just before instrumentation of the first rod (stage II) and after the fixation of both rods (stage III). A final data acquisition was made after closure of the skin (stage IV). Each data acquisition consisted of 2 series of measurements: at the end of inspiration and at the end of expiration. The 2 series of measurements acquired for each stage were averaged to allow comparison between the 4 stages of surgery.

The raw data (recorded in the axis system of the transmitter) were shifted into the global axis system defined by the Scoliosis Research Society.[2] The X axis follows the gravity line, which is directed anteriorly with respect to the prone patient. The Y and Z axes point toward left and cephalad directions, respectively. The origin of the axis system is at S1. Data collection was performed using custom-developed software that displays the position of all sensors with respect to the transmitter, the geometric indices and a schematic representation of the trunk (Fig. 4). The 7 geometric indices of the trunk were computed from the 3D position of all 11 sensors in the global axis system (Fig. 5). All angular indices were expressed relative to the orientation of the pelvis. A positive value for a linear index (in millimetres) is directed along the X, Y or Z axis whereas a positive value for an angular index (in degrees) indicates a counterclockwise rotation with respect to an X, Y or Z positive axis (Fig. 5).

The geometric indices of the trunk at each stage of the surgery are presented in Table 1. The transverse rotation of the shoulders was the only index that worsened after the surgery whereas the scoliotic trunk geometry improved with respect to the coronal rotation of the shoulders, the lateral shift, and the thoracic and lumbar angles of trunk rotation. The spinal instrumentation and surgical manoeuvres specifically decreased the lateral shift and the thoracic angle of trunk rotation but increased the lumbar angle of trunk rotation, and the transverse and coronal rotation of the shoulders. The linear distance between C7 and S1 decreased from stage I to stage II and progressively increased from stage II to stage IV. The posteroanterior diameter of the thorax was similar for stages I and IV but decreased when the spine was exposed at stages II and III.

Discussion

Many techniques have been developed to evaluate the 3D spinal geometry during surgical treatment of AIS.[10–17] However, the literature contains no data about the 3D overall geometry of the trunk during the various stages of AIS surgery, even though correction of the trunk deformity is a major concern, especially for the patients.[4,6]

This study showed the feasibility of a technique for intraoperative tracking of the scoliotic trunk geometry. This innovative technique enabled quantification of the trunk geometry for the major stages of AIS surgery, including the instrumentation process. Without this technique, the surgeon cannot modify his correction strategy based on the intraoperative geometry of the trunk that is mostly covered by the sterile drapes. Therefore, the amount of trunk correction can only be assessed postoperatively. However, the developed technique could provide real-time information to the surgeon about the current correction of trunk deformity, allowing for continuous evaluation and modification of surgical manoeuvres.

All the equipment (portable computer and motion tracking system) was installed before exposure of the vertebrae so the use of the technique did not prolong the operative time. After the initial setup, no modification to the surgical procedure was required. The surgeons were not disturbed by the presence of sensors underneath the draping sheets. The computer screen, controlled by a technician, can be visualized at any moment by the surgeon since the information on trunk geometry is displayed in real time (Fig. 4).

The accuracy of the acquisition technique in our operative environment has been measured previously at 2.5 mm (S. Delorme and R. Leblanc: unpublished

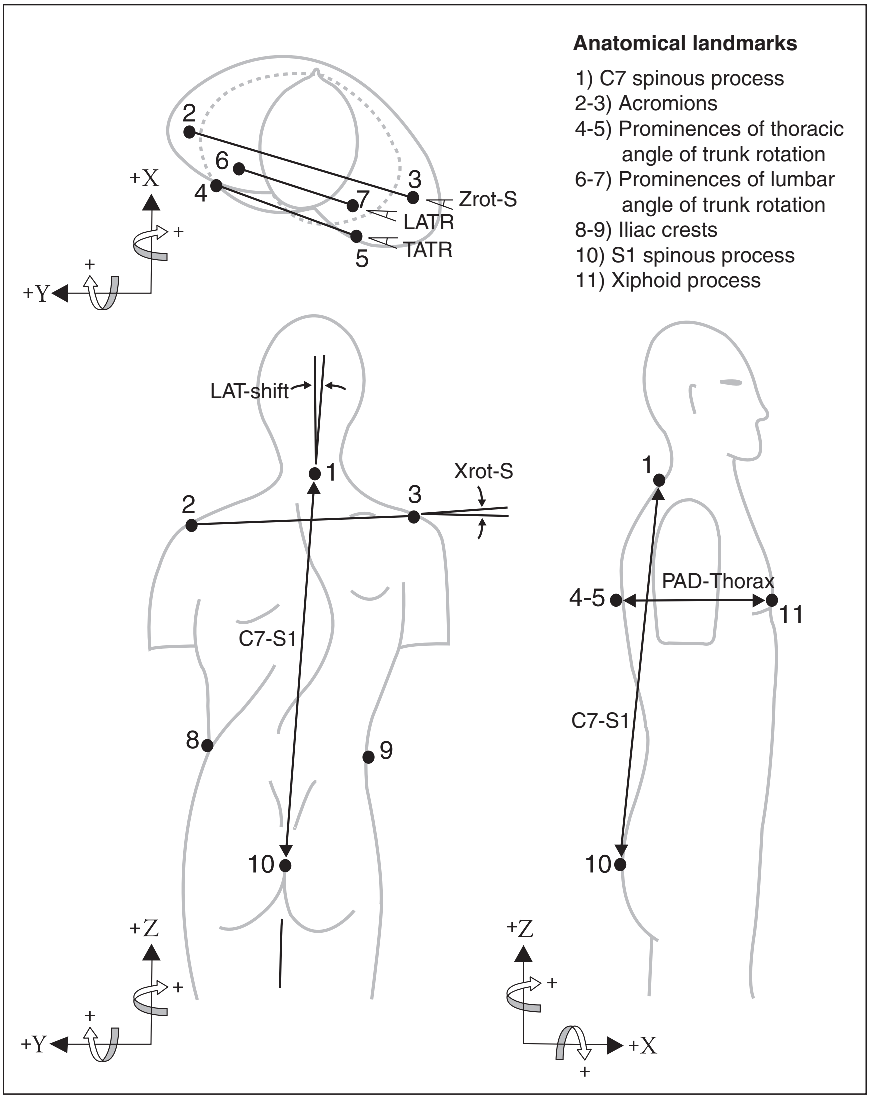

FIG. 5. Geometric indices of the trunk. Zrot-S = transverse rotation of the shoulders, LATR = lumber angle of trunk rotation, TATR = thoracic angle of trunk rotation, LAT-shift = lateral shift of C7 with respect to S1, Xrot-S = coronal rotation of the shoulders, PAD-Thorax = posteroanterior diameter of thorax.

Table 1

Intraoperative Geometric Indices of the Trunk

Geometric index	Abbreviation (units)	Stage of the procedure I	II	III	IV
Transverse rotation of the shoulders	Zrot–S (°)	0.4	1.1	4.2	3.5
Coronal rotation of the shoulders	Xrot–S (°)	–6.9	–4.9	–5.0	–2.1
Lateral shift of C7 with respect to S1	LAT–shift (°)	–7.1	–5.6	–3.2	–2.1
Thoracic angle of trunk rotation	TATR (°)	–7.0	–2.9	–1.0	–2.5
Lumbar angle of trunk rotation	LATR (°)	–5.9	–2.5	–4.5	–3.1
Linear distance from C7 to S1	C7–S1 (mm)	518.3	476.8	485.9	491.2
Posteroanterior diameter of thorax	PAD-Thorax (mm)	187.0	178.2	179.3	186.2

observations, 1997) using a custom-manufactured Plexiglas framework calibrated to ± 0.38 mm with an articulated mechanical arm (MicroScribe-3D; Immersion Corporation, San Jose, Calif.). These results were similar to those obtained by Milne and colleagues.[19] Moreover, the reproducibility of the measuring technique in the surgical setting has been evaluated at 0.9 mm.[16] We believe that the accuracy (2.5 mm) and reproducibility (0.9 mm) of the system in the operating room are clinically adequate for calculating geometric indices of the trunk. This is in agreement with Drerup,[20] who considered an accuracy of 5 mm sufficient for the calculation of geometric indices of the trunk. Furthermore, it has been shown that with a closely controlled environment free of ferromagnetic material such as mild steel, electromagnetic systems can be used successfully for even highly precise tasks such as computer-assisted pedicle screw insertion.[21] The main drawback associated with the use of this technique is the risk of magnetic interference. Accordingly, the instruments in the vicinity of the operative field were removed during the data acquisitions in order to ensure negligible magnetic interference with the transmitter.

A previous study in a controlled environment[18] showed that the clinical variability was about 2 mm and 2° for linear and angular indices, respectively. Any change greater than 2 mm and 2° could thus be considered clinically significant. For the girl used in the current study, the results showed that the surgery (stage I to stage IV) tended to improve trunk geometry with respect to the coronal rotation of the shoulders, the lateral shift, and the thoracic and lumbar angles of trunk rotation. The decrease in the thoracic angle of trunk rotation is particularly important in improving the cosmetic appearance for the patient.[6] Except for the lateral shift, the correction was mostly achieved by the exposure of the vertebrae (stages I to II) and not by the instrumentation (stages II to III). The significant increase in the transverse rotation of the shoulders between stages II and III does not necessarily mean a worsening of the scoliotic deformity. Since the Relton–Hall spine frame restrains shoulder and pelvis rotations in the transverse plane,[18] the increase in the transverse rotation of the shoulders could rather indicate a modification to the initial positioning caused by the surgeon or assistants pushing on the trunk between stages II and III.

Skin closure seemed to have a considerable impact on the measurements. Obviously, the indices after the spinal instrumentation (stage III) did not correlate with the end result for the patient lying on the operating table (stage IV). In the present study, the evaluation of trunk geometry after skin closure was made to document each step of the surgery and not to seek a correlation with the instrumentation process. In fact, the end result that is critical to patient well-being is the trunk geometry in the standing position after the surgery. Therefore, a strong correlation between trunk geometry during the instrumentation process (while the surgeon can still modify the spine geometry) and the postoperative standing position is essential if intraoperative guidance with the developed technique is to be of value. Accordingly, a study comparing the intraoperative geometry to the postoperative standing geometry of the trunk is currently underway since this technique allows evaluation of trunk geometry in both operative prone and standing positions.

As expected, the spinal length (linear distance from C7 to S1) was increased by the instrumentation by about 1 cm. This is in the same range as that reported by Sawatzky and colleagues.[11] However, the distance between C7 and S1 is higher in stages I and IV than in stages II and III. It is possible that this observation does not represent a true lengthening of the spine. Iit may be due to the displacement of the tracked anatomic landmarks (C7 and S1) relative to the underlying spinous processes. With surgical exposure, the released anatomic structures (skin, fascia and muscles) could cause the anatomic landmarks to be displaced with respect to C7 and S1 spinous processes.

The posteroanterior diameter of the thorax was defined as the distance along the X axis between the xiphoid process (sensor 11) and the midpoint of the line joining the prominences of the thoracic angle of trunk rotation (sensors 4 and 5). This index was not changed by the surgical procedure or the instrumentation. The decreased posteroanterior diameter of the thorax in stages II and III is only an artifact caused by the location of sensors 4 and 5. When the spine is exposed at stages II and III, sensors 4 and 5 are displaced as the skin flaps slide laterally and downward with respect to the bony prominences of the thoracic angle of trunk rotation.

The developed technique could help to characterize the effect of the surgery on the scoliotic trunk deformity and to clearly define the correlation between the spine and trunk deformities. Subsequently, the surgeon could rely on real-time data concerning the hidden scoliotic trunk geometry to guide the surgical procedure and thus optimize the final correction of the trunk deformity in AIS.

Acknowledgements: This research was funded by the Medical Research Council of Canada, the Canadian Arthritis Network and the Sainte-Justine Hospital Foundation. The authors sincerely thank Julie Joncas for her assistance.

References

1. Cobb JR. Outline for the study of scoliosis. The American Academy of Orthopaedic Surgeons. *Instr Course Lect* 1948;5:261-75.

2. Stokes IA. Three-dimensional terminology of spinal deformity. A report presented to the Scoliosis Research Society Working Group on 3-D terminology of spinal deformity. *Spine* 1994;19:236-48.

3. Raso VJ, Lou E, Hill DL, Mahood JK, Moreau MJ, Durdle NG. Trunk distortion in adolescent idiopathic scoliosis. *J Pediatr Orthop* 1998;18:222-6.

4. Theologis TN, Jefferson RJ, Simpson AH, Turner-Smith AR, Fairbank JCT. Quantifying the cosmetic defect of adolescent idiopathic scoliosis. *Spine* 1995;18:909-12.

5. Asher M, Manna B. Optimizing surgical improvement of trunk asymmetry from idiopathic scoliosis. In: Stokes IA, editor. *Research into spinal deformities 2.* Amsterdam: IOS Press; 1999. p. 250-3.

6. Weatherley CR, Draycott V, Benson DR, Gopalakrishnan KC, Evans JH, O'Brien JP. The rib deformity in adolescent idiopathic scoliosis. A prospective study to evaluate changes after Harrington distraction and posterior fusion. *J Bone Joint Surg Br* 1987;69:179-82.

7. Willers U, Transfeldt EE, Hedlund R. The segmental effect of Cotrel–Dubousset instrumentation on vertebral rotation, rib hump and the thoracic cage in idiopathic scoliosis. *Eur Spine J* 1996;5:387-93.

8. Margulies JY, Floman Y, Robin GC, Neuwirth MG, Kuflik P, Weidenbaum M, et al. An algorithm for selection of instrumentation levels in scoliosis. *Eur Spine J* 1998;7:88-94.

9. Zeller R, Dubousset J. [Surgical treatment of idiopathic scoliosis.] *Rachis* 1999;11: 87-101.

10. Cheriet F, Delorme S, Dansereau J, Aubin C-É, de Guise JA, Labelle H. [Perioperative radiographic reconstruction of the scoliotic vertebral column.] *Ann Chir* 1999;53:808-15.

11. Sawatsky BJ, Tredwell SJ, Jang SB, Black AH. Effects of three-dimensional assessment on surgical correction and on hook strategies in multi-hook instrumentation for adolescent idiopathic scoliosis. *Spine* 1998;23:201-5.

12. Dufour F, Chopin D, Godillon Maquinghen AP. Acquisition of 3D vertebral displacement during surgery. In: Stokes IA, editor. *Research into spinal deformities 2.* Amsterdam: IOS Press; 1999. p. 113-7.

13. Durdle NG, Bhalla K, Raso VJ, Hill DL. A computer vision system for real-time intra-operative monitoring of scoliosis surgery. In: Sevastik JA, Diab KM, editors. *Research into spinal deformities 1.* Amsterdam: IOS Press; 1997. p. 407-10.

14. Ghanem IB, Hagnere F, Dubousset JF, Watier B, Skalli W, Lavaste F. Intraoperative optoelectronic analysis of three-dimensional vertebral displacement after Cotrel–Dubousset rod rotation. A preliminary report. *Spine* 1997;22:1913-21.

15. Liu X-C, Fabry G, Labey L, Van Den Berghe L, Van Audekercke R, Molenaers G, et al. A new technique for the three-dimensional study of the spine in vivo by using a motion-analysis system. *J Spinal Disord* 1997;10:329-38.

16. Bellefleur C, Labelle H, Dansereau J, De Guise J, Stokes IA, Rivard C-H, et al. [Intraoperative 3D evaluation of Cotrel–Dubousset procedure for the treatment of idiopathic scoliosis.] *Ann Chir* 1994;48: 723-30.

17. Delorme S, Labelle H, Poitras B, Rivard C-H, Coillard C, Dansereau J. Pre-, intra-, and postoperative three-dimensional evaluation of adolescent idiopathic scoliosis. *J Spinal Disord* 2000;13:93-101.

18. Mac-Thiong J-M, Labelle H, Vandal S, Aubin C-É. Intra-operative tracking of the trunk during surgical correction of scoliosis: a feasibility study. *Comput Aid Surg* 2000;5:333-42.

19. Milne AD, Chess DG, Johnson JA, King GJ. Accuracy of an electromagnetic tracking device: a study of the optimal operating range and metal interference. *J Biomech* 1996;29:791-3.

20. Drerup B. Accuracy requirements in optical back shape analysis. What is enough for the clinic? In: Sevastik JA, Diab KM, editors. *Research into spinal deformities 1.* Amsterdam: IOS Press; 1997. p. 477-80.

21. Amiot L-P, Lang K, Putzier M, Zippel H, Labelle H. Comparative results between conventional and computer-assisted pedicle screw installation in the thoracic, lumbar and sacral spine. *Spine* 2000;25:606-14.

Correction

Dans le numéro d'avril du journal, à la première ligne de la version française du résumé de l'article «An expanding role for cardiopulmonary bypass in trauma» (*Can J Surg* 2002;45[2]:96), l'expression «cardiopulmonary bypass» a été incorrectement traduite. La phrase devrait se lire comme suit : «**Objectifs :** Analyser l'expérience de la circulation extracorporelle (CEC) en traumatologie au Centre de...». Dans le reste du texte, il faut remplacer l'acronyµme PAC par CEC.