11 males and 6 females ranging in age from 25 to 56 years with a mean age of 43.3 years. Of the 17 patients, 13 were treated for atlantoaxial dislocation, and 4 were treated for atlantoaxial deformity. All patients suffered from neck and shoulder pain, including 5 patients with accompanying cervical cord compression. Imaging examination showed that all 17 patients suffered from cervical instability or dislocation. Fifteen of the patients could fully recover before the surgery, while the other 2 could only generally recover. After surgery, there was no obvious pressure on the anterior aspect of the spinal cord. This study was approved by the ethics committee.

Design and production of a modified 3D-printed navigation template

We used a LightSpeed 16-slice spiral CT machine (GE, USA) for the imaging examinations. The scanning range included three segments from the first cervical vertebra to the third cervical vertebra with a 1.25-mm slice thickness, 5.0-mm pitch, 9.37-mm/s table speed, 120-kV voltage, and 200-mA current. Scanned images were saved in DICOM format, and the DICOM files were imported into the 3D image producing and editing software Mimics 17.0 (Materialise, Belgium) to construct 3D models of the target cervical area. To avoid damage in the trajectory to the pedicle cortex, preliminary simulation of pedicle screw placement was conducted with computer-aided design software Creo2.0 (PTC, America) using a cylindrical simulated screw with a diameter of 3.5 mm to observe the positional relationship between the trajectory and pedicle in the transverse, sagittal and coronal views of the 3D image. The axis of the cylinder 3.5 mm in diameter was used to build a screw placement guide tube with an inner diameter of 2.1 mm and a vertebral lamina with a length of 15 mm. The template location surface was formed by removing the interfering parts of the template and 3D model after designation of the screw hole position. A cylindrical range pole 3.5 mm in diameter was rebuilt based on the preset axis line of the screw hole. The range pole was moved approximately 10 mm toward the screw hole, and the average thickness of the template was set at approximately 6 mm. The template file was imported into a Formlab 3D printer (Formlabs, USA) to print the cervical pedicle screw placement template. Ethylene oxide was subsequently used to disinfect the template, which was later sealed for future use.

Clinical application of modified 3D-printed template

A preoperative simulation surgery was conducted using the 3D-printed template in this study. Kirschner wire was drilled through the guide channel of the modified 3D-printed navigation template and the pedicle to ensure that the wire was completely in the pedicle and would not break the pedicle cortex. *In vitro* testing demonstrated the accuracy of the modified 3D-printed navigation template. After feasibility of the treatment was assured, the navigation template was disinfected with ethylene oxide before use on patients. All patients maintained an atlantoaxial reduction position with a skull traction weight of 3-6 kg. After receiving general anesthesia, patients in the prone position were incised in the middle of neck to expose the posterior atlantoaxial region with complete dissection of the muscles and ligaments attached to the lamina and spinous process. The disinfected modified 3D-printed navigation template was later attached to the lateral mass, lamina, and spinous process of the corresponding vertebra. Next, after close observation, the surgeons drilled into the vertebral bone cortex to a depth of 10 mm with an electric drill and a 2.0-mm-diameter bit, and assistants subsequently attached the template. Parallel with the direction of the guide posts, the electric drill was used in the guide channels to investigate optimum screw placement and to observe the post's direction and movement. Probes were used after drilling to detect whether the internal walls of the screw channels were intact. Threads and pedicle screws with a diameter of 3.5 mm were placed once the intact screw channels were confirmed. After screw placement and lateral observation using a C-arm X-ray machine, the screw position was confirmed, and the surgeons kept patients in the optimum reduction position after adjusting their heads and necks. Bone grafting was completed after screw-rod fixation. Finally, drainage tubes were inserted, and the incision was sutured outward.

Postoperative management

After surgery, patients were kept under strict bed rest with the cervical spine held stationary and were turned over axially as needed. The drainage flow of the operative site was observed, and the drainage tube was removed if the drainage flow was less than 50 ml/24 h without cerebrospinal fluid leakage. Before surgery, the patients had taken an antibiotic for 24-48 h, a dehydrant for 3-5 d, and a gastric acid suppression agent for 3-5 d. Adrenalineand was added for 3-5 d if there was impaired spinal cord function before surgery. Patients wore a cervical support device to perform bedside exercises 3 d after surgery.

Assessment

Regular atlantoaxial CT scanning was used to observe the position of the pedicle screw. The accuracy of screw placement was assessed with the Kawaguchi standard by observing the positional relationship between the screw and pedicle, as follows: Level 0: the screw is completely in the pedicle; Level 1: the screw is out of the cortex of the pedicle by less than 2 mm, and no screw-related complications occurred, including nerve or vertebral artery injury; Level 2: the screw is out of the cortex of the pedicle by more than 2 mm, and no screw-related complications occurred, including nerve or vertebral artery injury; Level 3: Screw-related complications occurred, including nerve or vertebral artery injury. Levels 0 and 1 were considered to represent accurate screw placement.

Using deviation analysis in Mimics software, the transverse and sagittal angles of the pre- and postoperative trajectories were measured and compared (7). Transverse angle: the angle between the CT-reconstructed trajectory and the sagittal midline. Sagittal angle: the angle between the left view of the CT-reconstructed trajectory and the endplate of the vertebra.

The VAS score for cervical and shoulder pain was recorded 1 d before, 3 d after and six months after surgery. In this scoring system (with a full score of 10), 0 represents no pain, and 10 represents insufferable pain. The JOA score was used (with a full score of 17) to evaluate the patient's cervical nerve function; in this system, the higher the score, the better the nerve function.

RESULTS

Assessment of surgical results

The surgeries on all 17 patients were successful, with a mean procedure time of 106 ± 25 min and a mean operative