Cervical Spine Status of Pilots and Air-Controllers of Airborne Early Warning and Control Aircraft

Young Ho Shin; Chul Yun; Andrew Hogyu Han

INTRODUCTION: Many countries have developed their own airborne early warning and control (AEW&C) systems for use in surveying their territorial sky in real time. However, a review of the literature suggests that no studies have been conducted to analyze the cervical spine of pilots and air-controllers of AEW&C aircraft.

METHODS: The study subjects were 80 pilots and air-controllers of AEW&C aircraft with a period of service of > 1 yr and had data on physical examinations, simple radiographs and functional scores of the axial skeleton, and questionnaires about lifestyle and working conditions. Information about physical characteristics and experience of neck pain were collected. Functional scores including the neck disability index and short-form 36-item health survey were obtained. Radiological measurements were performed for the C2-7 Cobb angle and degree of forward head posture.

RESULTS: Of the 80 subjects, 33 (41.3%) had experienced neck pain and 63 (78.8%) had impaired cervical lordosis. The results of functional and radiological evaluations were not significantly different between pilots and air-controllers. In multivariate analysis, only the age was significantly related to the occurrence of impaired cervical lordosis. However, there were no significant factors related to the occurrence of neck pain.

DISCUSSION: The results of this study suggest that the working environment of pilots and air-controllers of AEW&C aircraft has a negative effect on their cervical spine. Age seemed to be the most significant factor affecting the occurrence of impaired cervical lordosis in these subjects.

KEYWORDS: airborne early warning and control, neck pain, cervical lordosis, air-controller.

Shin YH, Yun C, Han AH. *Cervical spine status of pilots and air-controllers of airborne early warning and control aircraft.* Aerosp Med Hum Perform. 2017; 88(5):476–480.

The airborne early warning and control (AEW&C) system is an airborne radar system designed to detect aircraft, ships, and vehicles at long ranges, enabling command and control of the battlespace. As this system is managed by a mobile aircraft, it could carry out wide range surveillance and is less vulnerable to counter-attacks than a fixed ground-based radar. Many countries have developed their own AEW&C systems for use in surveying their territorial sky in real time.

Pilots and air-controllers of AEW&C aircraft are exposed to different flight environments from those of usual military aircraft, such as high-performance aircraft (HPA) or rotary-wing aircraft (RWA). Pilots who operate AEW&C aircraft are not exposed to the high gravity forces of HPA or the repetitive vibrations of RWA. Instead, as the number of AEW&C aircraft is limited, the duration of a single duty is longer in an AEW&C aircraft than in other aircraft types, to minimize the vacancies between surveillances. Behind the cockpit of AEW&C aircraft, the air-controllers are focused on their computer monitors to analyze the information from the AEW&C systems. When an abnormal movement or signal is detected through the radar, the air-controllers clarify the target and deliver the information to their superior. Therefore, air-controllers need to keep their eye on their computer monitors at all times during their duty, regardless of aircraft movements.

Several studies have evaluated the role of occupations or specific postures on the functional and radiological changes of an individual`s spine.[6,16,24] In addition, it is known that the aircraft type and the flight environment are risk factors for spinal disorders in aviators.[11] However, no studies have analyzed the

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This manuscript was received for review in August 2016. It was accepted for publication in January 2017.

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DOI: https://doi.org/10.3357/AMHP.4734.2017

cervical spine of pilots and air-controllers of AEW&C aircraft. The purpose of this study was to evaluate the functional and radiological status of the cervical spine of pilots and air-controllers of AEW&C aircraft, and to determine whether the role of these aircrew personnel (pilot or air-controller) could influence the status of their cervical spine. We hypothesized that the functional and radiological status of the cervical spine of air-controllers are worse than those of pilots. In addition, factors related to the occurrence of neck pain and cervical spine malalignment were analyzed.

METHODS

Subjects

All AEW&C aircraft are managed by one command station in our country. Between May 2014 and December 2014, 101 pilots and air-controllers of AEW&C aircraft underwent a thorough musculoskeletal evaluation at our institution. The evaluation included physical examinations performed by one flight surgeon specialized in orthopedic surgery, taking of simple radiographs and functional scorings of the axial skeleton, and questionnaire surveys about lifestyle and working conditions. Among the potential subjects, we enrolled those who met the following inclusion criteria: 1) had worked more than 1 yr as AEW&C aircraft crew; and 2) agreed to enroll in the study and filled in all questionnaires and functional scorings. We excluded subjects with any history of spine surgery and major spinal problems such as spinal fractures or herniated intervertebral disc. There were 80 pilots and air-controllers who met our criteria and were finally enrolled. The study was approved by the institutional review board of the Aerospace Medical Center of the Republic of Korea Air Force (ROKAF) (ASMC-15-IRB-008).

Materials

The studied subject variables in the subjects consisted of three categories: 1) physical characteristics including body size; 2) lifestyle information; and 3) working condition and period of service in the AEW&C aircraft. The physical characteristics of age, sex, height, weight, and body mass index (BMI) were included. BMI was calculated by using the provided height and weight. The mean age of the enrolled pilots and air-controllers was 31.8 ± 5.2 yr (range, 23–42 yr); mean height, 175.3 ± 6.0 cm (range 161–186 cm); mean weight, 73.1 ± 10.4 kg (range 51–98 kg); and mean BMI, 23.7 ± 2.7 kg · m^{-2} (range, 18.1–30.9 kg · m^{-2}). Of the 80 subjects, 7 (8.8%) were women, and all of them were pilots.

The evaluated lifestyle characteristics included smoking, alcohol use, and regular exercise. Smoking included whether the respondent smoked cigarettes or not, and the amount smoked. Alcohol use included whether the respondent drank alcohol or not, the frequency of alcohol consumption, the amount of alcohol consumed per occasion, and the amount of alcohol consumed per week. Finally, exercise included whether the respondent engaged in regular aerobic or anaerobic exercise. We defined regular exercise as at least three exercise sessions per week.[13]

The amount of cigarettes smoked was quantified in pack years (py). In the analysis, nonsmokers were considered to smoke 0 py. Smokers accounted for 26.3% (21 of 80) of the cohort. The mean amount of cigarettes smoked was 2.0 ± 4.0 py (range, 0–16 py). Pilots and air-controllers who drank regularly accounted for 86.3% (69 of 80) of the cohort. The frequency of alcohol consumption was 0.9 ± 0.7 times/week (range, 0–2.5 times/week). The amount of alcohol consumed per occasion was measured in bottles, in which 1 bottle is equal to one bottle of soju (Korean gin, about 360 ml, and 20–25% alcohol by volume). The mean amount of alcohol consumed per occasion was 1.1 ± 0.7 bottles (range, 0–2.5 bottles). The weekly alcohol consumption was calculated by multiplying the frequency of alcohol consumption by the amount of alcohol consumed per occasion. Accordingly, the mean weekly alcohol consumption was 1.2 ± 1.3 bottles/week (range, 0–5 bottles/week). Nondrinkers were considered to drink 0 bottles of alcohol. Regular aerobic or anaerobic exercises were performed by 82.5% (66 of 80) of the subjects.

The members of AEW&C aircraft were composed of two different duties: pilots and air-controllers. Of the cohort 21 were pilots and 59 were air-controllers. The mean period of service for this group was 32.0 ± 9.9 mo (range, 12–60 mo). As the flight schedule of AEW&C aircraft was systematically controlled according to job rotation of the pilots and air-controllers, the mean working hours in the aircraft was not different between each subject.

Experience of neck pain was defined as the presence of any neck pain or pain radiating to an upper extremity during or after a flight. The functional evaluations of subjects were performed by using subject-reported outcomes: 1) neck-related disability: neck disability index (NDI);[22] and 2) general health-related quality of life: short-form 36-item health survey (SF-36), physical component score (PCS), and mental component score (MCS).[10]

Simple cervical spine radiographs were taken in all subjects. A lateral radiograph of the cervical spine was taken with the subjects standing in neutral position with their head straight. The subjects were asked to elevate their chins straightly and to drop their shoulders as far as possible.

Procedure

The cervical spine radiographs were assessed on a 21.3-in liquid crystal display monitor (MDNG-6121; Barco, Kortrijk, Belgium) in portrait mode by using Picture Archiving and Communication System software. We evaluated the sagittal curve of the cervical spine by using the Cobb method, with the angle between the inferior end plate of C2 and the inferior end plate of C7.[17] The normal values of C2-7 Cobb angle were determined to range from 20° to 35° according to previous studies.[4,7,9] To measure the degree of forward head posture, the following two parameters were measured: distance 1 (D1), the horizontal distance between the anterior margin of the C1 body and the posterior margin of the C7 spinous process, and distance 2 (D2), the horizontal distance between the ear hole and the midline of the C7 lower margin (**Fig. 1**).[21] These

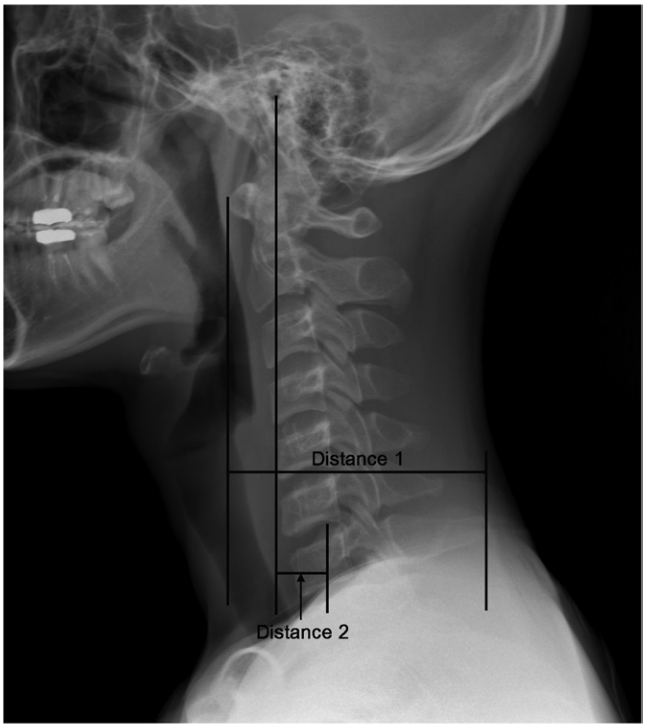

Fig. 1. Lateral radiograph of the cervical spine. The forward head posture was measured with two parameters: distance 1 (D1), the horizontal distance between the anterior margin of the C1 body and the posterior margin of the C7 spinous process, and distance 2 (D2), the horizontal distance between the ear hole and the midline of the C7 lower margin.

measurements were performed by two of the authors, and the mean value of the two measurements was used for analyses.

Statistical Analysis

All statistical analyses were performed by using IBM-SPSS ver. 22.0 software (IBM Corp., Armonk, NY, USA), and a P-value of < 0.05 was considered significant. Descriptive statistics, including means and 95% confidence intervals, were estimated for the subjects. Differences in subject variables and dependent variables between pilots and air-controllers were assessed with Student's t-test or Fisher's exact test according to the characteristics of the evaluated parameters. Associations between subject variables and the occurrence of neck pain and impaired cervical lordosis were analyzed with univariate analysis by using binary logistic regression analysis. Multivariate logistic regression analyses were done to analyze the odds ratio (OR) for the occurrence of neck pain and impaired cervical lordosis with all variables that were used in the univariate analysis (binary logistic regression, forward conditional method). The interobserver reliability of radiographic measurements was assessed with intraclass correlation coefficients (ICCs) derived from a two-way random effect model.[20]

RESULTS

Of the 80 subjects, 33 (41.3%) had experienced neck pain during or after a flight. The mean NDI score was 9.3 ± 6.5 (range, 0–30), PCS was 54.0 ± 4.4 (range, 42.0–61.9), and MCS was 50.1 ± 7.1 (range, 19.4–62.3) on the SF-36. The mean C2-7 Cobb angle was 12.5° ± 8.2° (range, −4.0°–34.5°). The C2-7 Cobb angle of 63 of 80 patients (78.8%) was < 20°, and no patients showed a C2-7 Cobb angle of > 35°. The mean D1 was 78.7 ± 8.6 mm (range, 55.6–104.9 mm) and D2 was 0.9 ± 8.7 mm (range, −25.6–27.6 mm). The radiological measurements presented excellent ICC for interobserver reliability, as follows: ICC = 0.965 (95% CI, 0.943–0.979) in the C2-7 Cobb angle, ICC = 0.930 (95% CI, 0.886–0.957) in D1, and ICC = 0.916 (95% CI, 0.838–0.957) in D2.

The comparisons of subject variables and dependent variables between pilots and air-controllers are described in **Table I**. BMI, amount of cigarettes smoked, and amount of alcohol consumption were significantly lower in the pilot group ($P = 0.018$, $P = 0.002$, and $P = 0.049$, respectively). The results of univariate analysis with binary logistic regression for variables associated with the occurrence of neck pain and impaired cervical lordosis are shown in **Tables II** and **III**. None of the variables were statistically significant on multivariate analysis for the occurrence of neck pain (binary logistic regression, forward conditional method). However, age (OR, 1.481; 95% CI, 1.217–1.802; $P < 0.001$) was statistically significant on multivariate analysis for the occurrence of impaired cervical lordosis (binary logistic regression, forward conditional method).

Table I. Subject and Dependent Variables in Aviators of AEW&C.

SUBJECT VARIABLES	PILOT (*N* = 21)	AIR-CONTROLLER (*N* = 59)	*P*-VALUE
Age (year)	31.5 (1.7)	31.9 (5.2)	0.562
Sex (men: women)	19:2	54:5	0.885
BMI (kg/m^2)	22.7 (1.6)	24.0 (2.4)	0.018*
Amount smoked (pack years)	0.6 (1.2)	2.4 (3.8)	0.002*
Alcohol consumption amount (bottles/wk)	0.8 (0.9)	1.4 (1.1)	0.049*
Regular exercise (yes: no)	17:4	49:10	0.829
Period of service (months)	29.9 (8.1)	32.6 (8.3)	0.202
Dependent variables			
Experience of neck pain (yes: no)	8:13	25:34	0.734
NDI	8.9 (6.0)	9.5 (6.8)	0.742
PCS	53.5 (4.6)	54.2 (4.4)	0.530
MCS	50.1 (5.3)	50.1 (7.7)	0.993
C2-7 Cobb angle (°)	14.7 (5.5)	11.7 (8.8)	0.151
Distance 1 (mm)	77.5 (8.5)	79.1 (8.6)	0.470
Distance 2 (mm)	-1.4 (9.0)	1.7 (8.6)	0.163

* Statistically significant ($P < 0.05$).

DISCUSSION

Several studies have evaluated neck pain and spinal status in pilots and flight crew.[3,12,15] However, most studies were focused on pilots and flight crew of HPA or RWA. To our knowledge, this is the first study to evaluate the

Table II. Results of Univariate Analysis Using Binary Logistic Regression for Variables Associated with the Development of Neck Pain.

	B(SLOPE)*	*P*-VALUE	ODDS RATIO (95% CI†)
Aviators\` duty: pilot vs. air-controller	0.622	0.312	1.862 (0.558-6.207)
Sex: men vs. women	1.741	0.145	5.701 (0.549-59.161)
Age (years)	0.023	0.706	1.024 (0.907-1.155)
BMI (kg/m^2)	-0.134	0.343	0.875 (0.663-1.154)
Service period (months)	0.001	0.983	1.001 (0.937-1.069)
Amount smoked (pack years)	-0.344	0.039	0.709 (0.512-0.982)
Weekly alcohol consumption (bottles/wk)	0.340	0.229	1.406 (0.807-2.447)
Regular exercise: yes vs. no	0.523	0.462	1.687 (0.419-6.793)

* The binary form \`characteristic α vs. β\`, \`slope\` is positive if characteristic β is more positively related to the dependent variable than characteristic α, and vice versa.
† CI = confidence interval.

functional and radiological status of the cervical spine of pilots and air-controllers of AEW&C aircraft.

It is known that the rapid changes of gravity forces of HPA and vibrations of RWA could contribute to the development of neck pain in pilots and flight crew. The 1-yr prevalence of neck injury in F16 pilots was 56.6%, and of 127 helicopter pilots, 57% experienced neck pain with a 3-mo prevalence.[1,3] Although the crew of AEW&C aircraft are not exposed to high gravity forces and vibrations, 41.3% of the subjects in this study had experienced neck pain. This suggests that the flight performance and the flight environment itself could be risk factors for neck pain without special considerations.[23]

Improper posture and spasms of posterior neck muscles are two important causes of cervical spine malalignment and posterior neck pain.[15] Air-controllers of AEW&C aircraft are required to keep their eye on the computer monitors at all times during a flight, to analyze the information from the AEW&C system. To facilitate communication between members and effectively utilize the limited space of an aircraft, the computers are attached side to side on the inner walls of the aircraft body in two columns. Therefore, the neck of an air-controller is fixed in a flexed position regardless of aircraft movement, and there is insufficient space and time for stretching or loosening the body. We hypothesized that the functional and radiological status of the cervical spine of air-controllers are worse than those of pilots. However, the proportion of neck pain experience and the functional scores were not different between pilots and air-controllers. In radiological evaluations, the loss of cervical lordosis and forward head position were not significantly different between the two groups.

The lack of a significant relationship between the type of duty, and the functional and radiological status of the cervical spine could be explained in a few ways. First, there are many work-related risk factors for neck pain above the type of job. These risk factors include physical factors such as repetitive tasks, awkward body postures, vibration, and forceful exertion, as well as psychosocial factors such as a fast work pace, time pressure, competing demands, and the combination of high demands and poor controls.[5,19,23] Although the role of a pilot and that of an air-controller are different, each of them performs repetitive duties under urgent situations in the same aircraft. Therefore, risk factors other than the type of duty could be similar between the two groups. This could explain the lack of a relationship between the type of duty and cervical spinal status. Second, as the population of this study was limited to the pilots and air-controllers of AEW&C aircraft, the numbers of the two groups were small for drawing meaningful results. Most studies about work-related risk factors of neck pain were done with tens of thousands of subjects.[18,23]

A few studies have evaluated the cervical spine of pilots and flight crew in other aircraft similar to AEW&C aircraft. In an analysis of cervical magnetic resonance images of 10 transport pilots with 20 yr of experience, Landau et al. reported that 8 of 10 pilots had cervical spine degeneration but only one pilot had neck pain.[14] Hermes et al. analyzed the spinal disorders of 13,273 military cockpit aircrew of fixed-wing aircraft. In their analysis, a statistically significant association was observed between older age category and cervical disorders.[11] Although the study design and populations were different from those of our study, we could confirm the harmful effect of the working environment on the cervical spine of pilots and flight crew of large aircraft.

Impaired cervical lordosis is not the direct cause of neck pain, but is understood as a process of degenerative change.[8] The exact etiology and mechanisms of impaired cervical lordosis remain unclear in most cases.[2] In our study, aging is the only variable that was related to impaired cervical lordosis. This result could be attributed to age-related degenerative disc disease; however, as most of the subjects in our study were $<$ 40 yr of age, this phenomenon could not be explained solely as due to

Table III. Results of Univariate Analysis Using Binary Logistic Regression for Variables Associated with the Impaired Cervical Lordosis.

	B(SLOPE)*	*P*-VALUE	ODDS RATIO (95% CI†)
Aviators\` duty: pilot vs. air-controller	0.431	0.660	1.538 (0.226-10.470)
Sex: men vs. women	19.550	0.999	0.001 (0.001-99.999)
Age (years)	0.473	0.001‡	1.604 (1.199-2.147)
BMI (kg/m^2)	-0.032	0.843	0.969 (0.707-1.327)
Service period (months)	-0.028	0.549	0.972 (0.886-1.066)
Amount smoked (pack years)	-0.159	0.157	0.853 (0.685-1.063)
Weekly alcohol consumption (bottles/wk)	0.085	0.784	1.089 (0.594-1.997)
Regular exercise: yes vs. no	-0.328	0.747	0.720 (0.098-5.297)

* The binary form \`characteristic α vs. β\`, \`slope\` is positive if characteristic β is more positively related to the dependent variable than characteristic α, and vice versa.
† CI = confidence interval.
‡ Also revealed to be significant in multivariate analysis.

the normal aging process. Because age was proportional to the total flight hours of the pilots and air-controllers, including in other types of aircraft, the cumulative effect of flight could indirectly influence this result.[12]

Our study has several limitations that need to be considered. First, as this study is a cross-sectional study, this result could not properly reflect the influence of the aircraft environment on the health status of the pilots and flight crew. A further longitudinal study with this cohort is needed. Second, to simplify the lifestyle questionnaire, we only evaluated the amount of cigarettes smoked, alcohol consumption, and exercise pattern as the lifestyle variables. Other factors including sleep pattern and duration of use of a personal computer or smartphone could be interesting subject variables in future studies. Third, the characteristics of neck pain including symptom severity and duration were not examined.

In conclusion, although the pilots and flight crew of AEW&C aircraft are not exposed to the high gravity forces of HPA and vibrations of RWA, 41.3% of the subjects had experienced neck pain and 78.8% of the same cohort had impaired cervical lordosis. These results suggest that the working environment of AEW&C aircraft could have a negative effect on the cervical spine of the pilots and flight crew. The functional and radiological status of the cervical spine was not significantly different between pilots and air-controllers. Among the variables, aging was significantly related to the occurrence of impaired cervical lordosis. AEW&C aircraft are widely used in many countries. To enable the pilots and air-controllers to securely defend the territorial sky, it is necessary to closely manage their musculoskeletal system, especially their cervical spines.

ACKNOWLEDGMENTS

This work was supported by a grant of the Aerospace Medicine Research Project funded by the Medical Division, Headquarter, Republic of Korea Air Force (ROKAF-ASMC-2015-AMRP-008).

We thank Sohyun Oh for her help with literature collection and statistical assistance, and Joo Hyun Oh for her English proofreading.

The opinions stated in this article are not the representative of those of the Republic of Korea Air Force.

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