The changes of corneal biochemical properties after simulated ejection on the ground

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Abstract

Ejection in high acceleration force may result in several physiologic responses and injuries. However, little is known about the effects of ejection on corneal rigidity and elasticity when pilots ejected from the cabinet after high + Gz acceleration. The aim of this study was to determine the changes of corneal biomechanical properties after simulated ejection. Thirty male pilots were enrolled in the study. The ejection seat training system at the Aviation Physiology Research Laboratory (Taiwan) was used to simulate ejection process at 8 times of gravitational force in head to toe Z-axis direction (+8 Gz force). Ocular Response Analysis (ORA) was applied to detect the dynamic bi-directional changes of cornea in the subjects who underwent simulated ejection. The related parameters were evaluated before ejection such as corneal hysteresis (CH), corneal resistance factor (CRF), and central corneal thickness (CCT). The bare visual acuity and refraction were also recorded. At instant, 15mins and 30mins after ejection, the parameters were detected as well. Two hours after ejection, the anterior chamber and relative position of lens were observed under the slit lamp. All the bare visual acuity and refractive errors remain unchanged during the study. There were no significant change of CH and CRF before and after ejection. However , the CCT increased significantly immediately after(548.5 ± 18.7 vs 590.8 ± 15.4, $p < 0.005$) and 15 min after (548.5 ± 18.7 vs 587.5 ± 16.2, $p < 0.005$) compared with the values before ejection. No hyphema, sub-location, or dislocation of the lens, or any rupture of the anterior lens surface were observed. After safe ejection on the ground, the main corneal biomechanical properties had no significant change. Besides, the refraction and bare visual acuity remained stable. We concluded that the rigidity and elasticity of the cornea, the stability of lens and the anterior segment of ocular structure were not apparently affected by high G-force. Nevertheless, our experiments were performed on the ground. During real high altitude ejection, true environmental factors such as windblast, low temperature, and hypoxia remained challenger to pilots. We need further studies in the future. [Life Science Journal. 2010; 7(1): 46 – 50] (ISSN: 1097 – 8135)

Key Words: Corneal hystresis, Corneal resistance factor, G-force

Introduction

The ejection seat has been responsible for saving the lives of thousand of pilots around the world since its introduction in the later 1940's. Escape system in fighters is a device which was first developed by German Air Force and designed to rescue the pilot in crisis (1). In early stage of World War II, military aircrafts flied at lower altitudes and slower speeds in combat. When an emergency occurs, they can use manual parachutes and make rapid escapes in time (2). With increasing in speed of modern vesicle developed, older manual methods might induce more risks during ejections associated with downward acceleration (3). For that reason, new equipment is necessary and ejection seat system developed. The ejection seat is the main component of the modern emergency rescue system. When the military pilots must leave the aircraft immediately, they should push the button at once. One aircrew with his seat may eject by an explosive cartridge stowed beneath a rocket system from the cabinet under high acceleration force around 6-12 times of G (gravitation) (4).

However, ejection in high acceleration force may result in several physiologic responses (5). The cornea has been a subject of interest to ophthalmologist and other eye careers because it playa a critical role in human undergoing high-acceleration movement. To our knowledge, there were no related articles to evaluate the effects of ejection after high-acceleration force exposure on human corneal rigidity and elasticity (so called biomechanical properties). The goal of this study was to investigate the influence of ejection on corneal biomechanical characteristics. In our experiment, Fig. 1 shows a simulated ejection seat on the ground was used to elicit an acceleration force set at eight times of gravitational force in head-to-toe Z-axis direction of (+8 Gz force). The ORA (Ocular Response Analyzer) was applied to evaluate the changes of corneal biomechanical properties.

Materials and Methods

The subjects were 30 healthy male pilots between 20 and 28 (mean = 24.5) yr of age. Informed consent was obtained from each volunteer before participation in the studies began. All experimental protocols were conducted in accordance with the Declaration of Helsinki. Ethical approval for this study in advance was obtained from the institution review board. All the subjects with history of ocular or systemic diseases, such as hypertension, diabetes, cataracts, glaucoma, or uveitis were excluded from the study. They were instructed to not to take any medication within 72 hours. In Fig 2, the simulated ejection seat system at the Aviation Physiology Research Laboratory (Kaohsiung, Taiwan) was used to elicit an acceleration force set at +8Gz on the ground level. The total height of the instrument was 8 meters. When ejected, the subject within the seat reached the highest point (8 meters in height). Then the subject sent back by machine within 5 seconds.

Before ejection, each volunteer underwent a series of examinations including corneal biochemical properties, refraction and bare visual acuity. The Ocular Response Analyzer (ORA, Reichert, Buffalo, NY, USA) are the new instrument that measures the main corneal biomechanical properties including cornea hysteresis (CH), cornea resistance factor (CRF) and central corneal thickness (CCT). Bare visual acuity was tested were at 4 meter distance and recoded by EDTRS (Early Treatment of Diabetes Retinopathy) logMAR chart. Refractive errors were gained by Auto-refractometer (AR310, Nidek, Tokyo, Japan). Due to the limitations of time, only the left eyes of all subjects (total 30 eyes) were enrolled.

After the investigation, one subject sat on the ejection seat. At the instant of ejection (the seat may be sent back by automobile machine within 5 seconds, and now we represent the data as the immediate time after ejection), 15 minutes, and 30 minutes after ejection, the above series of examinations should be repeated again. All results are corrected and analyzed. Two hours after ejection, we checked the anterior chamber and its 360 degree of angle (hemorrhage or not) by the three-mirror gonioscopy and the relative position of the lens (dislocation, sub-dislocation or not) from full-dilated pupils with cyclopegia under the slit-lamp examination.

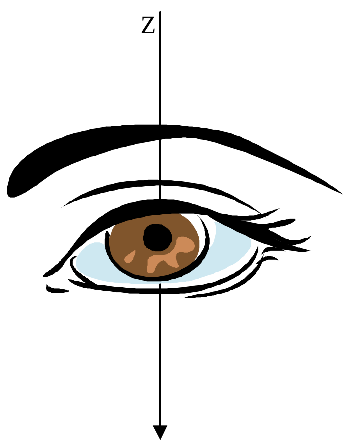

Fig 1：The direction of gravitational force is from head to toe in Z-axis direction (+ Gz force) after ejection. .

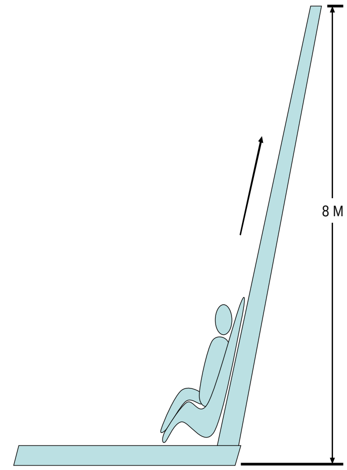

Fig 2：The simulated ejection seat system at the Aviation Physiology Research Laboratory (Kaohsiung, Taiwan) was used to elicit an acceleration force set at +8Gz on the ground.

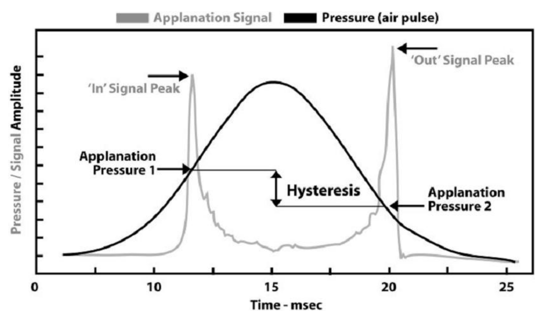

Fig 3: Explanation of corneal hystresis by the ocular response analyzer. By applying air-puff, a light reflex from the corneal surface changes and is detected by a sensitive sensor. There is a “delay time” in recovery from the convex condition, which is an indicator of absorbed energy during the deformation processes (corneal hystresis) .

All results are expressed as the mean ± standard deviation (SD). Bare visual acuity is indicated as LogMAR (The chart has five letters per low ranging in size from + 1.0 to -0.3 log MAR). A paried t-test was used to compare the physiological parameters before and after ejection associated with +8 Gz. $P<0.005$ was accepted as significant.

Results

All the data were collected for 30 eyes. In Table 1, there were no significant changes of CH and CRF before and after ejection associated with +8Gz. However ,in Table 2, the CCT increased significantly immediately after(548.5 ± 18.7 vs 590.8 ± 15.4, $p<0.005$) and 15 min after (548.5 ± 18.7 vs. 587.5 ± 16.2, $p<0.005$) compared with the values before ejection. Remarkable central corneal thickness increase was observed and persisted at least for 15 mins after ejection.

The bare visual acuity of all the pilots were 0.05 ± 0.03 (logMAR) and the mean refraction of subjects were – 0.50 ± 0.25 diopters (D) before ejection. In Table 3, two parameters of visual acuity remained un-change after simulated ejection at the same time.

Two hours after ejection, no hyphema or apparent blood clots tin the anterior chamber, and its 360 degrees of angles b y the Goldmann gonioscopy. In addition, we failed to find out the sub-location or dislocation of the lens or any rupture of the anterior lens surface under slit lamp examination.

Discussion

We can not commonly kwon the effects of high force around several times of gravitation (G-force) on the ground level. Meanwhile, every pilot especially the military aircrews had the special experience. Now ejection seats are installed in most military fighter and training aircraft around the world, and have saved the lives of many pilots. In time of crisis, they may survive with the eject system from high-speed fighter/attack by 8 times or higher of G gravitation on the sky. Now the egress systems of these weapon platform (such as F-15, F-16 and A-10), which use the Advanced Concept Ejection Seat (ACES-II), were developed and deployed after the Vietnam conflicts. The engineering design of the ACES-II provides for an escape envelope (system) of o to 600 KIAS(Knots Indicated Air Speed) and safe ejections up to high altitude, by mean of versatile operation depending upon both speed and altitude. During Operation Desert Storm, USAF lost four F-16 aircraft while mission on combat missions over Iraq and Kuwait, with four pilots ejecting safety (4). Today the simulated seat ejection system is very popular in the worldwide. Many military aircrews will receive well-training programs on the ground in peacetime. In the experiment, we use the system to create the impact of ejection safely to investigate corneal biomechanical properties and visual acuity of the volunteers in the ground level in Taiwan.

The emergencies that required ejection were obtained form accident records in which ejections were involved in the Japan Air Self-Defense Force between 1956 and 2004 (6). Engine failure was the most frequent reason. Mid-air collision, fire, and explosion, pilots' loss of human error, and fuel exhaustion comprised the majority of reasons for deciding to eject. Ejection under high acceleration force may result in several physiologic responses (7, 8), injuries and even fatality. The fatality rate ranged between 2.4% (Germany)(1) and 17.7% (USA) (9). They may die from cervical fracture, cardiac injury (10), and traumatic asphyxia. The other major and minor injuries including chronic subdural hematoma, spinal fracture (11), atlanto-axial dislocation (12), head injury, long bone fracture, rib fracture, burn, abrasion, limb injuries and neck sprain (13,14,15).

The abnormal ocular findings under different circumstance after ejection were sub-conjuctival hemorrhage, temporary loss of vision, and peri-ocular edema. It was caused by the high decelerative forces of abrupt onset applied from the rear while the blood vessels of the head and face are congested by high hydrostatic pressure. In addition, contusions and laceration over the eyes were ever reported (15,16). However, the impact of the corneal biomechanical properties after ejection was never surveyed in the past. Understanding corneal biomechanics is important for the accurate prediction of refractive surgery outcomes (17, 18), the use of contact lenses to change corneal topography, and the development of reliable correct factors for tonometry measurement .

In the past, we only use the concept of central corneal thickness (CCT) to investigate the corneal rigidity/elasticity and its function. In the last few decades, corneal biomechanics received more attention to define the corneal hyper-elasticity, the effects and hydration. Until 2005, the ocular response analyzer (ORA) was introduced as devices capable of acquiring an IOP measurement by Luce (19). The machine offers a new metric, corneal hystresis, it represents visoelastic properties. In addition, we can measure the corneal resistance factor and central corneal thickness (an ultrasound pachymetry attach to ORA) together. Now the CH and CRF were widely used by the ophthalmologists to predict the probability of ecstatic cornea after LASIK (20) as well as the early detection and difference diagnosis of glaucoma (21).

The ORA release a precisely metered air pulse that cause central 3mm of the cornea to move inwards. Thus, the cornea passes through applanation- inward applanation(P_1), then the past applanation phase where its shape becomes slightly concave. Twenty milliseconds after applanation, the air puff shuts off resulting in pressure decrease in a symmetrical fashion. During this phase the cornea shape tries to gain its normal shape. During this process the cornea again passes through an applanation phase-outward applnation(P_2). Theoretically, these two pressures should be the same, but this is not the cause. It is described as the bi-dynamic response that is the resistance to applanation manifested by the corneal tissue due to the viscoelastic properties. In Fig 3, the difference between the outward and inward pressure (P_1-P_2) is termed corneal hystresis (23) and is measured in mmHg. The P_1 is normally higher than P_2 where P_1 and P_2 are arbitrary units. The conversion formula of CRF by Luce (19) is that $CRF = \{ 0.1324 [(P_1 - 0.7)] P_2 \} - 7.46$. In general, CH was refers to the viscosity of cornea. Luce (19), however, regards that CH is the absorbing and dispersing ability of cornea and CRF represents the elastic properties of cornea. Ortiz (24) defined CRF as the sum of the corneal rigidity to resist the external force and the ability to prevent from deformation of the cornea.

However, it has never been reported in any studies about corneal biomechanics change after ejection in literatures review. In our experiment, we could not find the significant change of CH and CRF after ejection. We know that the cornea has viscoelastic characteristics due to its numerous fibers thickness, hydration, and the crossed distribution of collagenous fibers (22). The effect of high gravitational force on human including cardiovascular system was well-known. Meanwhile, the rigidity and elasticity of cornea may absorb and disperse the external G-force. Then the changes of CH and CRF were not significant after ejection. We suggested that if the military aircrew ejected on the sky, the CF and CRF may remain unchanged under high G force exposure.

Our experiment also revealed that the thickness of central cornea (CCT) increased significantly immediate and 15 mins after ejection. It means that the signs persisted at least for 15 mins after ejection. The values returned to the pre-ejection normal range 30 min after exposed to + 8 Gz. The minor changes may result from fiber arrangement or corneal edema after exposure to G-force, meanwhile because of the rebounding ability of the cornea, it returns to the value before ejection. We had ever observed a 10 % increase in CCT after + 9 Gz for exposure created by human centrifugation (25). The transient hydrostatic pressure may explain that findings. When the subject exposed to high gravity, the hydrostatic pressure of the ocular anterior chamber may increase. Then it may push the aqueous humor to flow across the corneal endothelium into the stroma, which may increase the corneal thickness (26).

In this experiment, we also found that the bare visual acuity remain stable even just immediately after ejection. Previous reports concerned with the occurrence of pathology in human during + Gz exposures have suggested some adverse effects including temporary vision, chest pain, dyspnea, motion sickness, nonpathological changes in the electrical activity of the brain, various cardiac arrhythmias, and unconscious (27). Some reasons of that symptoms and signs may be due to the hemodynamics changes of the pilots. It is the tendency that massive peripheral blood stasis in the lower extremities and the difficulty in returning to the heart and brain were noted under high G-force (8-12G). However, that effect may be apparent during a longer time (always persisted for 8 to 15 seconds). The exposed time was only 1 to 3 seconds after injection. Then the visual acuity of the military pilots may remain unchanged. Nevertheless, our experiments were performed on the ground. During the real ejection in crisis in the sky , the pilots may loss their helmet by the massive force (1). The strong effects of the windblast should be take into consideration. If the corneal biomechanics properties and visual function were affected by severe windblast or not, further studies are necessary in future.

The weight of human lens at 1 yr of age is about 140 mg. As it grows with age, it eventually weighs about 250 mg at the age of 80 yr of age (28). Till now, no previous studies have showed that the position of the lens of pilots will change under high speed flying or even after ejection. The structure and relative position of the lens play a important role in refraction. In our experiment, we also found that the refractive errors of the subjects remain stable after ejection. It is well known by ophthalmologists that if the relative position of lens had changed (such as dislocated into the vitreous cavity or anterior chamber of the eye, or sub-dislocation) after massive external forces, the zonules of the lens may tear. Then the refraction of the patient may be change and myopic shit is the predominant sign under auto-refractometer. Meanwhile, we checked the angle of anterior chamber and the relative position of the lens from full-dilated pupils two hours after ejection. No hyphema or apparent blood clots in the anterior chamber and its 360 degrees of angles. At the same time, we failed to find out the sub-location or dislocation of the lens or any rupture of the anterior lens surface. Although little platelet aggregation on the endothelium of Schlemm's canal under transmission electron microscopy (29), we could easily make the diagnosis of hyphema after stress under the slit-lamp examination. We should be able to make a conclusion that the stability of human lens and the anterior segment of ocular structure were not apparently affected by high G-force.

Table 1: The corneal hystresis and corneal resistance factor before and after ejection

	Before	**Immediate after**	**After 15 min**	**After 30 min**
CH(mmHg)	9.11 ± 1.86	10.22 ± 2.54	10.18 ± 1.49	9.19 ± 2.13
CRF(mmHg)	11.04 ± 2.05	12.11 ± 2.08	11.84 ± 1.56	11.12 ± .098

N=30 eyes
*Statistically significant difference ($P<0.005$).

Table 2: The central corneal thickness before and after ejection

	Before	**Immediate after**	**After 15 min**	**After 30 min**
CCT(μm)	548.5 ± 18.7	590.8 ± 15.4*	587.5 ± 16.2*	550.5 ± 20.4

N=30 eyes
*Statistically significant difference ($P<0.005$).

Table 3: The refraction and bare visual acuity before and after ejection

	Before	**Immediate after**	**After 15 min**	**After 30 min**
Refraction (D)	-0.50±0.25	-0.25±0.25	-0.25±0.25	-0.50±0.25
Bare visual acuity (LogMAR)	0.05±0.03	0.05±0.08	0.04±0.07	0.06±0.05

N=30 eyes
* Statistically significant difference ($P<0.005$)

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