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Neuropathological Evaluation of Military Parachutists: A Series from the DoW/USU Brain Tissue Repository

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DISCLAIMER

The opinions expressed herein are those of the author(s) and are not representative of those of the Uniformed Services University of the Health Sciences, The Walter Reed National Military Medical Center, the United States Armed Forces, or the United States Department of War.

CONFLICTS OF INTEREST

No conflicts of interest to report.

Parachute Operations - Exposure

Static-line parachuting

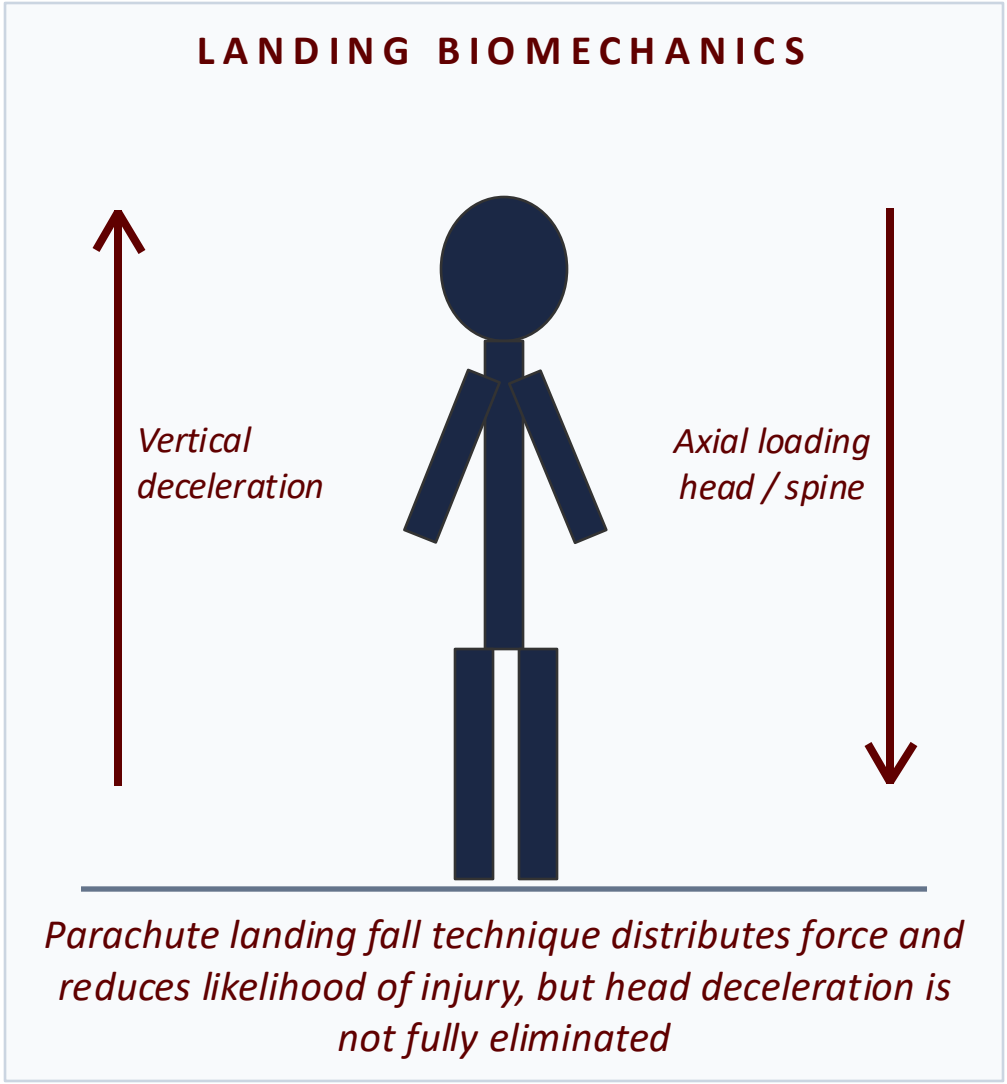
Standard descent rates approximately 22 ft/sec (≈15 mph) at ground contact, generating high-magnitude vertical deceleration forces transmitted axially through the spine and skull.

Career exposure is substantial

Airborne-qualified personnel routinely complete dozens to hundreds of jumps over a career. Many also sustain blast exposures and blunt head impact exposures, and related TBI, from other combat- and training-related activities.

Recognized acute morbidity

Concussions, vertebral compression injuries, and lower-extremity fractures related to parachute operation are well-documented. Chronic neuropathological sequelae are uncharacterized.



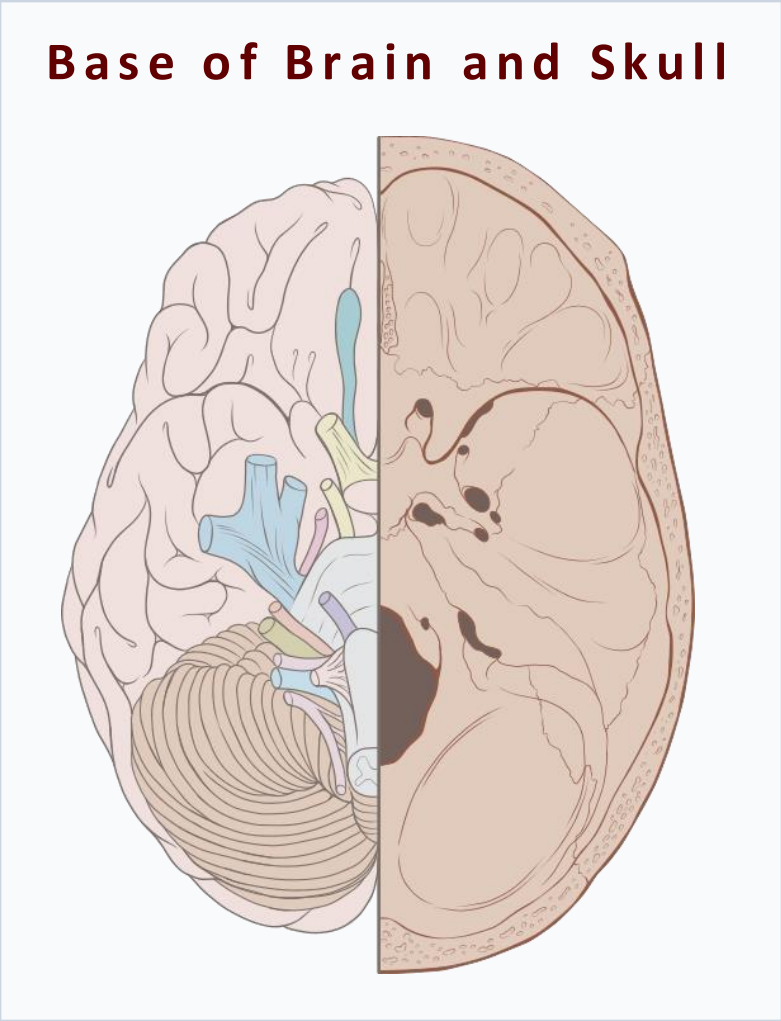
Parachute landing fall technique distributes force and reduces likelihood of injury, but head deceleration is not fully eliminated

MARINE CORPS BASE CAMP LEJEUNE, N.C. - Marines with 2nd Reconnaissance Battalion practice parachute landing fall (PLF) drills during pre-dawn hours

Parachute landing fall technique distributes force and reduces likelihood of injury, but head deceleration is not fully eliminated.

Additional, and less characterized, forces may include but not be limited to acceleration/deceleration associated with chute opening, mid-air collisions and other accidental events.

Anatomical Vulnerability of the Brain Base



Credit: Patrick J. Lynch

Why these regions?

Inferior brain structures rest against irregular bony surfaces of the anterior and middle cranial fossae and the tentorial edge.

Vertical deceleration forces are transmitted downward and may produce shear and/or compressive forces between brain and adjacent bone, dura, or vasculature.

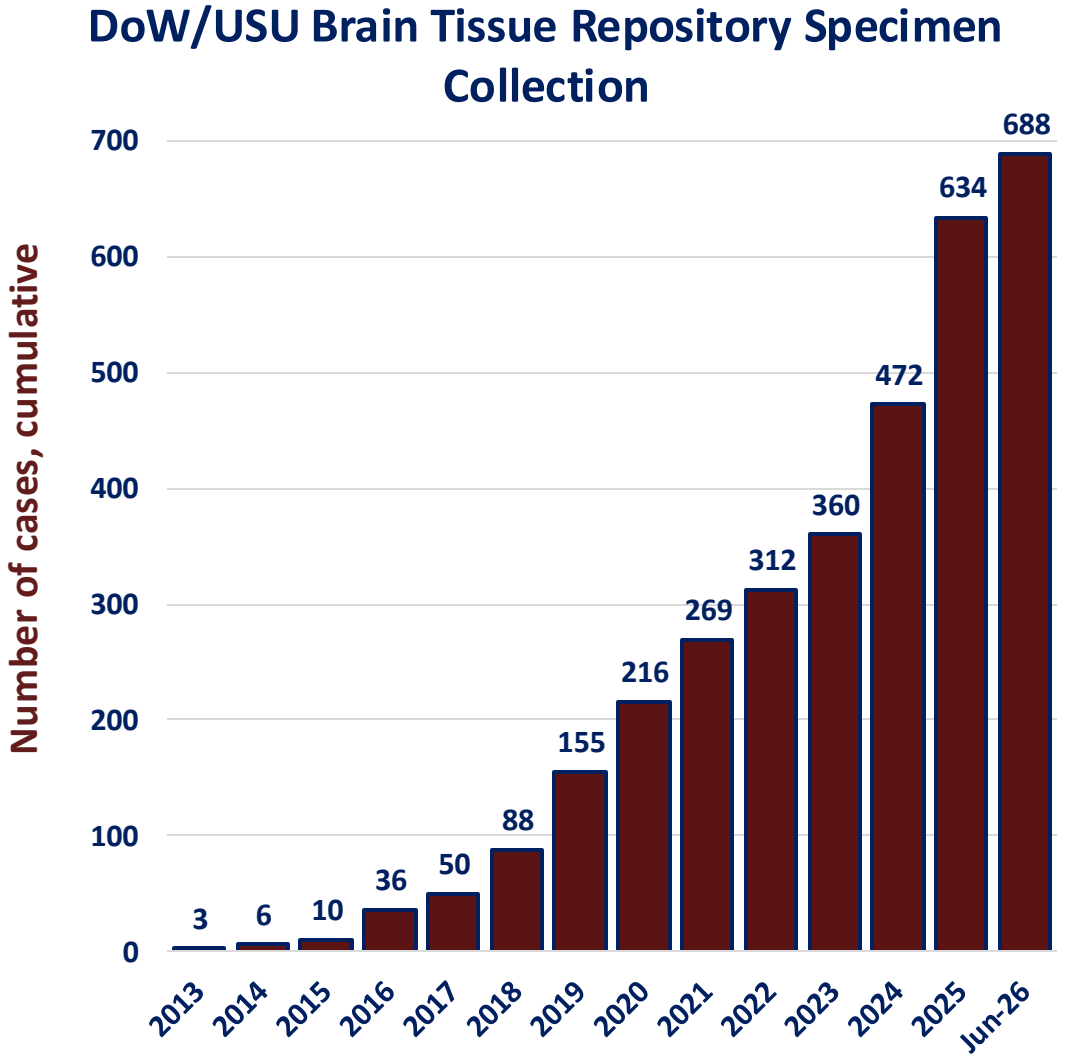
Analogous mechanisms are well described for impact-related TBI (e.g., orbitofrontal contusions, central herniation–type injury, downward displacement of the cerebellar tonsils).

The DoW/USU Brain Tissue Repository

Established in 2012 as the only brain bank in the world exclusively dedicated to the collection and study of brain specimens derived from US military personnel.

- **Accepts brain donations from anyone who has served in the military:**
  Active duty or retired/former
  Regardless of TBI history, neuropsychiatric disease, cause/manner of death, or other factors
- **Each brain receives a comprehensive neuropathologic examination.**
- Collects, stores, and characterizes the donated brains to research the **effects of a military career** on brain health.

With increased donations, the DoW/USU Brain Tissue Repository is increasingly capable of beginning to examine several individual occupations and/or occupational exposures.



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Knowledge Gap & Study Aim

THE GAP

Acute injuries from parachute landings are well-documented.

Chronic neuropathological consequences of repetitive parachute exposure have not been systematically characterized in post-mortem human tissue.

Most prior military neuropathology work has emphasized blast exposure and relatively non-specific impact exposures and TBI; parachute service is often subsumed within broader combat-exposure histories.

OUR AIM

To begin to characterize the neuropathological findings in a case series of brain donors whose military service histories included parachute operations and specialization, with particular attention to regions along the base of the brain that are anatomically positioned to experience the dynamic forces of repetitive parachute landings

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The DoW/USU BTR Series

Nine male brain donors with documented parachute specialization (DoW/USU BTR)

9

MALE DONORS

24–57

AGE RANGE (yrs)

Avg: 47; Median: 54

SERVICE COMPOSITION

7 Army · 1 Marine · 1 Marine/Navy

Rangers, EOD, parachute riggers, combat engineers, infantry, SF

COMPLEX AND OVERLAPPING EXPOSURE HISTORIES AND COMORBIDITIES

Exposure category	Cases	Representative history
Blast exposures +/- related TBI	5 / 9	IED blasts, ambushes, EOD operations, recoilless rifle exposure
Documented parachute-specific TBI events	3 / 9	Parachute landing concussion/LOC, ICH, post-traumatic seizures, freefall collision
Contact sports	7 / 9	Football, hockey, wrestling, rugby, lacrosse
Alcohol/substance misuse	4 / 9	Four with alcohol and/or substance misuse history
Documented psychiatric diagnosis	4 / 9	Four with documented psychiatric diagnoses, PTSD +/- depression
Suicide as manner of death	4 / 9	Not all had formal documented psychiatric diagnoses

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Methodology – Pathology Review

Neuropathology review, qualitative/semi-quantitative regional comparison of basal vs. dorsal brain samples

1. REGIONAL ASSESSMENT

Basal regions (test):

Orbitofrontal, mammillary bodies/hypothalamus, amygdala, rostral and tail hippocampus, basal forebrain, inferior cerebellum

Comparison regions (dorsal):

Occipital lobe, inferior parietal lobule, superior cerebellum

2. STAINS

H&E - routine histological stain

GFAP - astrocytes and gliosis

IBA1 - microglia

APP - axonal injury

AT8 - phosphorylated tau protein

4G8 or 6E10 - Aβ peptide

3. SCORING OF ASTROGLIOSIS

GFAP:

Semiquantitative scale 0–3 of astrogliosis (none, mild, moderate, severe), with pattern annotation (e.g., subpial, perivascular, subcortical WM).

Pairwise comparison:

Within-case basal vs. dorsal scores.

GFAP Results

GFAP immunohistochemistry demonstrated **increased astrogliosis** in subpial, perivascular, and/or subcortical white matter distributions in one or more basal brain regions, relative to within-case dorsal comparison regions, in **all donors (9/9 by overall mean).**

FINDINGS BY REGION

	Region	Subpial	Perivascular	Subcortical WM	Overall
BASAL	Orbitofrontal	2.06 ± 0.58	1.50 ± 0.87	2.06 ± 0.77	**1.87** ± 0.69
BASAL	Hypothalamus / mammillary bodies	3.00 ± 0.00	2.00 ± 0.50	1.78 ± 0.67	**2.26** ± 0.28
BASAL	Basal forebrain	2.56 ± 0.63	2.06 ± 0.63	1.56 ± 0.77	**2.06** ± 0.58
BASAL	Inferior cerebellum	0.78 ± 0.83	1.33 ± 1.32	2.33 ± 1.00	**1.48** ± 0.65
DORSAL	Inferior parietal lobule	0.83 ± 0.35	0.28 ± 0.44	0.67 ± 0.43	**0.59** ± 0.35
DORSAL	Occipital lobe	0.67 ± 0.50	0.78 ± 0.83	1.78 ± 0.83	**1.07** ± 0.62
DORSAL	Superior cerebellum	0.67 ± 0.50	0.44 ± 0.53	1.33 ± 0.50	**0.81** ± 0.34
	All basal regions (pooled)	**2.16** ± 0.38	**1.73** ± 0.47	**1.91** ± 0.55	**1.93** ± 0.42
	All dorsal regions (pooled)	**0.75** ± 0.28	**0.44** ± 0.41	**1.11** ± 0.40	**0.77** ± 0.30

Scores 0–3 (none / mild / moderate / severe); values are case-level means averaged across n = 9 donors (mean ± SD).

PATTERN OF GFAP STAINING

Subpial astrogliosis — most consistent and uniform in hypothalamus / mammillary bodies (max score in 9/9 cases); also prominent in basal forebrain and orbitofrontal cortex.

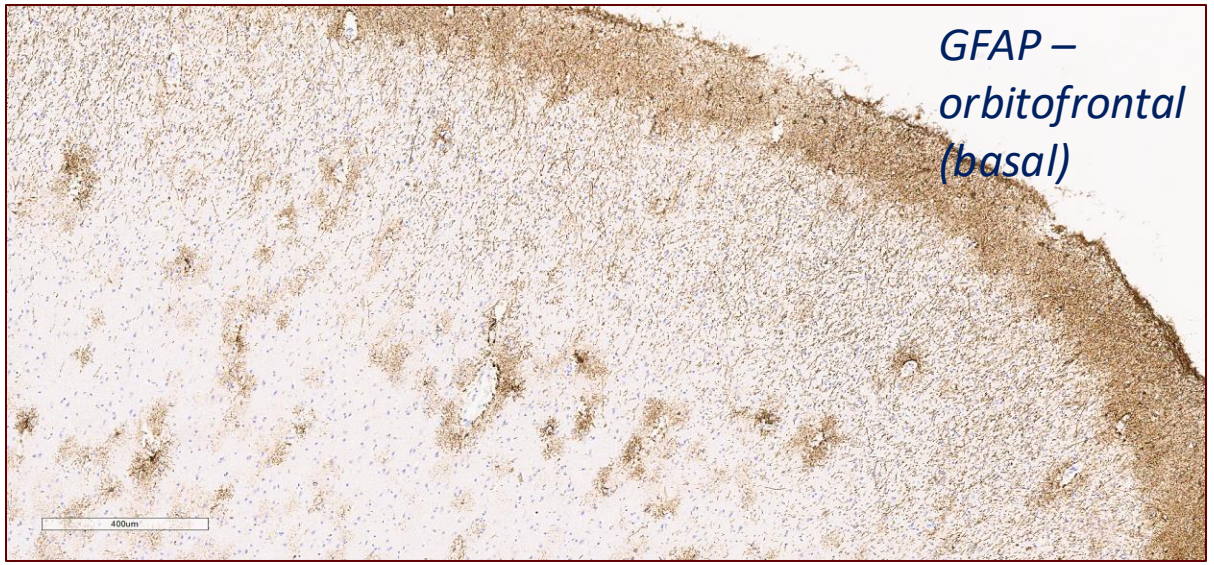
Perivascular astrogliosis — accentuated in basal regions, most pronounced in basal forebrain and hypothalamus; less prominent dorsally.

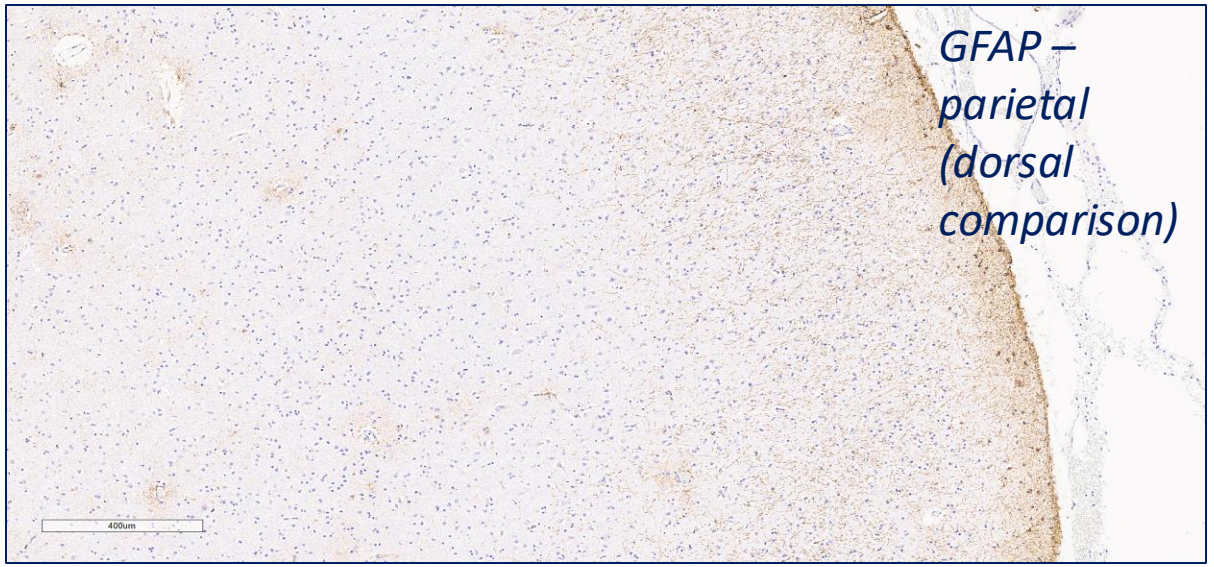
Subcortical white matter astrogliosis — most prominent in inferior cerebellum, with patchy / sometimes confluent involvement also at orbitofrontal and hypothalamic samples.

Dorsal comparison regions consistently demonstrated lesser involvement than basal regions within the same donor (9/9 by overall mean); the inferior parietal lobule had the least GFAP staining.

Within-cerebellum gradient — inferior samples exceeded superior in 7/9 cases (no reversals).

GFAP – Orbitofrontal Cortex vs Dorsal Comparison

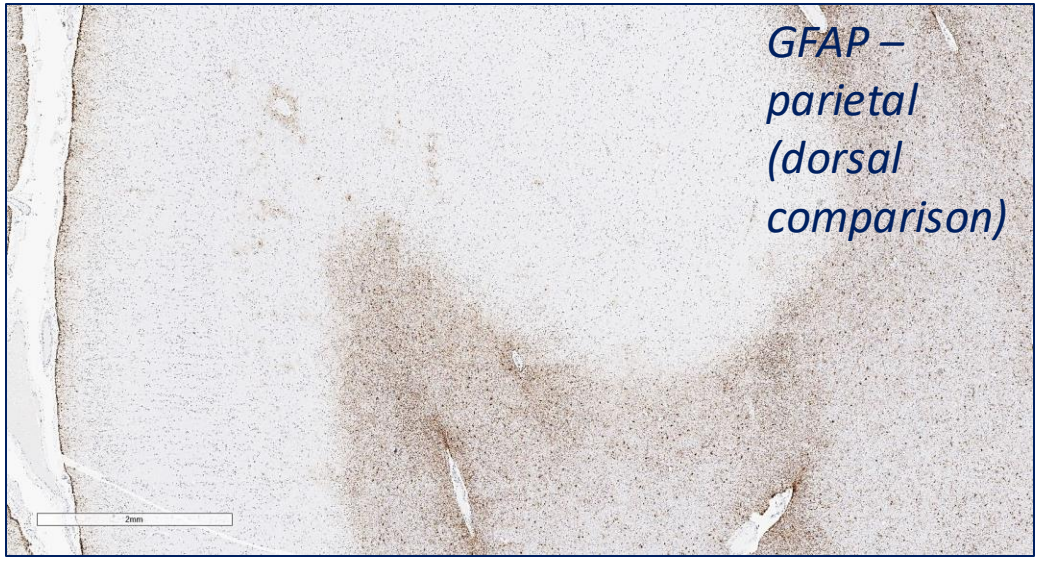




CASE

Middle-aged male (50's), U.S. Army; extensive parachute service with documented parachute landing injury history, including TBI. Subpial and perivascular astrogliosis at the orbitofrontal cortex (top) relative to the dorsal parietal sample (bottom).

GFAP – Orbitofrontal Cortex vs Dorsal Comparison

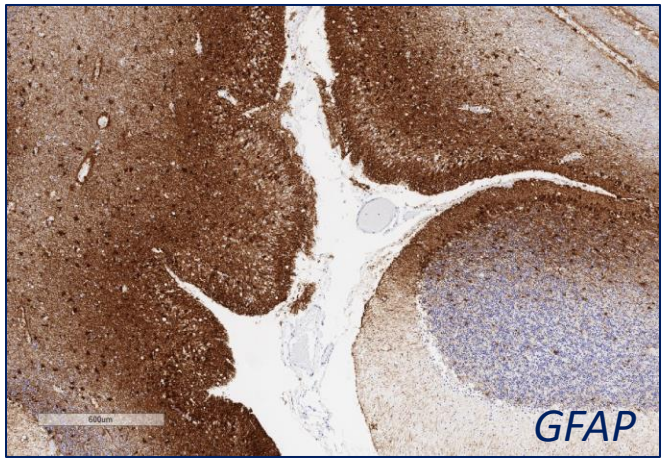


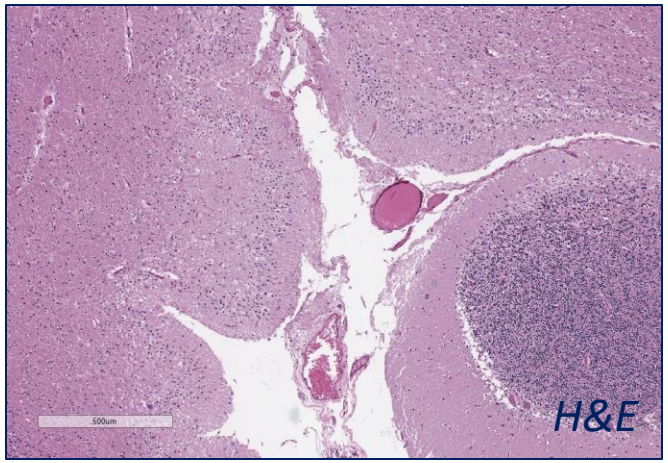
CASE

Young male (20s), Marines; Documented concussive impact head trauma in Service. Subpial, perivascular, and white matter astrogliosis in the orbitofrontal sample (top) relative to the dorsal parietal sample (bottom).

GFAP – Cerebellum

Inferior cerebellar samples demonstrated increased astrogliosis ratings relative to superior samples in 7/9 cases. This included a case (40 y/o Army Ranger, Jumpmaster) with multiple discrete foci of healed cortical injury/loss and gliosis in the inferior cerebellar sample.





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Additional Findings

CHRONIC TRAUMATIC ENCEPHALOPATHY (CTE)

1/9 – Low Severity

One case met diagnostic neuropathological criteria for CTE (low-CTE; orbitofrontal and temporal-pole pathognomonic lesions).

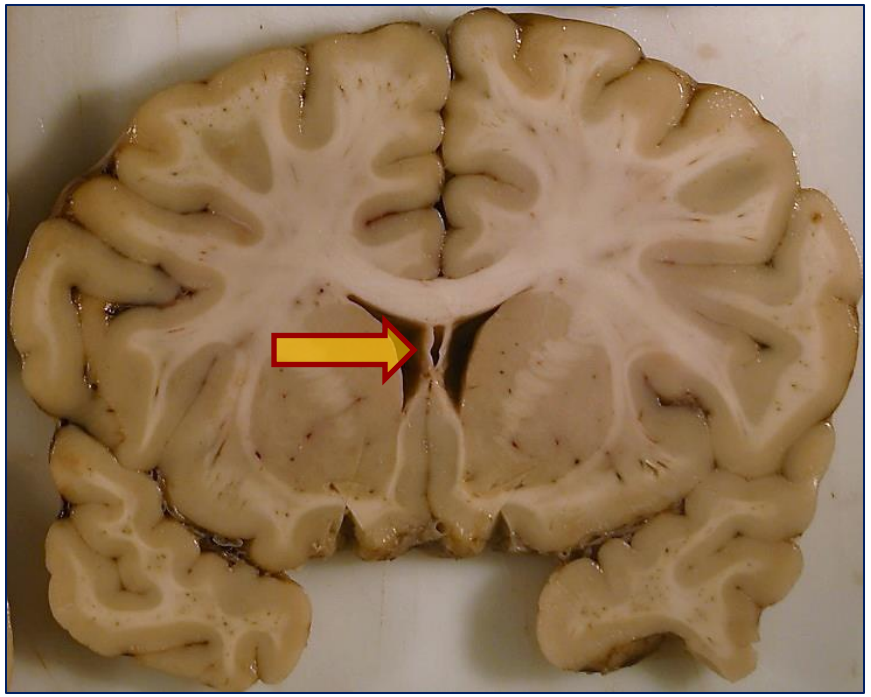
Donor history included extensive blast and impact TBI in addition to airborne service as well as a history of contact sports (Football, Wrestling).

CAVUM SEPTUM PELLUCIDUM (CSP)

3/9

Identified in 3 donors, 2 with documented TBIs associated with parachute operations (including complicated by concussion, loss of consciousness, subdural hematoma, and post-traumatic seizures), among other TBI history.

Typically an asymptomatic lesion and, while it can be congenital, the presence or enlargement of a CSP may also be TBI-related and it is frequently observed in adults with histories of impact TBI.



Arrow = cavum of the septum pellucidum

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Additional Findings

ALZHEIMER DISEASE AND RELATED PATHOLOGY

6/9 – Minimal severity*

- 5 cases (all aged 50's) demonstrated **ADNC, low-likelihood severity (A1B1C0 or A1B1C1)**
- 1 case (also aged 50's) demonstrated **PART (Braak I)**

AGE-RELATED TAU ASTROGLIOPATHY

3/9 – Focal, minimal*

3 cases (all aged 50's) demonstrated focal ARTAG lesions, including:

- Subpial (orbitofrontal cortex)
- Periventricular (Temporal horn of the lateral ventricle)
- Amygdala

IBA1 & APP EVALUATION

No consistent regional pattern

- Microglial labeling did not consistently mirror the basal-predominant pattern observed with GFAP.
- APP-positive axonal swellings were rare; abundant only in the one case with terminal fatal motor vehicle accident (acute, traumatic diffuse axonal injury).

***This reflects age-appropriate pathology that is commonly noted in aged/aging, cognitively intact individuals.**

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Limitations & Future Directions

LIMITATIONS

- **Small case series** (n = 9); descriptive, semiquantitative scoring.
- No matched non-paratrooper military comparison cohort in this analysis. **This analysis involved within-case comparisons only**.
- Heterogeneous, overlapping exposures, including blast, impact, and contact sports, **limit attribution to parachuting specifically.**
  - **The contribution of concurrent exposures and other potentially confounding variables have yet to be determined, and as yet no causal conclusions regarding parachute operation specifically can be made.**
  - **It is critical to treat human studies concerning the sequalae of specific exposures with appropriate caution and care, particularly regarding extrapolation to Warfighters, at large.**
- **Our observations relate strictly to neuropathological changes**, and as yet clinical manifestations cannot be implied.

FUTURE DIRECTIONS

- Systematic evaluation of **cerebrovascular pathology**.
- **Expand the series**, and **add matched non-airborne military and civilian comparators** with adequate controls for blast exposure, other head impact exposures, and additional factors.
- **Optimize sampling protocol** to enhance within-case comparisons.
- **Quantitative analyses** including but not limited to: Purkinje cell density along the inferior–superior cerebellar axis, digital quantification of GFAP burden, and digital assessment of microglial labeling.
- Stratify by documented jump count, jump type (static-line vs. military freefall), and total airborne years.
- Review and correlate with clinical symptomatology.

Conclusions

1. **A basal pattern.** Across all nine donors with parachute-service history, the basal brain samples demonstrated increased astrogliosis by semi-quantitative rating (scaling based on pathological interpretation by pathologists) relative to within-case dorsal comparison regions.

2. **Region prominence may align with biomechanical exposure.** The orbitofrontal cortex, hypothalamus/mammillary bodies, and inferior cerebellum, structures anatomically positioned to experience axial deceleration forces, were most consistently involved. Although blast, impact TBI, and contact-sport histories are common in this cohort, the basal-predominant astrogliosis pattern was present across donors with markedly different exposure profiles.

3. **An initial neuropathological observation.** Though **preliminary**, these data motivate larger, controlled studies comparing airborne vs. non-airborne military donors with otherwise comparable exposures.

Acknowledgements

We thank Service Members and families who have agreed to brain donation. Without this precious gift, we could not do our work.

Many of our donor families have said that although their loved ones made the ultimate sacrifice, through brain donation, they continue to serve their Country.

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DOW USU BRAIN TISSUE REPOSITORY

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THANK YOU

Questions?

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