Eur Spine J (2000) 9 : 61–66

ORIGINAL ARTICLE

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The anatomic variability of human cervical pedicles: considerations for transpedicular screw fixation in the middle and lower cervical spine

Received: 3 May 1999
Revised: 13 August 1999
Accepted: 21 August 1999

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Abstract Transpedicular screw fixation has recently been shown to be successful in stabilizing the middle and lower cervical spine. Controversy exists, however, over its efficacy, due to the smaller size of cervical pedicles and the proximity of significant neurovascular structures to both lateral and medial cortical walls. To aid the spinal surgeon in the insertion of pedicle screws, a number of studies have been performed to quantify the gross dimensions and angulations of the cervical pedicle. Notwithstanding these quantitative studies, there has been a conspicuous absence of research reporting the qualitative characteristics of the cervical pedicle. The purpose of our study was to provide comparative graphical data that would systematically document the anatomic variability in cervical pedicle morphology. Such information should better elucidate the complexity of the pedicle as a three-dimensional structure and provide the spinal surgeon with a more complete understanding of cervical pedicle architecture. Twenty-six human cervical vertebrae (C3–C7) from six fresh-frozen spines were secured to a thin sectioning apparatus to produce three 0.7-mm-thick pedicle slices along its axis. Radiographs taken of these pedicle slices were scanned, digitized, and traced to facilitate visual comparison. The pedicle slices were found to exhibit substantial variability in composition and shape, not only between individual spines and vertebral levels, but also within the pedicle axis. However, the lateral cortex was consistently found to be thinner than the medial cortex in all samples. These physical findings must be noted by surgeons attempting transpedicular screw fixation in the cervical spine.

Key words Anatomy · Pedicles · Cervical spine · Pedicle instrumentation

Introduction

As a surgical procedure, transpedicular screw fixation has attained considerable popularity in the treatment of spinal instabilities resulting from fractures or neoplasm [22]. The advantages of pedicle screws have been well documented in the thoracolumbar spine. Recently, clinical studies have demonstrated the efficacy of pedicle screws for the repair of non-traumatic lesions in the middle and lower cervical spine [1–5]. While other techniques such as anterior plating, interspinous wiring, and lateral mass screw fixation are still being used to stabilize the cervical spine, transpedicular screw fixation has been found to confer superior levels of fixation with a reduced likelihood of hardware loosening, particularly in the repair of three-column fractures [1, 8, 9, 11].

The challenge in transpedicular screw fixation in the cervical spine lies in the technical skill required for accurate placement. Just adjacent to cervical pedicles lie important neurovascular structures such as the spinal cord, nerve roots, and vertebral arteries. Major cortical wall violations could seriously damage these structures. Jeanneret et al. [8] noted in a study on cadaveric specimens that 30.3% of inserted cervical pedicle screws violated the cortex of the pedicle. Another study by Miller et al. [13] reported pedicle wall violation rates of 47.4% with blind screw placement and 25.0% with the partial laminectomy and tapping technique. They concluded that transpedicular screw fixation in the cervical spine should be reserved only for patients who have experienced significant bony trauma or for those in whom rigid internal fixation cannot be achieved by other techniques. Other clinical trials have reported better success with cervical pedicle screws, with few or no cortical wall violations [1, 2]. Clearly, opinions vary regarding the safety and effectiveness of transpedicular screw fixation for the stabilization of the middle and lower cervical spine. With a better understanding of cervical pedicle morphology, it should be possible to improve the percentage of successful surgical outcomes.

A number of studies have quantified the gross external dimensions and angulations of human cervical pedicles [6, 9, 10, 14, 16, 20]. Cervical pedicle heights and widths have been well characterized, particularly at the isthmus. Cancellous core heights and widths have also been delineated at the isthmus and along the pedicle axis [10, 16]. While these studies have given the spinal surgeon quantitative information on the external and internal architecture of the pedicle, they do not consider the possible complexity of the pedicle's shape. This is a significant omission in light of the recent discovery that thoracic pedicles, which were once considered to be cylindrical structures [17, 19, 23], are actually teardrop or kidney shaped when viewed on cross-section [15]. It was also discovered that the thoracic pedicle shape changes as one moves along the pedicle axis, down the spine, and among individuals [15]. Such information is crucial to the proper execution of transpedicular screw fixation in the cervical spine, and suggests that quantitative data are not sufficient to predict proper insertion of pedicle screws.

The cumulative evidence suggests that it is necessary to elucidate the cross-sectional shape, in addition to the cross-sectional dimensions, of the cervical pedicle. The purpose of our investigation was to examine a series of cervical pedicle slices cut transversely across the central axes and to present visual data derived from these cross-sectional slices. We were able to analyze differences in pedicle architecture between anatomic specimens, document changes in pedicle structure between vertebral levels, describe the shape of the pedicle along its central axis, and characterize both the external and internal morphology of cervical pedicles. We believe that the data from this study will substantially augment the spinal surgeon's understanding of the cervical pedicle when used in conjunction with currently available quantitative information.

Materials and methods

Specimen preparation

Twenty-six cervical vertebrae were harvested from six fresh-frozen human specimens. All specimens were radiographed to find any damage or abnormality; none were discovered. Soft tissues were removed by sharp dissection. The specimens (six C3, six C4, six C5, five C6, and three C7 vertebrae) were then immersed in a 1 : 1 solution of water and 5.25% hypochloride bleach for 12–15 h to remove remaining soft tissues. Cervical vertebral body dimensions were then measured from antero-posterior and lateral plain film radiographs (Table 1).

Table 1 Cervical vertebral body dimensions (mean values in mm are shown in *bold*, with standard deviations presented below)

	C3	C4	C5	C6	C7
Upper end-plate, depth	14.4	14.7	14.6	15.6	15.5
	2.0	1.5	1.2	1.6	2.1
Upper end-plate, width	15.2	16.5	16.8	17.6	18.7
	1.6	1.3	1.9	1.7	2.1
Lower end-plate, depth	14.9	15.0	16.9	16.1	15.5
	1.4	1.3	2.2	1.6	0.8
Lower end-plate, width	16.4	16.0	18.3	19.1	21.6
	1.0	1.7	1.7	1.7	2.3
Vertebral body height, anterior	12.6	13.0	12.6	12.9	14.0
	0.9	0.9	0.7	1.5	1.2
Vertebral body height, posterior	13.3	13.4	13.3	13.3	14.3
	0.9	0.6	0.5	1.2	0.2

Pedicle slices

Vertebral specimens were mounted in a polyester/styrene resin (Bondo, Dynatrom/Bondo Corp., Atlanta, Georgia) and placed in a specially designed fixation device for rigid attachment to the thin sectioning machine (Hamco Machines, Inc., Rochester, New York). Superior and lateral plain film radiographs taken of each vertebra prior to sectioning were used to orient the 0.3-mm-thick diamond circular blade perpendicular to the long axis of each pedicle, from which 0.7-mm slices were cut. The first slice was made at the level of the isthmus of each pedicle (Fig. 1 A), the second anteriorly, and the third posteriorly to the first slice (Fig. 1 B). This procedure was duplicated for both right and left pedicles of the vertebrae. The superior-most aspect of each pedicle was marked, so that the orientation of each pedicle slice could be determined after sectioning.

Data collection

Plain film radiographs of all pedicle thin slices were taken and placed into 35-mm-slide holders for use in scanning. Radiographs were scanned at 3970 dpi using the Polaroid Sprint-Scanner LE/35 and edited with Adobe Photoshop 5.0, run on a Macintosh computer.

These scans were subsequently transferred to an IBM computer, edited further for contrast and brightness, and transformed into bitmapped images at identical threshold levels using Corel Photo-Paint. The internal and external contours of each pedicle slice were subsequently traced and presented graphically for visualization (Fig. 1 C).

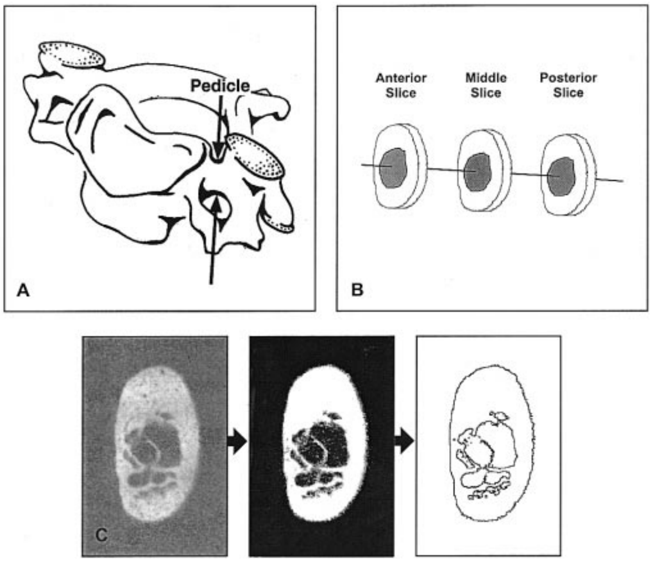

Fig. 1 A–C Methodologies for obtaining bitmapped digitized images of cervical pedicles. **A** Drawing of a typical cervical vertebra viewed obliquely, with *arrows* pointing to the isthmus of the left pedicle. **B** Enlarged schematic view of the pedicle slices. The line through the slices represents the pedicle long axis. **C** Representative plain film radiograph *(left)* contrast-enhanced digitized image *(middle)* and bitmapped digitized image *(right)* of a pedicle slice

Results

For this study, we digitized images of cross-sectional slices from 26 vertebrae spanning C3 to C7, representing a total of 52 pedicles. The data presented are strictly visual in nature (Figs. 2–6). The qualitative characteristics of the cervical pedicle are described separately for each vertebral level.

Pedicles at C3 exhibit a semi-circular shape, with the flat surface directed towards the lateral aspect of each pedicle (Fig. 2). As the slices progress antero-posteriorly along the pedicle long axis, the shape of the pedicle changes to a more circular conformation. Pedicle slices from spine 550 deviate from this pattern, exhibiting a triangular shape, with one pointed end directed towards the lateral wall. The right pedicle slices from spine 551 are more pointed at their superior aspects and take on a narrow triangular form. The lateral wall of the cortex is significantly thinner than the medial cortex in all pedicle specimens. The cancellous core of each specimen occupies a small percentage of the total cross-sectional area, except in spine 551, where the slices exhibit a large and finely trabeculated cancellous core structure. While most of the pedicle samples manifested symmetry between right and left pedicles, specimens from spines 549 and 551 exhibit unequivocal asymmetry in shape. The left

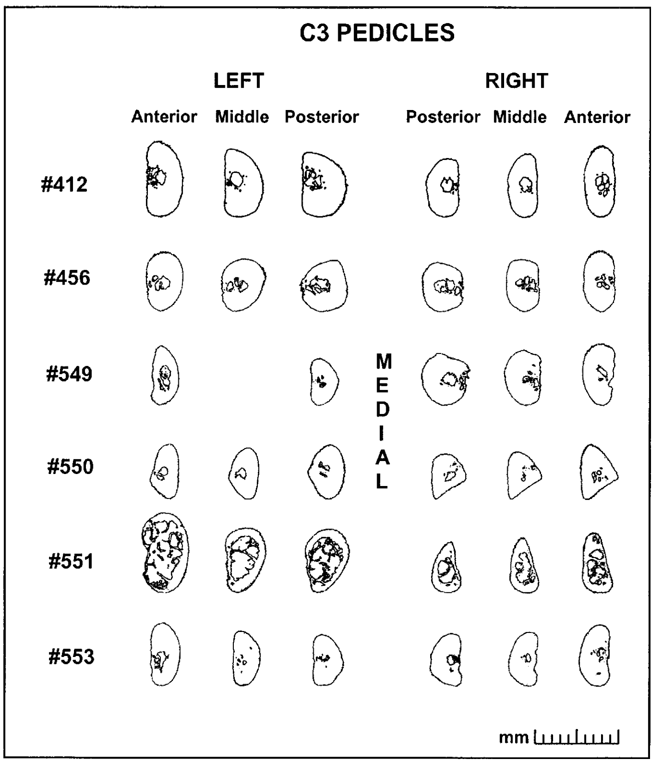

Fig. 2 Serial cross-sections of C3 pedicles. Anterior, middle, and posterior slices of both left and right pedicles from six vertebral specimens

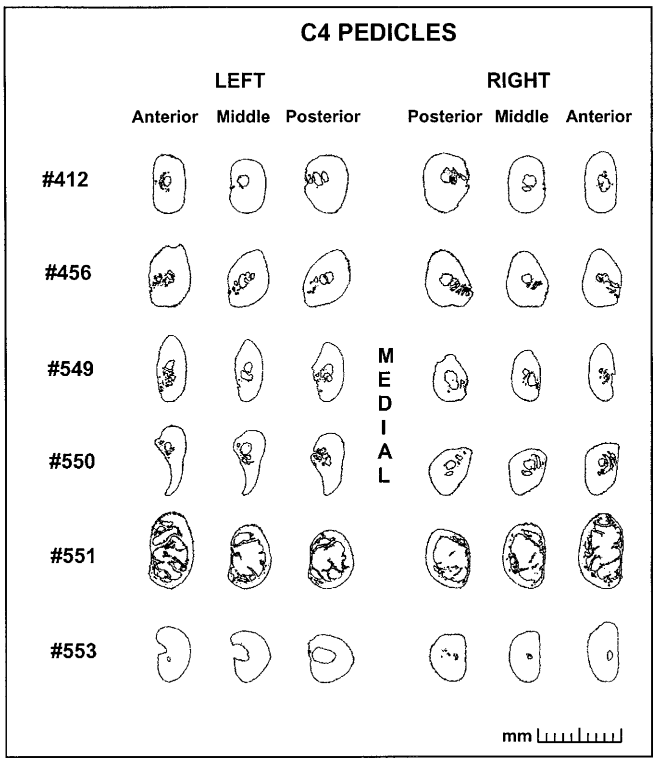

Fig. 3 Serial cross-sections of C4 pedicles. Anterior, middle, and posterior slices of both left and right pedicles from six vertebral specimens

middle slice of spine 549 was damaged prior to radiography and could not be included in this study.

Pedicles at C4 change from a rectangular conformation to a semi-circular shape as the slices progress antero-posteriorly (Fig. 3). Exceptions to this include the left pedicle slices from spine 550, which exhibit an unusual hook shape at their inferior aspects. Like C3 pedicle slices, all of the specimens here demonstrate a marked divergence in the thickness of the lateral and medial cortices, with the lateral cortex being substantially thinner than the medial cortex. Interestingly, the lateral cortex of the left pedicle of spine 553 appears to be missing. In the posterior slice, however, the lateral cortex materializes, and it becomes apparent that the cancellous core had simply merged with the external wall of the pedicle in the anterior and middle slices.

Pedicles at C5 show two distinct patterns: either

1. Slices change from a rectangular conformation to a circular shape as the slices progress antero-posteriorly, or
2. Slices exhibit a triangular form with one pointed end directed towards the lateral wall (Fig. 4).

Both pedicles of spine 412, the left pedicle of spine 549, and both pedicles of spine 553 exhibit the first pattern, while the remaining pedicles exhibit the second pattern. The lateral cortex is again noticeably thinner than the medial cortex in all specimens, and the cancellous core appears to be more finely trabeculated than previously seen in C3 and C4 pedicle slices. The right pedicle of spine 456 produced only two viable specimens due to the shorter length of the pedicle itself.

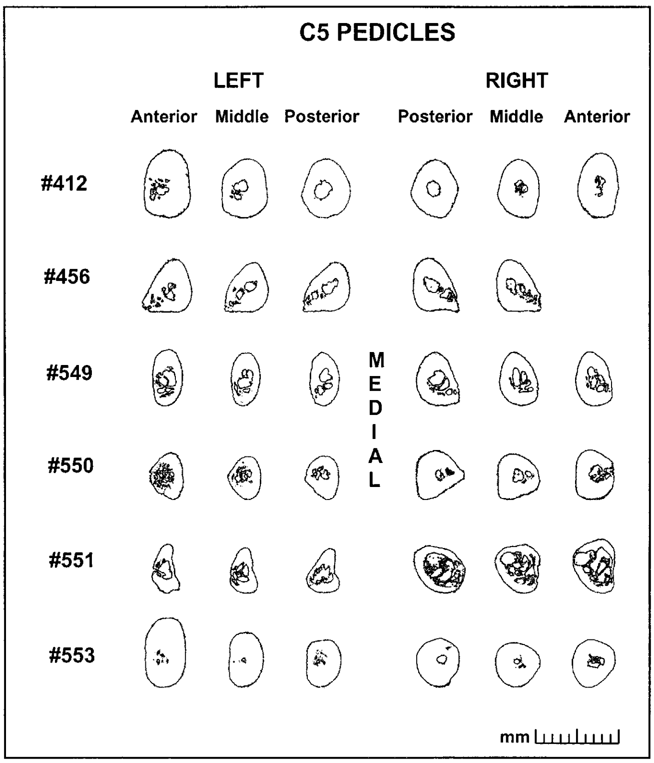

Fig. 4 Serial cross-sections of C5 pedicles. Anterior, middle, and posterior slices of both left and right pedicles from six vertebral specimens

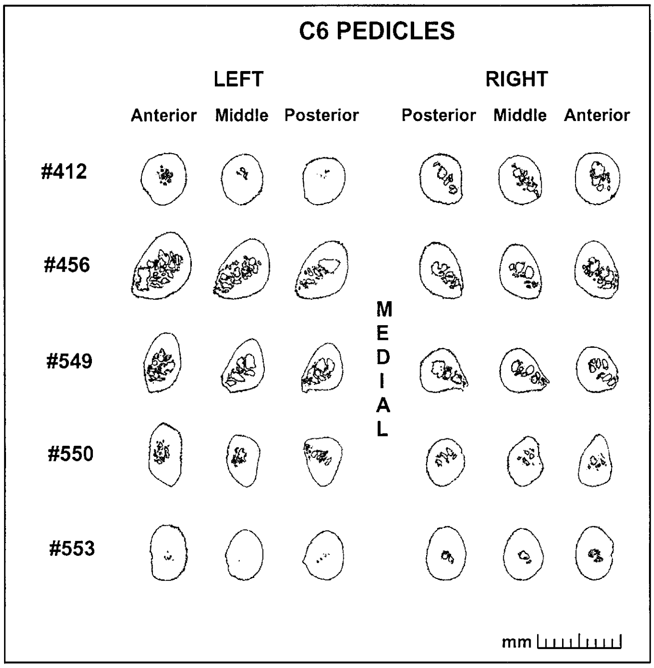

Fig. 5 Serial cross-sections of C6 pedicles. Anterior, middle, and posterior slices of both left and right pedicles from five vertebral specimens

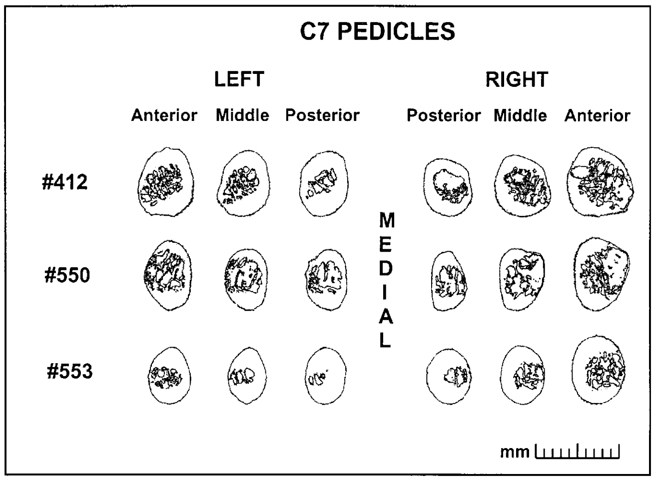

Fig. 6 Serial cross-sections of C7 pedicles. Anterior, middle, and posterior slices of both left and right pedicles from three vertebral specimens

Pedicles at C6 again display two discrete patterns: either

1. Slices appear circular in shape as shown in spines 412, 550, and 553, or

2. Slices exhibit a triangular shape as shown in spines 456 and 549 (Fig. 5).

Compared to specimens from C3 to C5, the pedicle slices from C6 were smaller in height. The pedicle sizes are also much more uniform as the slices progress antero-posteriorly. Symmetry is better maintained between right and left pedicles. The cancellous core becomes increasingly trabeculated and occupies a relatively larger area.

Pedicles at C7 appear ovoid in shape, with the slices becoming narrower as they move antero-posteriorly (Fig. 6). Again, the lateral wall of the cortex is substantially thinner than the medial wall in all pedicle slices. The cancellous core is finely trabeculated in nearly all specimens. Though only six pedicles were examined at this spinal level, the specimens collectively exhibit greater uniformity in shape than specimens from other vertebral levels. There is less variability in the shape of the pedicle at C7.

Discussion

Because transpedicular screw fixation has been found to be effective in the stabilization of the middle and lower cervical spine, a number of studies have quantified the dimensions and angulations of the cervical pedicle [6, 9, 10, 14, 16, 20]. While these studies have contributed critical information to the spinal surgeon's fund of knowledge, there has been a notable absence of research describing the shape of the cervical pedicle along its axis. A computed tomography scan study by Karaikovic et al. [10] presented transverse radiographs of the cervical pedicle at its isthmus. Only three pedicle specimens were exhibited in this manner, however, and the main objective of the investigation was to document anatomic measurements of the pedicle. We believe that more detailed descriptive information is necessary, particularly in light of the recent finding that thoracic pedicles appear as teardrop or kidney shaped structures on corss-section [15]. The information presented in this paper should give the spinal surgeon an improved understanding of the cervical pedicle.

Most of the information currently available documents the dimensions of the cervical pedicle at its isthmus and the orientation of the pedicle in the transverse and sagittal planes. Because we hoped to elucidate any changes taking place along the pedicle axis, we elected to cut three thin slices from each pedicle, radiograph each slice, and use computer programming to create digitized images.

Pedicle specimens from C3 through C5 demonstrated wide variations in cross-sectional morphology. While most of the specimens exhibited a semi-circular external contour, other specimens were triangular or rectangular in shape. Many pedicles changed shape along their axes. There was also asymmetry between some of the right and left pedicles, and the cancellous core was observed to be either finely trabeculated or almost devoid of trabecular bone in select pedicle slices. All of the variability exhibited in cervical pedicles between individuals, vertebral levels, and right and left sides points to the importance of taking complete radiographs of the patient prior to transpedicular screw fixation. Without an appreciation for the true three-dimensional structure and asymmetry of the cervical pedicle, it is possible to perforate the wall of the cortex when inserting a circular screw through pedicles that are, for example, triangular on cross-section.

Though pedicle specimens from C6 and C7 were more uniform in size and shape, it was noted that the cancellous core occupied a relatively larger area compared to specimens from C3, C4, and C5 pedicles. This finding is significant, because recent studies have suggested that it is the cortical purchase of a pedicle screw that determines screw stability and pull-out strength [7, 21]. While pedicles in C6 and C7 are larger in cross-sectional area, pedicle screws must be inserted precisely so as to obtain maximal bony purchase in the lower cervical spine. Otherwise, these screws may have an increased chance of loosening, leading to post-operative complications.

In all pedicle specimens, the lateral cortex was observed to be substantially thinner than the medial cortex. This finding was observed in thoracic pedicles by Kothe et al. [12] and Panjabi et al. [15], and also corroborates the preliminary qualitative data shown by Karaikovic et al., which noted that the thinnest pedicle cortex was always the lateral cortex [10]. The lateral cortex of cervical pedicles is responsible for protecting the vertebral artery, with the exception of C7 pedicles. Thus, extreme caution must be exercised when inserting pedicle screws, so as not to perforate the thin lateral cortex of the cervical pedicle. Screws should not be inserted too medially, however, due to the observed variability in pedicle morphology and the proximity of the spinal cord.

We hope that the results of the present study will aid the surgeon in improving the percentage of successful outcomes while minimizing risk to the patient. Early descriptions of the pedicle may have biased most surgeons to believe that it is simply a cylinder of bone [18], when it is, in fact, a complex three-dimensional structure. Our results show that the effective diameter that would permit insertion of a screw of a given size is much less than one would expect on the basis of simple measurements of pedicle height and width. We acknowledge the small number of specimens made available for this study. However, the goal of this investigation was not to demonstrate a common pattern or shape for cervical pedicles, but rather to expose the variability in external and internal pedicle morphology. For these reasons, we believe our results are meaningful and hope that this study stimulates future investigation into the three-dimensional complexity of the cervical spine and pedicle instrumentation.

Acknowledgements This study was funded in part by the Yale University School of Medicine Fellowship Program and NIH Grant AR-42211. We would like to thank Nara Sun, Yale University School of Medicine, New Haven, Connecticut, for her comments on this manuscript.

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