

# Kinematics of the Equine Carpus

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## Summary

*Five equine forelimbs prepared with markers fixed in the axial carpal bones were suspended by the proximal radius in full flexion. Allowed to free fall in a pendular swing, they were filmed in the sagittal plane using high-speed cinematography. Precision motion data reduction was accomplished by use of an electronic digitizing system interfaced with a microcomputer. The distal row of carpal bones and the metacarpus attained similar angular displacement, velocity and acceleration which were significantly greater than that of the proximal row of carpal bones. Within the proximal row, the radial carpal bone attained maximum angular displacement, velocity and acceleration, followed by the intermediate and ulnar carpal bones. It was concluded that significant differences in angular displacement, velocity and acceleration of the individual carpal bones may play a role in the consistent pattern of carpal fractures seen in racehorses.*

*Index terms: Equine biomechanics; high speed cinematography; equine carpal injury.*

## Introduction

Disease of articular and periarticular structures of the carpus is a major cause of lameness in the racehorse. Understanding the pathogenesis of carpal degeneration and fracture is critical to its successful management. Such an understanding hinges upon knowledge of joint anatomy, biomechanics, and physiology.

The purposes of this study were (a) to describe the normal amplitude of motion of the carpal bones in the sagittal plane of the composite joint, and (b) to estimate the relative mean velocity and acceleration attained by these carpal bones during the swing phase of the stride.

## Materials and Methods

Five equine forelimbs were harvested by disarticulation at the elbow joint. Skin and subcutaneous tissues covering the dorsal aspect of the carpus were removed. The tendons of the extensor carpi radialis and the common digital extensor muscles were transected at the level of the distal radius. The joint capsule was dissected free of the dorsal surface of the carpal bones.

Two mm diameter steel marker pins (1 to each bone) were then drilled into the proximal end of the third metacarpal bone (MC3), third carpal bone (C3), fourth carpal bone (C4), radial carpal bone (RCB), intermediate carpal bone (ICB), ulnar carpal bone (UCB) and the distal end of the radius. All pins were placed parallel to the articular surfaces while the joint was maintained in an extended position. The pins protruded 50 mm from the bone surface. The tips of each pin were color coded for ease of identification.

The forelimbs were suspended by the proximal end of the radius which was securely clamped into a triangular iron brace which in turn was fixed to an overhead steel I beam. The limb was held in full flexion by a mechanical trigger which was wired to a photographic strobe flash unit (Fig 1). Activation of the trigger assembly allowed the limb to begin its free fall pendular swing and simultaneously signaled the exact instant of release by the flash of the strobe light. The limbs were allowed to complete their normal range of motion. Each trial was repeated 3 times.

High speed cinematography was performed using an electrically driven Locam (164-4DC) 16 mm camera, positioned perpendicular to the pendular phase of limb motion and operating at 100 frames/sec. Calibration of the operating speed of the camera was accomplished by the recording of a crystal controlled light emitting diode which placed exposure marks on the film edge every 1/100 of a second. Kodak 16 mm color VNF film (ASA 400) was used in conjunction with a 1/6 shutter. The exposure time for

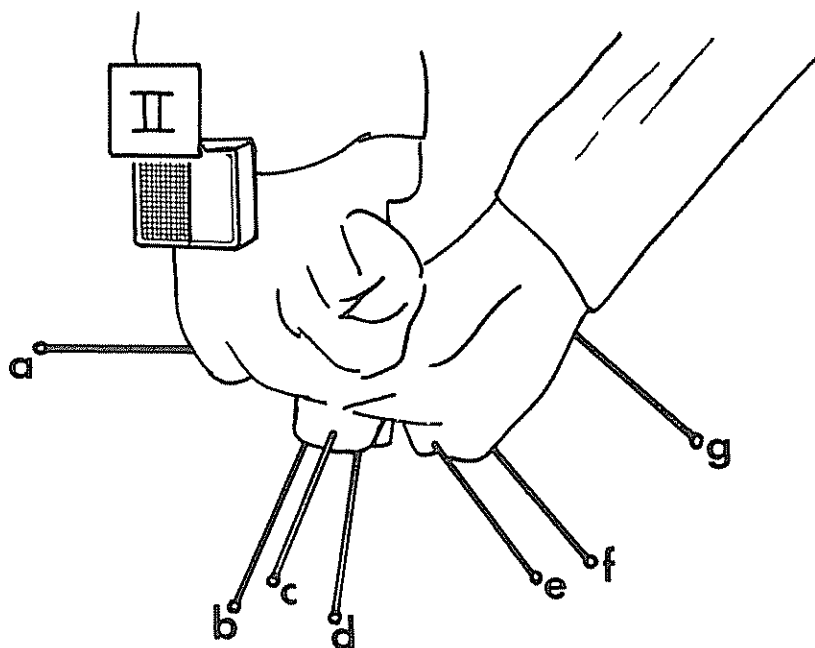


FIGURE 1. Specimen II suspended from a fixed radius in approximately 140 degrees of flexion. Markers were placed in the distal radius (a), intermediate carpal bone (b), ulnar carpal bone (c), radial carpal bone (d), fourth carpal bone (e), third carpal bone (f) and third metacarpal bone (g). A photographic strobe light located beneath the specimen signaled the exact instant of release by a mechanical trigger.

each frame of film was 1/600 of a second. An Angenieux zoom lens (12–120 mm) was set at a 100 mm focal length. The camera was placed at a position 12.0 m from the testing apparatus. Two banks of Mini-Brute "9" Colortran lights were positioned at 45 degree angles to the moving forelimbs. This arrangement produced a lighting intensity of 3000 foot-candles and was sufficient to ensure the proper lighting conditions for filming at high camera speeds.

Data reduction from high speed film was accomplished by use of a Summagraphics Bit Pad Digitizing System interfaced with a Vanguard Projection Head (M16-C) and a Franklin Ace 1000 microcomputer. Appropriate computer software enabled the kinematic determination and quantification of variables dealing with displacement, velocity and acceleration. The statistical analysis consisted of the utilization of traditional descriptive techniques, Pearson product moment correlation coefficients and multivariate analysis of variance (ANOVA).

### Results

The total angular displacement and average velocity of the respective carpal units is listed in Table 1. Data are expressed as mean and standard deviation. Angular displacement as a function of time for the axial carpal units is graphed in Fig. 2. Average velocity as a function of time for each carpal unit is graphed in Fig. 3.

The amplitude of motion (total angular displacement) of the composite carpal joint is defined by the angular position of the longitudinal axis of the metacarpus relative to that of the radius. The mean amplitude of motion of the composite joint for the five normal limbs in this study was  $139.45 \pm 1.76^\circ$ . The mean amplitude of motion for the third carpal bone was  $137.35 \pm 1.64^\circ$ , while that of the fourth carpal bone was  $130.62 \pm 2.86^\circ$ . The radial carpal bone had an amplitude of motion of  $82.23 \pm 3.18^\circ$ . The intermediate carpal bone had an amplitude of motion of  $67.70 \pm 3.64^\circ$  and that of the ulnar carpal bone was  $62.42 \pm 4.43^\circ$ . During extension of the joint, the middle carpal joint closed prior to the radiocarpal joint.

There was no significant difference in the total angular displacement, average velocity or angular acceleration among the proximal row of carpal bones (radial, intermediate and ulnar carpal bones). Nor was there a significant difference in angular dis-

TABLE 1. Total angular displacement and average velocity of the axial carpal bones.

| Carpal bone | Displacement (degrees) |      | Time (sec) | Angular velocity (Degrees/sec) |
|-------------|------------------------|------|------------|--------------------------------|
|             | $\bar{X}$              | SD   |            |                                |
| MC3         | 139.45                 | 1.76 | 0.54       | 258.54                         |
| C3          | 137.35                 | 1.64 | 0.54       | 254.65                         |
| C4          | 130.62                 | 2.86 | 0.54       | 242.19                         |
| RCB         | 82.23                  | 3.18 | 0.54       | 152.33                         |
| ICB         | 67.70                  | 3.64 | 0.54       | 125.55                         |
| UCB         | 62.42                  | 4.43 | 0.54       | 115.84                         |

Mean  $\pm$  standard deviation ( $\bar{X} \pm$  SD), MC3 = third metacarpal bone, C3 = third carpal bone, C4 = fourth carpal bone, RCB = radial carpal bone, ICB = intermediate carpal bone, UCB = ulnar carpal bone.

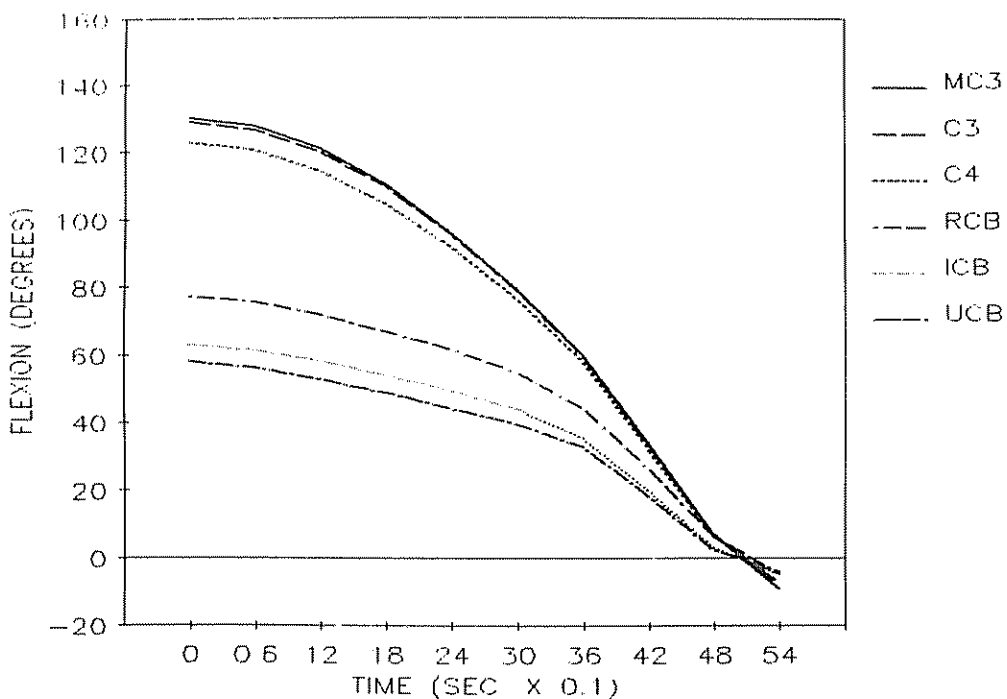


FIGURE 2 Angular displacement of the proximal row of carpal bones (RCB = radial carpal bone, ICB = intermediate carpal bone and UCB = ulnar carpal bone) and the distal row of carpal bones and metacarpus (C3 = third carpal bone, C4 = fourth carpal bone and MC3 = third metacarpal bone).

placement, average velocity or total angular acceleration among the distal row of carpal bones and the metacarpus (third carpal bone, fourth carpal bone and third metacarpal bone). However, the total angular displacement, average velocity and angular acceleration of the distal row of carpal bones and the metacarpus was significantly greater than that of the proximal row.

The proximal row of carpal bones displayed a pattern of velocity and acceleration which differed from that of the distal row of carpal bones and the metacarpus. Although the bones in the proximal row behaved similarly, the radial carpal bone moved independently from the intermediate and ulnar carpal bones and attained a maximum velocity and angular displacement ( $r = 0.64$  for RCB/ICB,  $r = 0.57$  for RCB/UCB and  $r = 0.93$  for ICB/UCB). The distal row of carpal bones and the metacarpus moved similarly throughout their amplitude of motion with a high correlation of movement between these bones ( $r = 0.91$  for MC3/C3,  $r = 0.88$  for MC3/C4 and  $r = 0.84$  for C3/C4).

Extension of the joint was not uniform among the axial carpal bones. While there was no significant difference in the degree of extension among either the proximal row of carpal bones or among the distal row of carpal bones and the metacarpus, there was a significant difference between the proximal and distal rows of carpal bones/metacarpus. The metacarpus achieved a maximum extension of  $189.41 \pm 3.6^\circ$ , followed by

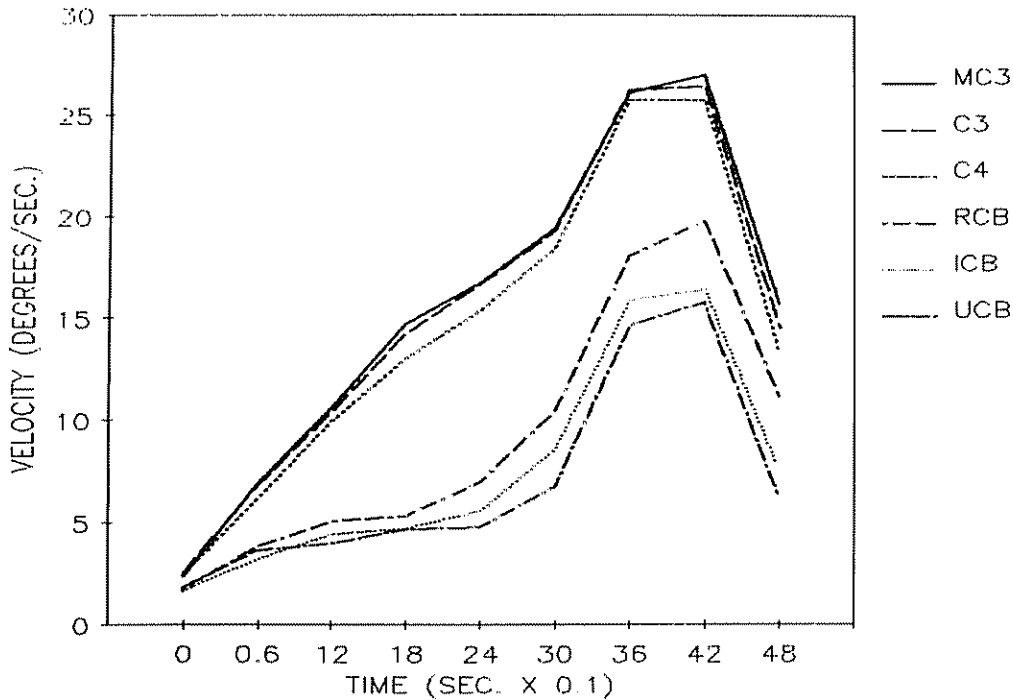


FIGURE 3. Angular acceleration of the proximal row of carpal bones (RCB = radial carpal bone, ICB = intermediate carpal bone and UCB = ulnar carpal bone) and the distal row of carpal bones and metacarpus (C3 = third carpal bone, C4 = fourth carpal bone and MC3 = third metacarpal bone)

the distal row of carpal bones ( $C3 = 188.30 \pm 2.0$ ,  $C4 = 187.70 \pm 1.96$ ) and the proximal row of carpal bones ( $RCB = 185.1 \pm 1.76$ ,  $ICB = 184.76 \pm 2.16$ ,  $UCB = 184.42 \pm 1.89$ ). There was very little data variation between repeated trials of an individual limb ( $r = 0.94$ ).

### Discussion

The equine carpus is a specialized anatomic structure relative to that of man and other species. Of the three joints which make up the carpus, the radiocarpal and middle carpal joints act as hinge joints while the carpometacarpal joint acts more as a gliding joint. Gross movement of the composite joint is restricted primarily to flexion and extension in the sagittal plane. Although the carpus is loaded in axial compression with the bones locked in a "close-packed" position of maximum congruency, the joint flexes during the protraction phase to reduce the moment of inertia of the limb, in turn minimizing drag and maximizing its angular acceleration (Rooney, 1977). Joint laxity is maximum in flexion and minimum in extension.

Fractures of the carpus are a common injury among performance horses. (Raker *et al.*, 1966; Auer, 1980; Palmer, 1986). Consistent patterns of fracture location are seen within the joint. While total numbers of carpal fractures are equally distributed between

the left and right limbs, fractures within the middle carpal joint are more common than those of the radiocarpal joint. Variation of fracture prevalence between the Thoroughbred, Standardbred and Quarter Horse reflect significant differences in their load distribution, track surfaces and shoeing practices (Palmer, 1986). The articulation of the distal aspect of the radial carpal bone and the proximal surface of the third carpal bone is the most common site of fracture in the racing breeds (Adams, 1966; Park *et al.*, 1970; Thrall *et al.*, 1971; Rooney, 1977; McIlwraith, 1984; Palmer, 1986).

High speed cinematography has lent insight into the subtle oscillation of the carpus at racing speeds (Fredricson and Drevemo, 1972). This movement is stabilized to some degree by flexor and extensor muscle tone. However, fatigue of muscle reduces its ability to store energy and thereby neutralize the stress imparted to the bone (Frankel and Nordin, 1966). In this way fatigue of the carpal extensors and forelimb flexor muscles may cause increased vibration of the joint during the period of maximum extension as the body passes over the limb during weight bearing. Thus fatigue and defective coordination may lead to abnormal cyclic loading of the carpal bones and contribute to carpal injury.

From the prevalence of fractures among the carpal bones there appear to be areas of force concentration within the composite joint which cause certain articular surfaces to wear excessively or fracture as the result of repetitive trauma. These unique patterns of injury reflect a complex interaction of biomechanical forces acting through the forelimbs of the horse in motion. Such forces are determined in part by conformation, articular surface area and the kinematics of the individual carpal bones. Although the carpus is comprised of at least 11 individual bones, the carpal bones which are axially-loaded move in closely-aligned groups due to the integrity of intracarpal ligaments and articular surface congruency. While the radial carpal bone moves independently, the intermediate and ulnar carpal bones function mechanically as a single unit, as does the distal row of carpal bones and the metacarpus (Fig. 4).

Because carpal fractures most frequently involve the dorsal joint margins, hyperextension has been the focus of considerable speculation regarding the etiology of these fractures (Adams, 1966; Park *et al.*, 1970; Rooney, 1977; Schneider, 1979; Auer, 1980; Bramlage, 1983). Maximum carpal extension measured in this study was similar to that measured by electrogoniometry in normal trotting horses (Ratzlaff *et al.*, 1982). The findings of this study support the concept that maximum extension of the joint causes stress concentration along the dorsal joint margins. However, the results of this study suggest that maximum extension is not a uniform event throughout the composite joint, but rather is more profound in the middle carpal joint than in the radiocarpal joint. This would appear to maximize compression forces along the dorsal margin of the middle carpal joint space and may be one reason that fractures are more commonly seen in that area. While this finding is apparent in horses of normal conformation, horses with "back-on-the-knee" conformation would appear to be subjected to magnification of this effect.

Differences in the total angular displacement, mean velocity and acceleration among the axial carpal bones may also play a role in the consistent pattern of carpal fractures seen in racehorses. The distal row of carpal bones and the metacarpus attained similar angular displacement and average velocity which was significantly greater than that of the proximal row of carpal bones. Among the proximal row of carpal bones, the radial carpal bone attained maximum velocity and angular displacement, followed by the in-

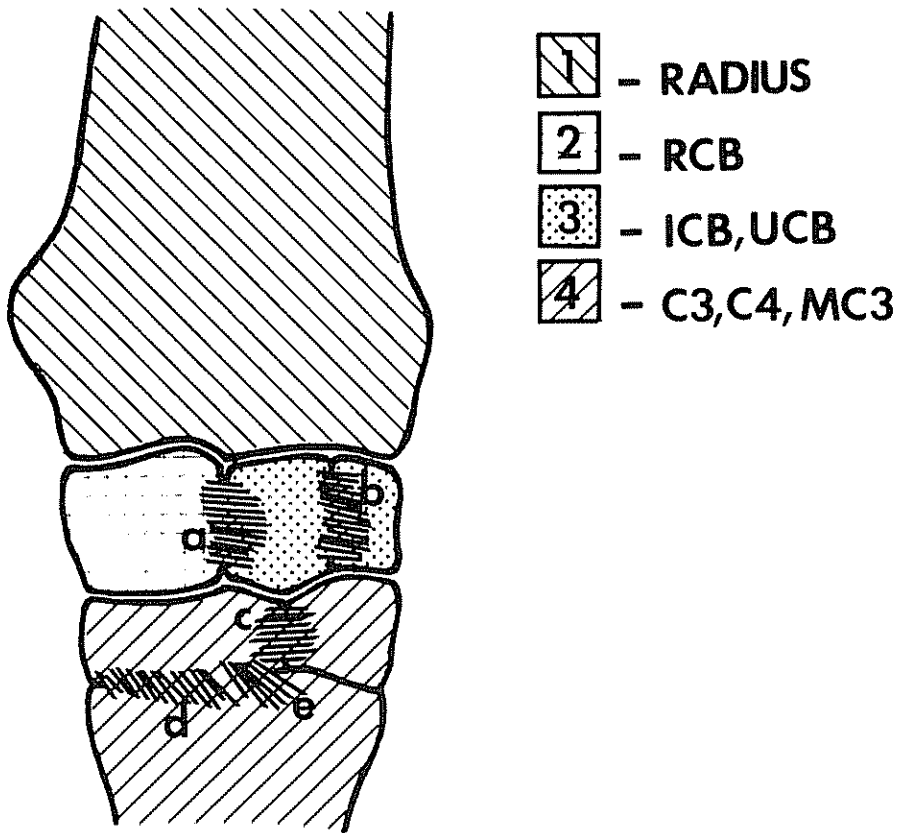


FIGURE 4. Functional units of the equine carpus: (1) distal radius (2) radial carpal bone (3) intermediate and ulnar carpal bones and (4) distal row of carpal bones and the metacarpus a, b, c: dorsal intercarpal ligaments. d, e: dorsal carpometacarpal ligaments

intermediate and ulnar carpal bones. These kinematic data appear to suggest a concentration of kinetic energy along the distal and medial aspect of the composite joint.

In vivo measurement of bone strain in horses during exercise indicates relatively large compressive forces acting along the medial aspect of both the radius and metacarpus (Turner *et al.*, 1975). This would suggest the medial aspect of the carpus to be an area of stress concentration as these compressive forces are transmitted across the joint. Consideration of such biomechanical forces in conjunction with the kinematic data summarized herein may help to explain the predilection for injury of the distal row of carpal bones and the medial aspect of the carpus.

### Acknowledgment

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## References

- Adams, O. R. (1966). *Lameness in horses*. 2nd ed. Lea & Febiger, Philadelphia, pp. 187–195.
- Auer, J. (1980) Diseases of the carpus. In: *The Veterinary Clinics of North America: Equine Lameness*. Vol. 2, No. 1. Moyer W., (ed.) W. B. Saunders Co, Philadelphia, pp. 81–99.
- Bramlage, L. (1983). Surgical diseases of the carpus. In: *The Veterinary Clinics of North America: Equine Orthopedic Surgery*. Vol. 5, No. 2. Turner, A., (ed.) W. B. Saunders Co, Philadelphia, pp. 261–274.
- Frankel, V. and Nordin M. (1966) *Basic Biomechanics of the Skeletal System*. Lea & Febiger, Philadelphia, pp. 42–44.
- Fredricson, I. and Drevemo, S. (1972). Methodological aspects of kinematics of the joints in the forelimbs of fast-moving horses. *Acta Vet. Scand.*, Suppl. **37**, 95–133.
- McIlwraith, C. (1984). Arthroscopy in retrospect. *Proc. Am. Ass. Equine Practnrs.* **30**, 321–331.
- Palmer, S. (1986). Prevalence of carpal fractures in Thoroughbred and Standardbred racehorses. *J. Am. Vet. Med. Ass.* **188**, 1171–1173.
- Park, R., Morgan, J. and O'Brien, T. (1970). Chip fractures in the carpus of the horse: A radiographic study of their incidence and location. *J. Am. Vet. Med. Ass.* **157**, 1305–1312.
- Raker, C., Baker, R. and Wheat, J. D. (1966). Pathophysiology of equine degenerative joint disease and lameness. *Proc. Am. Ass. Equine Practnrs.* **12**, 229–252.
- Ratzlaff, M., Grant, B. and Adrian, M. (1982). Quantitative evaluation of equine carpal lamenesses. *J. Equine Vet. Sci.* **2**, 78–88.
- Rooney, J. (1977). *Biomechanics of Lameness in Horses*. 2nd ed. R. E. Krieger Publishing Co, Huntington, NY, pp. 71–139.
- Schneider, R. (1979). Incidence and location of fractures within the carpus. *Proc. Am. Ass. Equine Practnrs.* **25**, 145–146.
- Thrall, D., Lebel, J. and O'Brien, T. (1971). A five year survey of the incidence and location of equine carpal chip fractures. *J. Am. Vet. Med. Ass.* **158**, 1366–1368.
- Turner, A., Mills, E. and Gabel, A. (1975). In vivo measurement of bone strain in the horse. *Am. J. Vet. Res.* **36**, 1573–1579.