Pediatric Type II Tibial Spine Fractures

Addressing the Treatment Controversy With a Mixed-Effects Model

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Background: Tibial spine fractures, although relatively rare, account for a substantial proportion of pediatric knee injuries with effusions and can have significant complications. Meyers and McKeever type II fractures are displaced anteriorly with an intact posterior hinge. Whether this subtype of pediatric tibial spine fracture should be treated operatively or nonoperatively remains controversial. Surgical delay is associated with an increased risk of arthrofibrosis; thus, prompt treatment decision making is imperative.

Purpose: To assess for variability among pediatric orthopaedic surgeons when treating pediatric type II tibial spine fractures.

Study Design: Cross-sectional study.

Methods: A discrete choice experiment was conducted to determine the patient and injury attributes that influence the management choice. A convenience sample of 20 pediatric orthopaedic surgeons reviewed 40 case vignettes, including physis-blinded radiographs displaying displaced fractures and a description of the patient's sex, age, mechanism of injury, and predominant sport. Surgeons were asked whether they would treat the fracture operatively or nonoperatively. A mixed-effects model was then used to determine the patient attributes most likely to influence the surgeon's decision, as well as surgeon training background, years in practice, and risk-taking behavior.

Results: The majority of respondents selected operative treatment for 85% of the presented cases. The degree of fracture displacement was the only attribute significantly associated with treatment choice ($P < .001$). Surgeons were 28% more likely to treat the fracture operatively with each additional millimeter of displacement of fracture fragment. Over 64% of surgeons chose to treat operatively when the fracture fragment was displaced by $\geq$3.5 mm. Significant variation in surgeon's propensity for operative treatment of this fracture was observed ($P = .01$). Surgeon training, years in practice, and risk-taking scores were not associated with the respondent's preference for surgical treatment.

Conclusion: There was substantial variation among pediatric orthopaedic surgeons when treating type II tibial spine fractures. The decision to operate was based on the degree of fracture displacement. Identifying current treatment preferences among surgeons given different patient factors can highlight current variation in practice patterns and direct efforts toward promoting the most optimal treatment strategies for controversial type II tibial spine fractures.

Keywords: tibial spine fracture; pediatric; type II Meyers McKeever; treatment decision making

Tibial spine fractures are relatively rare, occurring in approximately 3 out of 100,000 children annually, yet they account for about 2% to 5% of pediatric knee injuries associated with an effusion.[1,22] If not treated properly, patients with these injuries can develop significant complications, including arthrofibrosis, residual laxity, fracture nonunion or malunion, quadriceps atrophy, retropatellar pain, and tibial physis disruptions.[1,3,16,40] Tibial spine fractures have recently garnered increased attention owing to new noncontact sport injury mechanisms being reported for this injury in children.[17]

Fractures of the partially ossified tibial eminence occur after forced knee flexion with simultaneous tibia external rotation, or hyperextension, similar to anterior cruciate ligament (ACL) rupture mechanisms.[24] They are typically classified via plain radiographs with the Meyers and McKeever classification, based on displacement and morphology of the fracture fragment. Fractures were originally categorized into 3 types: type I fractures are nondisplaced; type II fractures are displaced anteriorly with an intact posterior cortical hinge; and type III fractures are completely displaced.[24] Further classifications include types

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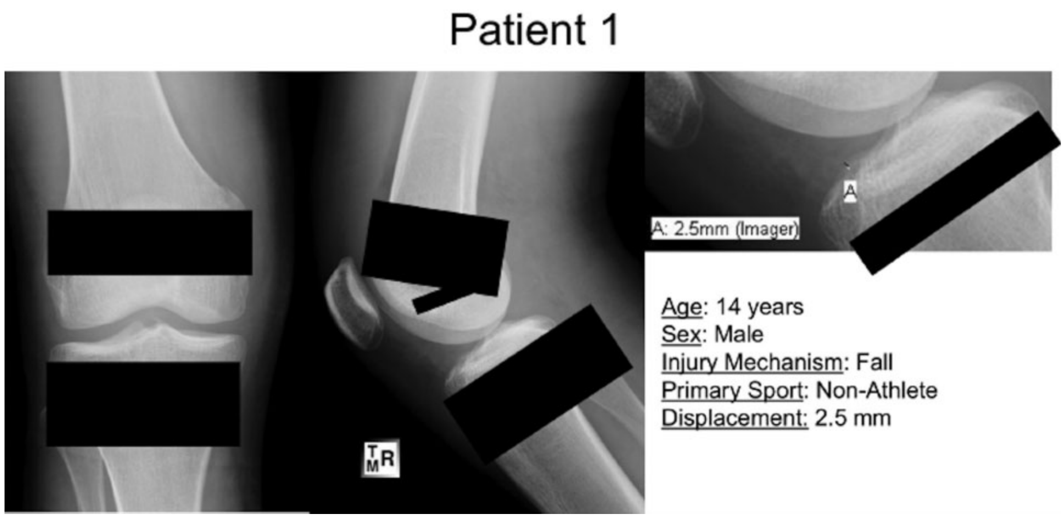

Figure 1. A sample vignette includes anteroposterior and lateral knee radiographs of a type II tibial spine fracture with patient and injury characteristics, as well as fracture fragment displacement value shown on zoomed lateral view.

IIIA and IIIB, with IIIA involving only the insertion point of the ACL and IIIB involving the entire intercondylar notch, as well as type IV for comminuted fractures.[20,39]

The Meyers and McKeever classification is a core basis of treatment practice for many surgeons, where type I cases are managed nonoperatively and types III and IV are almost universally managed surgically.[14,25] Controversy exists surrounding the management of type II fractures, the focus of this study; similar to the controversy around type II supracondylar humerus fractures, some surgeons advocate surgical treatment and others advocate nonoperative treatment.[4,11,18] Closed management may be appropriate when displacement is less than 3 to 5 mm, earning improved reduction at the cost of greater arthrofibrosis risk.[9] Surgical delay is associated with an increased risk of arthrofibrosis; thus, prompt treatment decision making is imperative.[35]

Relative indications for arthroscopic reduction and internal fixation depend on the degree of displacement and patient attributes, including age, sex, injury mechanism, and athletic level. Tibial spine fractures with these attributes thus may be variably managed by pediatric orthopaedic surgeons without a standardization of treatment modality for these injuries. Therefore, the purpose of this study was to identify and characterize variability among pediatric orthopaedic surgeons when treating type II tibial spine fractures. In addition, we aimed to identify injury characteristics, patient attributes, and surgeon demographics that affected clinical decision making.

METHODS

This was an observational cross-sectional study with level 4 evidence. A convenience sample of 20 pediatric orthopaedic surgeons in the United States, selected per their expertise in this area, reviewed 40 case vignettes that included radiographs displaying fractures with varying degrees of displacement and a brief description on the patient's sex, age, mechanism of injury, and predominant sport (Figure 1). A copy of the survey is included in Appendix Figure A1, available as supplemental material. Existing literature[1,8,18,24] and expert opinion were used to select the attributes (sex, age, mechanism of injury, primary sport participation, and displacement) and their respective levels to be entered into the model. Radiographs were reviewed and confirmed with fracture fragment displacement by an independent musculoskeletal radiologist.

Skeletal physes were blinded, as radiographs showing the ossification centers surrounding the knee could be used by experienced pediatric orthopaedic surgeons to approximate true age. This allowed age to be included as a variable within the computer-generated model, where a vignette of an 8-year-old child could be matched with radiographs of an actual 17-year-old or vice versa. Displacement was not presented as a variable but rather as a fixed effect incorporated into the study model based on actual measured displacement on the lateral radiograph, via an electronic ruler on a picture archiving and communication system. Respondents were asked whether they would treat the fracture

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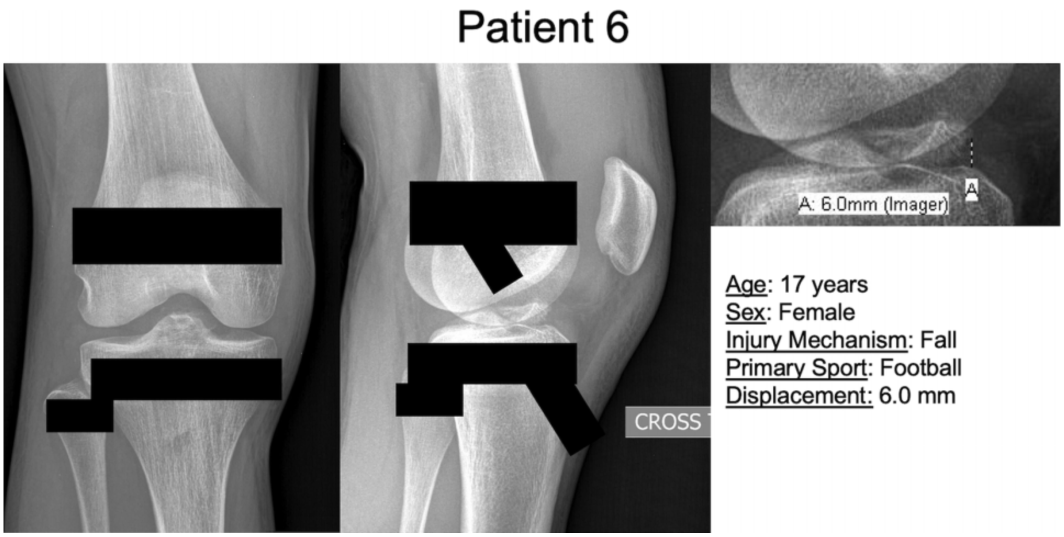

Figure 2. A second sample vignette illustrates a tibial spine fracture with greater displacement than in Figure 1, as an example.

operatively (ie, arthroscopic reduction and internal fixation) or nonoperatively (ie, long-leg cast).

Patient ages included 8, 11, 14, and 17 years, representing the most common age range of 8 to 14 years seen in this injury,[21] as well as the age spectrum of skeletally immature to mature for both males and females. Injury mechanisms included fall, collision, hyperextension, and twist. Primary sports included football, basketball, swimming, and nonathlete, with each representing a basic range of activity levels: contact sport with running/jumping, noncontact sport with running/jumping, noncontact and nonweightbearing sport, and no sport, respectively. Both the primary sports and injury mechanisms variables chosen in this study represented the most common reported in the literature.[1] Finally, displacement of fracture fragments ranged from 2.5 to 6.0 mm, with a mean ± SD value of 4.2 ± 1.1 mm, to represent a range of displacement that surgeons typically see in practice.[1] Figure 2 illustrates a vignette with larger displacement than Figure 1, as an example.

The Jackson Personality Inventory (JPI) Risk Taking subscale is a Likert scale, with 1 being risk averse and 4 being risk favorable, and it has been used in other peer-reviewed studies to examine providers' favorability toward risk taking in their treatment of patients.[6,8] The JPI Risk Taking subscale was incorporated to account for any differences in individual risk tolerance among surveyed surgeons, which could serve as a confounding variable in treatment decision making. It consists of 6 questions asking respondents to rate their level of agreement with the following: enjoyment of risk taking, avoidance of situations with uncertain outcomes, discomfort with risk taking if involved gains are higher, consideration of security as an important life element, whether people have told the respondent that he or she seems to enjoy taking risks, and whether the respondent takes risks when another alternative is present.

A computerized discrete choice experiment was then conducted to determine the patient and/or injury attributes (fixed effects) that influence the management of type II pediatric tibial spine fractures by the surveyed pediatric orthopaedic surgeons. An orthogonal and balanced factorial design combined levels and patient attributes via a Bayesian D-optimal design with the Choice Modeling Program within JMP (v 12; SAS Institute). Data were deemed significant for $P < .05$. In addition, surgeon respondents were queried regarding their demographics and practice (age, sex, years of practice, practice geography and type, fellowship training, weekly call commitments, annual tibial spine treatment frequency) as well as risk-taking behavior via the JPI subscale. The association between (1) surgeon propensity for operative treatment and (2) surgeon training, years in practice, and risk-taking behavior was then assessed. Finally, a receiver operating characteristic (ROC) curve was used to determine the probability of surgical treatment based on the degree of fracture displacement.

RESULTS

A total of 20 fellowship-trained pediatric orthopaedic surgeons participated in this study. Nineteen surgeons had completed pediatric fellowships; 1 had completed sports fellowship only; and 10 had completed multiple fellowships (Table 1). All surgeons were men, with a mean age of 43 years (range, 35-60 years) and a mean of 9 years of practice since fellowship training (range, 1-20 years). All participants ($N = 20$) had call responsibilities in pediatric orthopaedics at least 1 to 3 times weekly. Surgeon demographic and practice details are summarized in Table 1.

The degree of fracture displacement was the only attribute significantly associated with treatment choice ($P < .001$). Surgeons were 28% more likely to treat the fracture operatively with each additional millimeter of displacement ($P < .01$). The probability of opting for surgical treatment exceeded 64% when the fracture had $\geq$3.5 mm of displacement. Age, sex, mechanism of injury, and primary sport did not significantly influence treatment choice (Table 2).

TABLE 1
Demographics of Pediatric Orthopaedic Surgeon Participants (N = 20)

Characteristic	Mean ± SD (Range) or n (%)
Age, y	43.4 ± 7.1
Sex: male	20 (100)
Years of practice	8.9 ± 6.1
Practice geography	
Northeast	10 (50.0)
Southeast	1 (5.0)
Midwest	5 (25.0)
Northwest	2 (10.0)
Southwest	2 (10.0)
Practice type	
Academic	18 (90.0)
Academic and private mix	2 (10.0)
Fellowship training	
Pediatrics only	9 (45.0)
Sports only	1 (5.0)
Pediatrics and sports	9 (45.0)
Pediatrics and hip preservation	1 (5.0)
Days per week on-call	1.8 ± 0.6
Pediatric tibial spine fractures treated annually	
Rarely (<1)	1 (5.0)
1-3	8 (40.0)
4-6	4 (20.0)
6-9	4 (20.0)
10-14	1 (5.0)
≥15	2 (10.0)
Adult tibial spine fractures treated annually	
Rarely (<1)	10 (50.0)
1-3	8 (40.0)
4-6	1 (5.0)
6-9	1 (5.0)

Overall, surgical management was favored by the 20 respondents in 85% of the presented vignettes (Appendix Table A1). However, a statistically significant variation was identified in surgeons' propensity for operative treatment of this fracture ($P < .01$). Of the 20 surgeons, 13 demonstrated a preference for operative treatment of this injury. Surgeon training, years in practice, and risk-taking scores were not associated with the respondents' preference for surgical treatment. Overall, surgeon participants were neither highly risk averse nor risk favorable, with a mean risk score of 2.6 ± 0.3. Risk scores and preference for surgical management were very weakly correlated ($r = 0.24$, $P = .31$). Respondents' treatment preference and risk scores are summarized in Table 3.

DISCUSSION

We conducted a discrete choice experiment and corresponding mixed-effect regression model that emphasize rater preferences and the importance of different included levels and factors based on random utility theory.[23,32] Although this analysis type has been used in examining other health care decision making,[23,32] it has not been used to study the

TABLE 2
Fixed-Effects Parameter Estimates

Attribute: Level	Estimate	95% Lower	95% Upper	*P* Value
Sex				
Female	Reference	Reference	Reference	Reference
Male	0.00	–0.05	0.05	.96
Age, y				
17	Reference	Reference	Reference	Reference
14	0.04	–0.05	0.13	.36
11	–0.01	–0.10	0.08	.82
8	–0.08	–0.17	0.01	.11
Injury mechanism				
Fall	Reference	Reference	Reference	Reference
Hyperextension	0.04	–0.05	0.13	.40
Twist	0.06	–0.03	0.15	.23
Collision	–0.06	–0.16	0.03	.16
Primary sport				
Nonathlete	Reference	Reference	Reference	Reference
Swimming	–0.03	–0.12	0.06	.55
Basketball	0.04	–0.05	0.13	.34
Football	0.07	–0.02	0.17	.11
Displacement	0.28	0.23	0.32	<.001[a]

[a]Statistically significant ($P < .05$).

variables that may affect pediatric orthopaedic surgeons' management of tibial spine fractures. With a convenience sample of 20 pediatric orthopaedic surgeons, this study demonstrated that the presence of fracture displacement, as seen on plain knee radiographs, significantly influenced a surgeon's decision to surgically treat type II tibial spine fractures ($P < .001$). Surgeons began favoring surgery at 3.5 mm of fracture displacement and were 28% more likely to treat the fracture operatively with each additional millimeter of displacement of the fracture fragment. Sex, age, mechanism of injury, and athletic level did not significantly influence the treatment strategy.

The tibial spine is the distal attachment site of the ACL, the primary restraint to anterior translation of the knee joint that provides >85% of total restraining force of the knee in flexion.[28] Management of tibial spine fractures is traditionally based on the Meyers and McKeever classification, with type I treated nonoperatively and types III and IV treated surgically. Controversy exists in the literature regarding whether type II fractures, the focus of this study, should be managed surgically or nonoperatively.[4,11,18]

Nonoperative treatment usually involves closed reduction and immobilization in a long-leg cast with 20° of knee flexion, as originally advocated by Meyers and McKeever to minimize stress on the ACL during healing.[29,31] Others have advocated straight-leg casting, arguing improved fracture reduction from femoral condyle contact.[10,38] Regarding the prognosis of nonoperative treatment for type II fractures, Janarv et al[14] showed in a small series that 75% of their patients treated nonoperatively had excellent Lysholm and Tegner score outcomes. A similar case series described 13 patients with no pain, swelling, disability, or instability at a mean postinjury follow-up of 3.5 years,

TABLE 3
Pediatric Orthopaedic Surgeons' Predisposition to Treatment

Rater	Coefficient	Propensity for Surgical Treatment[a]	Risk Score[b]
1	0.15	Yes	2.50
2	0.24	Yes	2.67
3	0.19	Yes	2.17
4	0.06	Yes	2.67
5	0.24	Yes	3.17
6	–0.11	No	3.00
7	0.28	Yes	2.33
8	0.06	Yes	2.67
9	–0.33	No	2.83
10	–0.81	No	2.17
11	–0.37	No	2.50
12	–0.29	No	2.83
13	0.24	No	2.67
14	0.02	Yes	2.83
15	–0.15	No	2.50
16	–0.15	No	2.33
17	0.24	Yes	2.50
18	0.06	Yes	2.33
19	0.24	Yes	2.83
20	0.19	Yes	3.00
Risk score, mean ± SD (range)			2.63 ± 0.28 (2.17-3.17)
Participants preferring surgery, n (%)			13 (65.0)
Correlation between surgical propensity and risk score			$r = 0.24$

[a]Preference of surgical over nonsurgical management in the included scenarios.

[b]Risk assessment based on Jackson Personality Inventory Risk Taking subscale. Scores range from 1 to 4, with higher scores correspond to a greater likelihood/tolerance of taking risk.

although 4 patients had ACLs that were thinner or longer on magnetic resonance imaging.[36] Finally, a series of 15 type II fractures treated nonoperatively showed a mean 3.5 mm of anterior instability at final follow-up (mean, 4 years), despite patients having no symptoms.[37]

Surgical treatment of tibial spine fractures is most commonly accomplished via arthroscopic reduction and internal fixation. Arthroscopic fixation has gained slight favor over open procedures in multiple reports, owing to a restoration of anatomic reduction and a reported reduction in long-term instability.[12,15,18,29] In all tibial spine fracture types, subsequent ACL laxity has been described in 10% of patients treated surgically, as opposed to 22% in patients treated nonoperatively.[2] Furthermore, risk of ACL reconstruction in the ipsilateral knee was reported to be greater in patients treated nonoperatively (10.0% vs 1.04%, $P = .036$).[5] Type II fractures have been reported to have high rates of soft tissue entrapment, usually intermeniscal ligament or periosteum, which can increase risk of malunion and is often cited as justification for surgical management.[17,18,27] Louis et al[19] described a series of 17 patients with type II fracture treated with open reduction and internal fixation (ORIF), with a mean follow-up of 3 years, who had no reduction in sports activities or instability and a mean Lysholm score of 99.7.

These studies demonstrate the conflicting opinions and literature regarding which treatment strategy is most preferable for type II tibial spine fractures, and our study reflects this variability among our respondents. Until larger trials are completed, perhaps the most pragmatic approach, an initial attempt at closed reduction, followed by surgery if unsuccessful, avoids surgical risks while optimizing fracture reduction.[9,11] Our study examined other factors that may influence pediatric orthopaedic surgeons to treat these fractures surgically versus nonsurgically.

Although age was not found to be an influential factor in surgeon decision making in our study, it has been shown that the odds of later ACL reconstruction increase by a factor of 1.3 for every year of increasing age at the time of tibial spine fracture in patients aged 5 through 18 years.[26] Interestingly, this conclusion was not found by Janarv et al[14] in their series of pediatric tibial spine fractures, and they cautioned that growth disturbance remains a key risk of periphyseal orthopaedic surgery. In our study, patient sex also did not affect treatment choice. However, it can have a significant role in the severity of pediatric knee injuries, where girls are twice as likely to sustain knee injuries requiring surgery despite a higher overall rate of injury in boys.[13] Sex of the patient may have a role in injury patterns as well, as females were 5.4 times more likely to have an ACL injury and twice as likely to sustain noncontact knee injuries as compared with males.[13,30]

Although injury mechanisms did not affect treatment choice in our study, greater rates of arthrofibrosis have been described in the literature after high-energy mechanisms or the presence of concomitant soft tissue injuries.[33] Patients' athletic level/sport also has been reported as a factor for treatment approach, where surgery may be deemed appropriate for higher-level athletes with injuries such as metatarsal fractures, rotator cuff tears, medial epicondyle fractures, and ACL ruptures.[8,34] It has even been shown in orthopaedic literature that football has the highest severe knee injury rate, followed by wrestling, girls' basketball, and girls' soccer.[7] Despite these notions, our study found that neither patients' primary sport nor injury mechanism affected surgeons' treatment choice.

Fracture displacement was the only variable in our study that significantly influenced a surgeon's decision to operatively manage the type II tibial spine fracture ($P < .001$). Surgeons began favoring surgery at 3.5 mm of fracture displacement, slightly larger than the lower limit of reported acceptable displacement of 3.0 mm for nonoperative treatment[11] and lower than the upper limit of reported acceptable displacement of 5.0 mm for nonoperative treatment.[9] Our respondents were also 28% more likely to treat the fracture operatively with each additional millimeter of displacement of the fracture fragment. Outside these 2 studies and our own, the role of specific displacement measurement in tibial spine fracture treatment is overall scant in the literature and is a rich topic for future investigation.

This study has multiple limitations, despite its aim to identify variables affecting treatment choice for type II tibial spine fractures with a unique statistical model. First, our study was limited to a convenience sample of 20 academic surgeons with varied training backgrounds and institutions, which may have hindered our ability to detect smaller influential variables that may be detectable with a larger sample. We could not incorporate participant characteristics within the model, owing to a lack of statistical power, and the preponderance of respondents within the Northeast region may represent a geographic limitation. Second, the discrete choice experiment was limited to a dichotomous question, preventing differentiation of further treatment choice nuances, such as arthroscopic versus open approaches or the rationale behind surgeons' decisions. Third, regarding the lack of correlation between risk score and predisposition to treatment, the JPI Risk Taking subscale may not be the best indicator of the role of surgeon personality on treatment decision making. Future similar studies with larger respondent populations could determine if any additional patient, fracture, or provider attributes influence treatment decisions. Finally, we recognize that the qualitative appearance of the physis is an important factor in treatment decision making versus age alone, and physeal appearances were blinded within our study.

CONCLUSION

There was substantial variation among pediatric orthopaedic surgeons when treating type II tibial spine fractures. The degree of fracture displacement was the only factor significantly affecting surgeons' decision to operate. However, there is a lack of consensus in the literature regarding treatment of type II tibial spine fractures, and better treatment guidelines are needed to optimize patient outcomes. Learning about the current treatment preferences among surgeons, given different patient factors, highlights current variation in practice patterns and directs efforts toward promoting the most optimal treatment strategies.

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SUPPLEMENTAL MATERIAL

A Supplemental Figure for this article is available at http://journals.sagepub.com/doi/suppl/10.1177/2325967119866162

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APPENDIX

TABLE A1
Treatment Choice by Case Vignette

	Raters, n (%)			Raters, n (%)	
Case	Surgery	No Surgery	Case	Surgery	No Surgery
1	1 (5)	19 (95)	21	19 (95)	1 (5)
2	15 (75)	5 (25)	22	12 (60)	8 (40)
3	15 (75)	5 (75)	23	17 (85)	3 (15)
4	20 (100)	0 (0)	24	20 (100)	0 (0)
5	16 (80)	4 (20)	25	18 (90)	2 (10)
6	20 (100)	0 (0)	26	17 (85)	3 (15)
7	12 (60)	8 (40)	27	19 (95)	1 (5)
8	18 (90)	2 (10)	28	18 (90)	2 (10)
9	15 (75)	5 (25)	29	12 (60)	8 (40)
10	19 (95)	1 (5)	30	18 (90)	2 (10)
11	14 (70)	6 (30)	31	1 (5)	19 (95)
12	20 (20)	0 (0)	32	18 (90)	2 (10)
13	13 (65)	7 (35)	33	20 (100)	0 (0)
14	19 (95)	1 (5)	34	18 (90)	2 (10)
15	14 (70)	6 (30)	35	13 (65)	7 (35)
16	19 (95)	1 (5)	36	0 (0)	20 (100)
17	20 (100)	0 (0)	37	19 (95)	1 (5)
18	1 (5)	19 (95)	38	16 (80)	4 (20)
19	16 (80)	4 (20)	39	15 (75)	5 (25)
20	17 (85)	3 (15)	40	5 (25)	15 (75)