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J.A Landers


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Figure 1. Visual pathways and visual field defects resulting from injury to the pathways
Figure 2. Schematic representation of the anatomy of the eye
Figure 3. Schematic representation of the nerve fibre layer
Figure 4. Grey-scale of the left visual field showing progressive loss from glaucoma
Figure 5. Micrograph of retina in (A) Healthy patient and (B) Glaucoma patient
Figure 6. Schematic representation of visual field testing with a flat screen (campimetry)
Figure 7. Bjerrum screen
Figure 8. Schematic representation of visual field testing with a curved screen (perimetry)
Figure 9. The ‘Island of Traquair’
Figure 10 The Goldman Perimeter
Figure 11 Mapping a small visual field scotoma using (A) kinetic and (B) static perimetry.
Figure 12 Mapping a steep scotoma using (A) kinetic and (B) static perimetry
Figure 13. The Humphrey Field Analyzer
Figure 14. The Medmont perimeter
Figure 15. The relationship between stimulus brightness (Apostilbs) and visual field sensitivity (Decibels)
Figure 16. Schematic representation of the ‘Stair-case’ method used in static automated perimetry
Figure 17. Print-out of the visual field from a right eye using a Humphrey Field Analyzer
Figure 18. Visual field from the right eye using (A) manual kinetic perimetry and (B) automated static perimetry
Figure 19. Schematic representation of the colour sensitive visual pathways
Figure 20. Schematic representation of the target used in frequency doubling perimetry

Sinusoidal Grating <1 cycles per degree

Flickered at >15 Hz

Double Frequency Perceived
Figure 21. The Frequency Doubling Perimeter
Figure 22. Relationship between change in target stripe contrast and My, Mx, Koniocellular and Parvocellular pathway responses (modified with permission from Prof. E Kaplan).\textsuperscript{217} Shows the difference in target stripe contrast needed to achieve the same ganglion cell response.
Figure 23. The testing pattern used by the frequency doubling perimeter to test the left eye
Figure 24. Pattern deviations from two patients (MF1, MF65).
Medmont probabilities: •••, < 6 dB; ••, < 12 dB; ■, < 18 dB.
HFA probabilities: •••, P < 5%; ••, P < 2%; •, P < 1%; ■, P < 0.5%.
FDP probabilities: ••••, P < 5%; •••, P < 1%; ▪, P < 0.5%.
Figure 25. Pattern deviations from those patients both with short wavelength automated perimetry (SWAP) and frequency doubling perimetry (FDP) losses. Achromatic automated perimetry (AAP) and SWAP probabilities: ⊚, P < 5%; ⊙, P < 2%; ◯, P < 1%; ●, P < 0.5%.
FDP probabilities: ♦, P < 5%; ♣, P < 1%.
Areas of visual field loss are outlined.
Figure 26. (a) Disc photograph; (b) short wavelength automated perimetry visual field; and (c) frequency doubling perimetry visual field from a false negative subject.
Figure 27. (a) Disc photograph; (b) short wavelength automated perimetry visual field; and (c) frequency doubling perimetry visual field from a false positive subject.
<table>
<thead>
<tr>
<th>Test Time</th>
<th>AAP</th>
<th>SWAP</th>
<th>FDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 28. Pattern deviations from Patient 058 for Achromatic Automated Perimetry (AAP), Short Wavelength Automated Perimetry (SWAP) and Frequency Doubling Perimetry (FDP) over the four year study period.

HFA probabilities:  , P < 5%;  , P < 2%;  , P < 1%;  , P < 0.5%.

FDP probabilities:  , P < 5%;  , P < 1%;  , P < 0.5%
Figure 29. Pattern deviations from Patient 098 for Achromatic Automated Perimetry (AAP), Short Wavelength Automated Perimetry (SWAP) and Frequency Doubling Perimetry (FDP) over the four year study period.

HFA probabilities: ⊗, P < 5%; ⊘, P < 2%; ⊠, P < 1%; ■, P < 0.5%.

FDP probabilities: ≡, P < 5%; ⊡, P < 1%; ≢, P < 0.5%
Figure 30. Survival curve of patients with normal SWAP and abnormal SWAP, using the development of an AAP abnormality as end point.
Figure 31. Survival curve patients with normal FDP and abnormal FDP, using the development of an AAP abnormality as end point.
Figure 32. The position of visual fields zones for: A. Humphrey Field Analyzer for AAP and SWAP and B. Frequency Doubling Perimeter.

(Zone 1 (10° eccentricity), Zone 2 (15° eccentricity), Zone 3 (20° eccentricity), Zone 4 (24° eccentricity))

(Eccentricity of the visual field is indicated)
Figure 33. Graph of Mean Sensitivities across the Horizontal Midline of the Visual Field for: **Achromatic Automated Perimetry**, **Short Wavelength Automated Perimetry** and **Frequency Doubling Perimetry**.

(N.B Mean Sensitivities for Achromatic Automated Perimetry and Short Wavelength Automated Perimetry have been converted to Contrast Decibels in order to be Comparable with Frequency Doubling Perimetry)
Figure 34. Mean Visual Field Sensitivities in Decibels (Standard Deviation) for each Quadrant of each Zone for Achromatic Automated Perimetry using the Humphrey Field Analyzer.

(Eccentricity of the visual field is indicated)
Figure 35. Mean Visual Field Sensitivities in Decibels (Standard Deviation) for each Quadrant of each Zone for Short Wavelength Automated Perimetry using the Humphrey Field Analyzer.

(Eccentricity of the visual field is indicated)
Figure 36. Mean Visual Field Sensitivities in Decibels (Standard Deviation) for each Quadrant of each Zone for the Frequency Doubling Perimeter. (Eccentricity of the visual field is indicated)
Figure 37. The Slope of the Regression of Mean Sensitivity (Decibels) at each Visual Field Zone as a function of Decade of Age for A. Achromatic Automated Perimetry, B. Short Wavelength Automated Perimetry and C. Frequency Doubling Perimetry.

(* P<0.05, ** P<0.01, ***P<0.001, ****P<0.0001)

(Eccentricity of the visual field is indicated)
Figure 38. Showing the Area Contributing to a Nasal Step location, [square] an Arcuate location, [hatch] and a Temporal Wedge [hatch] Above and Below the Horizontal Midline in the Left Visual Field.

(Eccentricity of the visual field is indicated)
Figure 39. Showing Frequencies of Abnormal Zones for A) Controls, B) Glaucoma Suspects and C) Open-Angle Glaucoma Patients in the Left Visual Field.

(P<5%; upper frequency, P<1%; lower frequency)

(Frequencies ≥ 0.50 are Highlighted)
Aspects of FDP in the Detection of Early Glaucoma

Figure 40a. Showing Pattern Deviations from Patients Classified by Frequency Doubling Perimetry as True Positives Under a Nasal-Step Protocol.

Figure 40b. Showing Pattern Deviations from Patients Classified by Frequency Doubling Perimetry as False Positives Under a Nasal-Step Protocol.

(AAP Probabilities: ::, P < 5%; :, P < 2%; ::, P < 1%; ::, P < 0.5%)

(FDP Probabilities: :: P<5%, :: P<1%, :: P<0.5% )
<table>
<thead>
<tr>
<th>Patient</th>
<th>AAP</th>
<th>FDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF42</td>
<td><img src="image1" alt="AAP Diagram" /></td>
<td><img src="image2" alt="FDP Diagram" /></td>
</tr>
<tr>
<td>MF49</td>
<td><img src="image3" alt="AAP Diagram" /></td>
<td><img src="image4" alt="FDP Diagram" /></td>
</tr>
</tbody>
</table>

Figure 41a. Showing Pattern Deviations from Patients Classified by Frequency Doubling Perimetry as True Negatives Under a Nasal-Step Protocol.

<table>
<thead>
<tr>
<th>Patient</th>
<th>AAP</th>
<th>FDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF17</td>
<td><img src="image5" alt="AAP Diagram" /></td>
<td><img src="image6" alt="FDP Diagram" /></td>
</tr>
<tr>
<td>MF07</td>
<td><img src="image7" alt="AAP Diagram" /></td>
<td><img src="image8" alt="FDP Diagram" /></td>
</tr>
</tbody>
</table>

Figure 41b. Showing Pattern Deviations from Patients Classified by Frequency Doubling Perimetry as False Negatives Under a Nasal-Step Protocol.

(AAP Probabilities: ``, P < 5%; ``, P < 2%; ``, P < 1%; ``, P < 0.5%)

(FDP Probabilities: ``, P<5%, ``, P<1%, ``, P<0.5%)
Figure 42. The Humphrey Matrix perimeter
Figure 43. The print-out from (A) the Humphrey Matrix perimeter, compared with (B) the Humphrey Field Analyzer.
Table 1. Numbers of Normal and Abnormal Frequency Doubling Perimetry and Short Wavelength Automated Perimetry in the patient sample.
### Table 2. Results of short wavelength automated perimetry (SWAP) compared with frequency doubling perimetry (FDP) for patients with an abnormal clinical optic disc assessment.

<table>
<thead>
<tr>
<th>FDP result</th>
<th>SWAP result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abnormal</td>
</tr>
<tr>
<td>Abnormal</td>
<td>3</td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 3. Results of short wavelength automated perimetry (SWAP) compared with frequency doubling perimetry (FDP) for patients with a normal clinical optic disc assessment.
Table 4. Results of short wavelength automated perimetry (SWAP) compared with clinical optic disc assessment.
Table 5. Results of frequency doubling perimetry (FDP) compared with clinical optic disc assessment.

<table>
<thead>
<tr>
<th>SWAP result</th>
<th>Clinical optic disc assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abnormal</td>
</tr>
<tr>
<td>Abnormal</td>
<td>3</td>
</tr>
<tr>
<td>Normal</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
</tr>
</tbody>
</table>
Table 6 Description of patients within the study groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Males (%)</th>
<th>Mean age (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15</td>
<td>7 (47%)</td>
<td>52 years (15 years)</td>
<td>29–75 years</td>
</tr>
<tr>
<td>Glaucoma suspects</td>
<td>8</td>
<td>5 (63%)</td>
<td>56 years (16 years)</td>
<td>35–77 years</td>
</tr>
<tr>
<td>Ocular hypertension</td>
<td>8</td>
<td>1 (13%)</td>
<td>60 years (9 years)</td>
<td>47–74 years</td>
</tr>
<tr>
<td>Open angle glaucoma</td>
<td>32</td>
<td>16 (50%)</td>
<td>64 years (9 years)</td>
<td>41–79 years</td>
</tr>
</tbody>
</table>
### Humphrey Full Threshold MD

<table>
<thead>
<tr>
<th>Group</th>
<th>Average</th>
<th>(SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-0.75</td>
<td>1.05</td>
<td>0.59 to -2.34</td>
</tr>
<tr>
<td>Glaucoma Suspects</td>
<td>-0.66</td>
<td>1.23</td>
<td>1.57 to -1.72</td>
</tr>
<tr>
<td>Ocular Hypertension</td>
<td>1.19</td>
<td>2.39</td>
<td>0.90 to -6.41</td>
</tr>
<tr>
<td>Open Angle Glaucoma</td>
<td>8.20</td>
<td>7.51</td>
<td>1.04 to -26.58</td>
</tr>
</tbody>
</table>

Table 7. Description the amount of visual field loss for patients within the study groups
<table>
<thead>
<tr>
<th>Perimetry Type</th>
<th>Mean Test Time</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medmont Central Threshold</td>
<td>10 minutes</td>
<td>51 seconds</td>
</tr>
<tr>
<td>Medmont Flicker Perimetry</td>
<td>9 minutes</td>
<td>1 minutes</td>
</tr>
<tr>
<td>Humphrey Full Threshold</td>
<td>10 minutes</td>
<td>1 minutes</td>
</tr>
<tr>
<td>Humphrey SITA</td>
<td>5 minutes</td>
<td>1 minutes</td>
</tr>
<tr>
<td>Short Wavelength Automated Perimetry</td>
<td>10 minutes</td>
<td>1 minutes</td>
</tr>
<tr>
<td>Frequency Doubling Perimetry</td>
<td>5 minutes</td>
<td>30 seconds</td>
</tr>
</tbody>
</table>

Table 8. Mean test time (standard deviation) for Humphrey and Medmont perimetry
<table>
<thead>
<tr>
<th></th>
<th>Humphrey Full Threshold</th>
<th></th>
<th>Humphrey SITA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abnormal</td>
<td>Normal</td>
<td>Abnormal</td>
<td>Normal</td>
</tr>
<tr>
<td>Medmont Central Threshold (Strict)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>24</td>
<td>2</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
<td>36</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>Medmont Central Threshold (Loose)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>25</td>
<td>9</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>Normal</td>
<td>0</td>
<td>29</td>
<td>1</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 9. Numbers of normal and abnormal Medmont Central Threshold, Humphrey Full Threshold and SITA in the patient sample.
<table>
<thead>
<tr>
<th></th>
<th>Medmont Central Threshold (Strict)</th>
<th>Medmont Central Threshold (Loose)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compared with</td>
<td>Humphreys Full Threshold</td>
<td>Humphreys SITA</td>
</tr>
<tr>
<td></td>
<td>0.90</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>0.94</td>
<td>0.72</td>
</tr>
<tr>
<td>Sector Correlation ($r^2$ statistic):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superonasal</td>
<td>0.86**</td>
<td>0.85**</td>
</tr>
<tr>
<td>Superotemporal</td>
<td>0.80**</td>
<td>0.72**</td>
</tr>
<tr>
<td>Inferonasal</td>
<td>0.69**</td>
<td>0.62**</td>
</tr>
<tr>
<td>Inferotemporal</td>
<td>0.29**</td>
<td>0.23**</td>
</tr>
<tr>
<td>Mean Defect Correlation ($r^2$ statistic):</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.89**</td>
<td>0.88**</td>
</tr>
</tbody>
</table>

(*P <0.001, **P <0.0001)

Table 10. Comparison of Medmont Central Threshold with Humphreys Full Threshold and Humphreys SITA showing, Kappa Statistic, area under the ROC curve (AUC), quadrant analysis and mean defect correlation.
<table>
<thead>
<tr>
<th></th>
<th>Humphrey short wavelength Perimetry</th>
<th>Humphrey frequency doubling perimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abnormal</td>
<td>Normal</td>
</tr>
<tr>
<td>Medmont Flicker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Strict)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>23</td>
<td>8</td>
</tr>
<tr>
<td>Normal</td>
<td>3</td>
<td>29</td>
</tr>
<tr>
<td>Medmont Flicker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Loose)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>Normal</td>
<td>2</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 11 Numbers of normal and abnormal Medmont flicker perimetry, Humphrey short wavelength perimetry, and Humphrey frequency doubling perimetry in the patient sample.
### Table 12 Comparison of Medmont flicker perimetry with Humphrey short wavelength perimetry (SWAP) and Humphrey frequency doubling perimetry (FDP) showing kappa statistic, area under the ROC curve (AUC), quadrant analysis, and mean defect correlation

<table>
<thead>
<tr>
<th></th>
<th>Medmont Flicker (Strict)</th>
<th>Medmont Flicker (Loose)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compared with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humphreys SWAP</td>
<td>Humphreys FDP</td>
</tr>
<tr>
<td>Kappa Statistic</td>
<td>0.65</td>
<td>0.87</td>
</tr>
<tr>
<td>AUC</td>
<td>0.81</td>
<td>0.96</td>
</tr>
<tr>
<td>Sector Correlation ($r^2$ statistic):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superonasal</td>
<td>0.48**</td>
<td>0.67**</td>
</tr>
<tr>
<td>Superotemporal</td>
<td>0.25**</td>
<td>0.79**</td>
</tr>
<tr>
<td>Inferonasal</td>
<td>0.17*</td>
<td>0.64**</td>
</tr>
<tr>
<td>Inferotemporal</td>
<td>0.02</td>
<td>0.72**</td>
</tr>
<tr>
<td>Mean Defect Correlation ($r^2$ statistic):</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.57**</td>
<td>0.79**</td>
</tr>
</tbody>
</table>

(*P <0.001, **P <0.0001)
<table>
<thead>
<tr>
<th>FDP result</th>
<th>SWAP result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abnormal</td>
</tr>
<tr>
<td>All Subjects at Start of Study</td>
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</tr>
<tr>
<td>Abnormal</td>
<td>8</td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
</tr>
<tr>
<td>Subjects With Abnormal AAP Findings at End of Study</td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>5</td>
</tr>
<tr>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
</tr>
<tr>
<td>Subjects With Normal AAP Findings at End of Study</td>
<td></td>
</tr>
<tr>
<td>Abnormal</td>
<td>3</td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 13 SWAP Results Compared With FDP Results
### Global Indices Compared

**Between Tests, $r^2$ (P value)**

<table>
<thead>
<tr>
<th>Tests Compared</th>
<th>MD</th>
<th>PSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAP and SWAP</td>
<td>0.084 (&lt;0.001)</td>
<td>0.122 (&lt;0.001)</td>
</tr>
<tr>
<td>AAP and FDP</td>
<td>0.113 (&lt;0.001)</td>
<td>0.021 (0.07)</td>
</tr>
<tr>
<td>SWAP and FDP</td>
<td>0.108 (&lt;0.001)</td>
<td>0.005 (0.37)</td>
</tr>
</tbody>
</table>

Table 14 Comparison of Global Indices Among AAP, SWAP and FDP Throughout the Study
### Table 15. Showing Linear Regression Coefficients and Test Statistics for the Relationship between Visual Field Mean Sensitivities and Increasing Eccentricity.

Multivariate Analysis was Adjusted for Age.

(Short Wavelength Automated Perimetry: SWAP, Achromatic Automated Perimetry: AAP, Frequency Doubling Perimeter: FDP)

(* P<0.05, ** P<0.01, ***P<0.001, ****P<0.0001)

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Univariate Analysis</th>
<th>Multivariate Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Test Statistic</td>
</tr>
<tr>
<td>SWAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superonasal</td>
<td>-2.90</td>
<td>10.72****</td>
</tr>
<tr>
<td>Superotemporal</td>
<td>-2.56</td>
<td>9.44****</td>
</tr>
<tr>
<td>Inferonasal</td>
<td>-2.00</td>
<td>6.46****</td>
</tr>
<tr>
<td>Inferotemporal</td>
<td>-1.82</td>
<td>6.79****</td>
</tr>
<tr>
<td>AAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superonasal</td>
<td>-1.57</td>
<td>10.74****</td>
</tr>
<tr>
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<td>-1.70</td>
<td>10.91****</td>
</tr>
<tr>
<td>Inferonasal</td>
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<td>10.12****</td>
</tr>
<tr>
<td>Inferotemporal</td>
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<td>7.89****</td>
</tr>
<tr>
<td>FDP</td>
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<td></td>
</tr>
<tr>
<td>Superonasal</td>
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<td>1.32</td>
</tr>
<tr>
<td>Superotemporal</td>
<td>-1.16</td>
<td>2.66**</td>
</tr>
<tr>
<td>Inferonasal</td>
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<td>1.63</td>
</tr>
<tr>
<td>Inferotemporal</td>
<td>-1.14</td>
<td>2.63**</td>
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### Table 16. Showing Results of Achromatic Automated Perimetry (AAP) Compared with Frequency Doubling Perimetry (FDP) For Each Testing Pattern

<table>
<thead>
<tr>
<th>FDP</th>
<th>Abnormal</th>
<th>Normal</th>
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</thead>
<tbody>
<tr>
<td>Conventional Protocol</td>
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<tr>
<td>Normal</td>
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<td>Nasal Step</td>
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<td>Normal</td>
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<tr>
<td>Arcuate</td>
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<td>6</td>
</tr>
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<td>Normal</td>
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<td>36</td>
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<td>Temporal Wedge</td>
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</tr>
<tr>
<td>Normal</td>
<td>10</td>
<td>37</td>
</tr>
</tbody>
</table>

AAP = Achromatic Automated Perimetry
FDP = Frequency Doubling Perimetry