Pilot exposure to UV and blue light hazard in flight and developments in refractive surgery

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Aviation Vision Services
Plan

- UV and blue light hazard exposure
  - Summary of research conducted 2010 – 2015
  - Composed of 3 separate but interlinking studies:
    - Part 1: Irradiance levels received during flight
    - Part 2: Eye protection practices of professional pilots
    - Part 3: Effectiveness of sunglasses used in aviation environment

- Developments in refractive surgery
  - Description of some current surgical procedures
  - Latest CAA guidance material for refractive surgery
  - A personal perspective on refractive surgery
Non-ionising radiation

- Visible light from around 400-700nm
- UV-C (100-280nm) – absorbed at high altitudes
- UV-B (280-315nm) – attenuated by ozone layer
- UV-A (315-400nm) – 95% of terrestrial UV
- Blue light hazard peak effect around 440nm
- Photon energy $E = \frac{hc}{\lambda}$
- UV increases with altitude
- Acute / chronic ocular damage through UV exposure
Ocular effects of excess radiation exposure

- These conditions are multifactorial
- Good evidence of increase risk of cortical cataract (limited evidence for pterygium)
- No good evidence of increased prevalence of cataract in professional pilots
- Retinal photochemical damage by intense blue light
- Clinical changes mimicking Macular Degeneration (MD)
- No available data on MD in professional pilots
International Commission on Non-Ionising Radiation Protection (ICNIRP) guidelines

- Guidelines for eye and skin exposure limits based on best scientific evidence
- Exposure below limits would not be expected to cause adverse effects BUT exposure above limits does not guarantee adverse effects
- Ocular UV limits should be considered absolute for direct exposure
- Spectrally weighted radiant exposure (180-400nm) should not exceed 30 Jm\(^{-2}\) to unprotected eye
- Between 315-400nm, total unweighted radiant exposure over 8 hours should not exceed 10,000 Jm\(^{-2}\)
- Limits for retinal blue light exposure also defined
Equipment for measuring radiation

- Ocean Optics HR4000 spectrometer
- Associated diffuser and fibre optics
- Optical shutter for dark measurements
- Palmtop pc for automated software and data collection
- Battery power packs
- 2 illuminance UV data loggers
Equipment (2)

- Spectrometer calibrated against known reference source for wavelength and irradiance
- Calibration periodically re-checked
- Cosine diffuser error calculated
- Multi-region data acquisition
- Dark readings after each spectral reading
- Automated spectrometer data collection
- Automated illuminance UV data collection
- Manual illuminance UV data collection at pilot eye position (ahead and towards instruments)
Flights undertaken

- 6 flights (11 sectors)
- From London Gatwick
- Monarch Airlines

<table>
<thead>
<tr>
<th>Date</th>
<th>Destination</th>
<th>A/C type</th>
<th>flight time</th>
</tr>
</thead>
<tbody>
<tr>
<td>16/05/2012</td>
<td>Faro, Portugal</td>
<td>A320</td>
<td>290</td>
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<tr>
<td>22/05/2012</td>
<td>Barcelona, Spain</td>
<td>A320</td>
<td>206</td>
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<tr>
<td>26/05/2012</td>
<td>Barcelona, Spain</td>
<td>A320</td>
<td>204</td>
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<td>21/11/2012</td>
<td>Tobago</td>
<td>A330</td>
<td>555</td>
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<td>01/03/2013</td>
<td>Alicante, Spain</td>
<td>A321</td>
<td>258</td>
</tr>
<tr>
<td>21/08/2013</td>
<td>Rhodes, Greece</td>
<td>B757</td>
<td>452</td>
</tr>
</tbody>
</table>

- 4 Helicopter flights
- From Aberdeen Dyce to off-shore oil platforms
- Bristow Helicopters
Results

• No measurable UVB signal detected during any flight

• Wide variation in UVA irradiance measured during flight (airlines and helicopters)

• Position of solar disc relative to line of sight

• Higher irradiance (& hazard ratios) during sectors with significant cloud cover below aircraft

• Mean 4.1 times increase in Blue Light Hazard at altitude (large variation partly dependent on ground conditions)
## Results – Blue light hazard Airline flights

<table>
<thead>
<tr>
<th>Flight</th>
<th>Mean Radiance W/m².sr</th>
<th>Standard deviation</th>
<th>Min Radiance W/m².sr</th>
<th>Max Radiance W/m².sr</th>
<th>Flight duration (min)</th>
<th>Radiance dose for flight (J/m².sr)</th>
<th>Relative to ICNIRP guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Faro</td>
<td>5.87</td>
<td>1.58</td>
<td>3.74</td>
<td>11.28</td>
<td>290</td>
<td>60991</td>
<td>0.06</td>
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<tr>
<td>2 Barcelona</td>
<td>5.95</td>
<td>3.11</td>
<td>0.86</td>
<td>13.75</td>
<td>206</td>
<td>79974</td>
<td>0.08</td>
</tr>
<tr>
<td>3 Barcelona</td>
<td>4.34</td>
<td>1.57</td>
<td>0.75</td>
<td>7.05</td>
<td>204</td>
<td>50597</td>
<td>0.05</td>
</tr>
<tr>
<td>4 Tobago</td>
<td>3.5</td>
<td>4.73</td>
<td>0.18</td>
<td>32.06</td>
<td>588</td>
<td>58611</td>
<td>0.06</td>
</tr>
<tr>
<td>5 Alicante</td>
<td>13.31</td>
<td>20.71</td>
<td>0.19</td>
<td>94.81</td>
<td>301</td>
<td>245122</td>
<td>0.25</td>
</tr>
<tr>
<td>6 Rhodes</td>
<td>9.87</td>
<td>20.90</td>
<td>0.25</td>
<td>115.86</td>
<td>479</td>
<td>193783</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Maximum radiance dose over 10,000 sec to prevent type II damage = $1 \times 10^6$

### Eyes ahead

### Eyes down
## Results – UVA Airline flights

<table>
<thead>
<tr>
<th>Flight</th>
<th>UVA ahead, J/m²</th>
<th>Relative to ICNIRP guidelines</th>
<th>UVA down, J/m²</th>
<th>Relative to ICNIRP guidelines</th>
<th>Flight duration (min)</th>
<th>UVA ahead, J/m²</th>
<th>Relative to ICNIRP guidelines</th>
<th>UVA down, J/m²</th>
<th>Relative to ICNIRP guidelines</th>
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</thead>
<tbody>
<tr>
<td>1 Faro</td>
<td>23405</td>
<td>2.34</td>
<td>11804</td>
<td>1.18</td>
<td>290</td>
<td>30400</td>
<td>3.04</td>
<td>15286</td>
<td>1.53</td>
</tr>
<tr>
<td>2 Barcelona</td>
<td>17051</td>
<td>1.70</td>
<td>10320</td>
<td>1.03</td>
<td>206</td>
<td>19591</td>
<td>1.96</td>
<td>12249</td>
<td>1.22</td>
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<tr>
<td>3 Barcelona</td>
<td>1468</td>
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<td>771</td>
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<td>1641</td>
<td>0.16</td>
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<td>2167</td>
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<td>1700</td>
<td>0.17</td>
<td>588</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>5 Alicante</td>
<td>38158</td>
<td>3.82</td>
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<td>65630</td>
<td>6.56</td>
<td>45481</td>
<td>4.55</td>
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</tbody>
</table>

**UVA dose including turn around**

<table>
<thead>
<tr>
<th>Flight</th>
<th>UVA per hour J/m² (ahead)</th>
<th>UVA per hour J/m² (down)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Faro</td>
<td>4842</td>
<td>2442</td>
</tr>
<tr>
<td>2 Barcelona</td>
<td>4966</td>
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<td>432</td>
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<td>4 Tobago</td>
<td>221</td>
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<td>7606</td>
<td>5323</td>
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<tr>
<td>6 Rhodes</td>
<td>7816</td>
<td>5277</td>
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</tbody>
</table>
Ground Transmittance measurements

• 13 aircraft at stands assessed during turnaround
  • London Heathrow, Exeter International, Brooklands Museum
  • Assessed when solar UV levels higher

• 2 aircraft at turnaround (used for in flight measurements)

• Total 15 aircraft

• Front and side windshields measured
• Outside and dark measurements captured
• Also visors, side blinds and HUD (if fitted) transmittance measured
## Windshield transmittance at ground level

<table>
<thead>
<tr>
<th>Type</th>
<th>Built</th>
<th>Airframe hrs</th>
<th>as of</th>
<th>measured on</th>
<th>UVA attenuation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R front</td>
</tr>
<tr>
<td>B777-200</td>
<td>2000</td>
<td>48780</td>
<td>31/12/2011</td>
<td>06/11/2012</td>
<td>poor</td>
</tr>
<tr>
<td>B747-400</td>
<td>1993</td>
<td>89575</td>
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<tr>
<td>B777-200</td>
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<td>54961</td>
<td>31/12/2011</td>
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<td>poor</td>
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<tr>
<td>A321-200</td>
<td>2004</td>
<td>23440</td>
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<tr>
<td>B777-300</td>
<td>2011</td>
<td>919</td>
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<td>16/04/2013</td>
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<tr>
<td>B777-200</td>
<td>1998</td>
<td>66296</td>
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<td>16/04/2013</td>
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<tr>
<td>B777-200</td>
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<td>62462</td>
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<td>B747-400</td>
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<td>90272</td>
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<tr>
<td>B777-200</td>
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<tr>
<td>B747-400</td>
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<td>101859</td>
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<td>16/04/2013</td>
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<tr>
<td>A320-200</td>
<td>2007</td>
<td>10703</td>
<td>31/12/2011</td>
<td>16/04/2013</td>
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<tr>
<td>Concorde</td>
<td>1973</td>
<td>not available</td>
<td></td>
<td>26/06/2013</td>
<td>good</td>
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<td>Embraer 195</td>
<td>2008</td>
<td>8413</td>
<td>31/12/2012</td>
<td>28/08/2013</td>
<td>poor</td>
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<tr>
<td>Bombardier Dash8</td>
<td>2005</td>
<td>12195</td>
<td>31/12/2011</td>
<td>28/08/2013</td>
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<tr>
<td>B757-2T7</td>
<td>1987</td>
<td>91829</td>
<td>31/12/2012</td>
<td>21/08/2013</td>
<td>poor</td>
</tr>
</tbody>
</table>
Side blinds consistently better UV-A blockers than visors.
Part 1 Conclusions

- ICNIRP UVA ocular exposure limits exceeded during majority of flights (fastest within 1hr)
- This accounts for pilot use of visors / side blinds
- Windshield transmittance properties has greatest impact on UVA exposure
- Good UVA attenuating windshields do not cause excessive ocular exposure over 8 hours
- Most aircraft measured had poor UVA attenuating windshields
- Oldest aircraft tended to have good UVA attenuating windshields
- Similar findings for Boeing and Airbus fleet
- Pilots currently have no means to assess windshield UVA attenuating properties
- Increase in Blue light hazard at altitude quantified and well within international exposure limits – effects over lifetime / career unknown
Part 2 – Solar eye protection practices

- Web-based questionnaire (SurveyMonkey) developed
  - ‘piloted’ twice with minor modifications made following feedback
  - No personal identifiable data collected
  - Promoted to and completed by BALPA members

- Areas covered:
  - Use of sunglasses
  - Barriers to successful use
  - Disability and discomfort glare symptoms
  - Use of other standard / non-standard practices
  - Presence of UV/BL ocular related pathology
Part 2 results – participant demographics

- 2,917 fully completed questionnaires
- Majority airline: Short haul (SH) 58.7% or Long haul (LH) 33.8%
- Third category: Helicopter off shore (HOS) 1.9%
- 18.7% previous military experience
- 91.6% had total flight time logged over 2,500 hours
- Mean number of hours flown previous 12 months:
  - SH 707hrs (SD 150)
  - LH 640hrs (SD 151)
- Corrective spectacles required for 45.7% respondents (significant increase with age)
Part 2 results - Glare

- Discomfort glare reported ‘sometimes’ or ‘generally’ by 75% of respondents
- Disability glare reported ‘rarely’ or ‘sometimes’ by 83% of respondents (mainly during safety critical stages of flight)
- No difference in different flying categories
- No relationship between age or number of flying hours
- Significantly higher use of sunglasses with increasing reporting of glare
- Other symptoms reported: asthenopia, photophobia, epiphoria, photic sneeze
Sunglass use VDL vs Non VDL

Spectacle wearers use sunglasses significantly less.
Other reasons for not using sunglasses

• Instruments too dark to comfortable visualise through sunglasses
• Poor interaction with headset
• Other discomfort issues with frame
• Too much hassle to put on in flight
• Too expensive
• Not bothered by sunlight
• Aircraft has adequate protection with standard visors / blinds (more participants stated the opposite)
When are sunglasses used?

- **Walkaround**: Frequently used.
- **Taxi**: Sometimes used.
- **Take off**: Usually used.
- **Cruise**: Always used.
- **Approach**: Occasionally used.
- **Landing**: Usually used.
- **When tired**: Sometimes used.
- **When flying towards direct sun**: Always used.
- **When it feels too bright**: Rarely used.
- **Other**: Never used.
<table>
<thead>
<tr>
<th>Reasons for change in sunglass use</th>
<th>Increase</th>
<th>Decrease</th>
<th>Same</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Sunglass tint</td>
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<td>2</td>
<td>3</td>
<td>8</td>
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<tr>
<td>Sunglass comfort</td>
<td>7</td>
<td>9</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Change of operating environment</td>
<td>20</td>
<td>18</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Change of prescription</td>
<td>10</td>
<td>26</td>
<td>10</td>
<td>46</td>
</tr>
<tr>
<td>Increase awareness of potential impact to vision</td>
<td>23</td>
<td>1</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Eye contact with other pilot</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Lost / damaged sunglasses</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>6</td>
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<tr>
<td>Use other strategies instead</td>
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<td>3</td>
<td>1</td>
<td>4</td>
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<td>Visual fatigue</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Other</td>
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<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Change to light sensitivity</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>77</strong></td>
<td><strong>71</strong></td>
<td><strong>27</strong></td>
<td><strong>175</strong></td>
</tr>
</tbody>
</table>
Other protection strategies

• Aircraft visors / blinds – most commonly used
• Use of baseball cap
• Non-standard procedures: charts, checklists, envelopes, tray liners, HUD cover against windshield or attached to visor. Also jump seat cushion, newspapers or vehicle sun shields against windshield, adjusting seat position, using hand to block sun
• Long haul highest users of protection strategies; helicopter off-shore lowest
• Ex-military pilots lower users of non-standard procedures
• No difference in use of other strategies between those requiring spectacle correction and those not except sunglasses (higher in non-spec wearers) and baseball cap use (higher in spectacle wearers)
• High level of dissatisfaction with standard aircraft solar protection (significantly more with Boeing than Airbus)
Prevalence of eye disease

- 1.4% cataract diagnosis
- 0.6% had undergone cataract surgery (IOL implants)
- 1.5% MD diagnosis
- No significant difference with flying category
- Significantly associated with age but not with number of flying hours

- 0.3% took vitamins / supplements solely due to eye health concerns and also reported significantly lower levels of disability glare
Part 2 - some conclusions

• Spectacles are significant barrier to sunglass use
• High levels of dissatisfaction with standard aircraft solar protection systems
• Wide range of sunglasses used (91 different brands)
• Low take up of aviation marketed sunglasses (2%)
• Tint colour likely to be a personal preference
• Low use of graduated tint (11%)
• Targeted advice should increase sunglass success for those pilots wishing to use them more
Part 3 Sunglass transmittance

• Used pilot sunglasses and new sunglasses measured
• Used sample showed good correlation with part 2 results
• 20 used non-prescription (15 uniform, 5 graduated tints)
• 2 used prescription sunglasses
• 18 new non-prescription (12 uniform, 6 graduated tints)

• No significant difference in transmission R-L lenses
• High levels of UV-A attenuation afforded (<0.5% transmittance at 380nm and <5% for the majority at 400nm)
Prescription sunglasses

• 2 assessed and compared to typical non-prescription sunglass

<table>
<thead>
<tr>
<th>ISO requirements</th>
<th>Graduated tint</th>
<th>Prescription sunglass 1</th>
<th>Prescription sunglass 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminous transmittance, %</td>
<td>30.7</td>
<td>32.3</td>
<td>14.9</td>
</tr>
<tr>
<td>Weighted UV-A transmittance, %</td>
<td>0.1</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Filter category</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Average UV-A transmittance, %</td>
<td>0.2</td>
<td>6.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Average UV-A transmittance in 380-400nm, %</td>
<td>0.4</td>
<td>20.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

• Prescription sunglass 1 would not provide adequate protection in flight (lens material dyed during manufacture without UV coating)
• A sunglass filter still may be ISO compliant
• Additional requirement of 10% at 380nm recommended
Protection from blue light hazard

- Blue light transmittance between 0.6-16%
- All non-prescription sunglasses offered at least sufficient attenuation to counter the mean increase measured at altitude (in part 1)
- Radiance within ICNIRP limits, although effect over career unknown
- No reason to recommend additional blue light hazard blocking requirements
Recommendations of research

- Be aware of UVA and potential pilot eye exposure
- All EU or equivalent compliant sunglasses will reduce UVA exposure to within ICNIRP limits
- Standard spectacle lens materials and contact lenses may not offer sufficient UVA blocking properties
- Sunglasses offer a degree of blue light hazard reduction which will counter mean increase at altitude
- Consider recommending graduated tint for sunglasses
- Ensure new aircraft have good UVA blocking properties
- Introduction of windshield labelling system
Further ongoing research

• Spectrometer study (part 1) currently being replicated by Air New Zealand
• UK based dosimeter study to assess pilots’ typical occupational versus global UVA and UVB exposure
Acknowledgements

Dr Marina Khazova
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Dr Martin Benwell

Dr Simon Brown
Chris Ashpole

Guy Holmes
Developments in refractive surgery

• Prevalent and emerging types of refractive surgery
• EASA regulations regarding refractive surgery
• Current published and new CAA guidance material
• Post refractive surgery audit from CAA AeMC
Types of refractive surgery

• **Intraocular:**
  • Anterior chamber implants
  • ICL implants
  • Clear lens extraction (with single vision, toric or multifocal implants)

• **Peripheral corneal:**
  • CK (Conductive Keratoplasty)
  • AK (Astigmatic Keratotomoy)
  • Intacs
  • RK (Radial Keratotomy)

• **Central corneal**
  • PRK
  • LASIK
  • LASEK
  • ReLEx SMILE
  • Inlays
Implantable Contact Lens (ICL)
Clear Lens Extraction
Clear Lens Extraction

• High degrees of myopia and hyperopia can be corrected
• Complication rate as for cataract surgery (low)
• BUT no accommodation post surgery (will require reading glasses regardless of age)
• Multifocal implants – not acceptable for certification (GM)
• Accommodating implants only allow small refocusing ability
Laser Assisted In Situ Keratomileusis (LASIK)

- Most prevalent surgery conducted in UK
- Large range of refraction treatable
- Relatively painless
- Faster recovery
- Disadvantages
  - Reduced corneal sensitivity initially
  - Flap complications

Lasik Eye Surgery
Femtosecond laser (or FemtoLASIK / IntraLASIK)

- Used for creating LASIK flap
- More accurate than trephine cut
- Lower flap complications
- Now used for majority of LASIK procedures
- Risk of diffuse lamellar keratitis
Laser Assisted Epithelial Keratomileusis (LASEK)

• Higher degrees of myopia treatable than LASIK
• Equivalent visual outcomes to LASIK in low / moderate myopia

• Disadvantages
  • Increase incidence of regression / stromal haze in high myopia
  • Loss of epithelium during surgery (becomes PRK procedure)
  • Require ‘bandage’ contact lens after surgery
Wavefront guided technology

• Ability to measure total optical aberrations within the eye by passing many individual beams of light through the eye and measuring the distortion back.
• Wavefront map individual to each eye
• Allows wide treatment zones
Customised corneal surface treatment

• Increase in asphericity of surface can improve depth of focus
• ‘Blended monovision’
• Pilots should be warned that may require multifocal spectacles following treatment to meet requirements.
• Must be tolerant of spectacle correction
ReLEx (Refractive lenticule extraction)
SMILE (Small Incision Lenticule Extraction)

- Correction of myopia
- Stromal lenticule ablated and removed
- Relatively new technique
Corneal Inlays

- Marketed for presbyopia treatment
- Non-dominant eye treated
- Refractive
  - Similar to multifocal design
  - Not FDA approved
- Re-shaping
- Small aperture
  - KAMRA inlay
EASA requirements

• Implementing Rule:
  • Applicants who have undergone eye surgery may be assessed as fit subject to satisfactory ophthalmic evaluation

• Acceptable Means of Compliance:
  • After refractive surgery, a fit assessment may be considered, provided that:
    • pre-operative refraction was no greater than +5 dioptres;
    • post-operative stability of refraction has been achieved (less than 0.75 dioptres variation diurnally);
    • examination of the eye shows no postoperative complications;
    • glare sensitivity is within normal standards;
    • mesopic contrast sensitivity is not impaired;
    • review is undertaken by an eye specialist.
Current published Guidance Material

- Assessments undertaken at an AeMC
- LASIK: 3 month post-op with demonstration of refraction at 2 month post-op
- LASEK / PRK: 6 month post-op
- SMILE: 3 month post-op with demonstration of refraction at 2 month post-op
- Refractive lens exchange: 6/52 post-op (as for cataract surgery)
Audit of CAA AeMC refractive surgery cases

- 1 Jan 2009 – 31 Dec 2014
- Filtered by surgery type
- Outcome assessed
# Refractive surgery audit results

<table>
<thead>
<tr>
<th>Surgery type</th>
<th>Fit</th>
<th>awaiting final review</th>
<th>awaiting report only</th>
<th>denied (pre-op refraction)</th>
<th>denied (contrast sensitivity)</th>
<th>Total</th>
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</table>

0.7% of LASIK denied, 0.6% of all cases assessed denied as of 23 March 2015
Current CAA Guidance (awaiting publication)

- Refractive surgery not recommended
- Any procedure considered for certification (except multifocal IOLs)
- No minimum post surgical periods stipulated
- Applicant provides report from surgeon once stability of refraction is established, no adverse effects or complications from surgery
- Applicant has been advised by surgeon that can resume other lifestyle activities
- Assessments include detailed refraction and slit lamp examination at an AeMC
- Objective examination of glare sensitivity and mesopic contrast sensitivity. Additionally no symptoms of glare, haloes or starbursting
- No pre-op limits for myopia or astigmatism. Pre-op refractions over +5.00D deferred to AMS
- No more than 0.75D diurnal variation in refraction for RK cases only
- Certification may be postponed if recovery / stability not achieved