Extended Limb Lengthening in Dwarfs and Cosmetic Lengthening for Short Stature. Advances and Future Perspectives of Ilizarov

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Upper Limb and Sports Medicine Surgeon
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Outline

- Features of Achondroplasia
- Techniques of limb lengthening in ACH
- Complications of lengthening in ACH
- Cosmetic LL for short stature
- Innovations and the future of DI
Achondroplasia

most common form of dwarfism
incidence 1/15,000-30,000 live births
fully penetrant autosomal dominant

disturbance in endochondral bone formation
short stature
neurological and skeletal complications
normal intelligence
The gene of ACH was assigned in 1994.

Tyrosine-kinase domain activation loop of FGFR3

in 98% substitution of arginine for a glycine residue at position 380 (Gly380Arg)

other mutations (Gly375Cys, Gly346Glu and Ser279Cyst) have been exceptionally reported
- The phenotype observed in achondroplasia is the consequence of severe disturbances in endochondral bone growth induced by abnormal activity of FGFR3.

- Delayed maturation of chondrocytes in the hypertrophic zone (growth plate)

- Reduced longitudinal growth of bone
Phenotype

- disproportionate short stature
- rhizomelic shortening,
- trident hands,
- enlarged head, depressed nasal bridge & prominent forehead
- generalized joint laxity and mild hypotonia
- Medium adult heights are $131 \pm 5.6$ cm for males and $124 \pm 5.9$ cm for females
- delayed motor milestones
- recurrent middle-ear dysfunction
- hydrocephalus, foramen magnum stenosis
- craniocervical junction compression
- dental crowding
- upper-airway obstruction,
- psychosocial problems
- excessive weight gain
Orthopaedic manifestations

- atlantoaxial instability
- thoracolumbar kyphosis (infancy), (10% of may progress)
- excess lumbar lordosis (childhood) and prominent buttocks
- spinal stenosis (17%) and disc prolapse (adult life)
- hip flexion, contractures and limitation of elbow extension, genu varum, internal tibial torsion and varus deviation of the ankle
Life expectancy & QoL

- Children often have lower IQ

- Overall and age-specific mortality rates are increased at all ages (cardiovascular and neurological diseases)

- The average life expectancy for this cohort was decreased by 10-15 years

- Have lower annual incomes, less education, and are less likely to be married than people without achondroplasia

**Treatment**

- Reduce the hyperactivity of FGFR
  - Selective chemical inhibition of tyrosine kinase activity in FGFR3,
  - antibodies which block activation of FGFR3
  - C-type natriuretic peptide as an antagonist of the signal triggered by FGFR3

**Growth hormone** has shown increase in growth velocity (65–75%) during the first year or a gain of 0.2–0.5 SD of height during the first year of treatment, short term studies

**Orthopaedic treatment**

- bone elongation?
- correction of axial deviations
- spinal stenosis & kyphosis
Extended lengthening for ACH

Still controversial, special considerations:

- age and sex of the patient
- initial segment length and axial deformities
- estimation of the potential lengthening
- elongation obtained
- type of fixator
- time for consolidation
- complications
- rehabilitation problems
- psychological aspects of the child and family
Methods and Strategies in Limb Lengthening and Realignment for Skeletal Dysplasia

John E. Herzenberg and Dror Paley

University of Maryland Center for Limb Lengthening and Reconstruction, Baltimore, Maryland, USA

1st stage: 15 cm bilateral tibial lengthening at age 11

2nd stage: 10 cm bilateral humeral lengthening at age 13

3rd stage: 10 cm bilateral femoral lengthening at age 16
STAGED LENGTHENING IN ACHONDROPLASTIC DWARFS.
27 YEARS OF CLINICAL AND SURGICAL EXPERIENCE

G. PERETTI, W. ALBISSETTI, O. DE BARTOLOMEO, A. MEMEO, G. M. PERETTI
and F. VERDONI

*Department of Surgical, Reconstructive and Diagnostic Sciences, Section of Orthopedics,
Traumatology, Rheumatology and Rehabilitation, University of Milan, Milan, Italy*

<table>
<thead>
<tr>
<th>surgical approach</th>
<th>age (yrs)</th>
<th>segment</th>
<th>initial length of the segment (cm)</th>
<th>forecast lengthening (cm)</th>
<th>final length (cm)</th>
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</thead>
<tbody>
<tr>
<td>first</td>
<td>5 to 6</td>
<td>tibiae</td>
<td>13-16</td>
<td>5 to 6</td>
<td>18 to 22</td>
</tr>
<tr>
<td>second</td>
<td>6 to 7</td>
<td>femuri</td>
<td>15-19</td>
<td>5 to 7</td>
<td>20 to 26</td>
</tr>
<tr>
<td>third</td>
<td>11 to 12</td>
<td>tibiae</td>
<td>22-27</td>
<td>7 to 10</td>
<td>29 to 37</td>
</tr>
<tr>
<td>fourth</td>
<td>12 to 14</td>
<td>femuri</td>
<td>25-29</td>
<td>8 to 12</td>
<td>33 to 41</td>
</tr>
<tr>
<td>fifth</td>
<td>16</td>
<td>humeri</td>
<td>12-20</td>
<td>8 to 12</td>
<td>20 to 32</td>
</tr>
</tbody>
</table>
99 patients/ 592 operations: satisfactory correction, improves limbs and body function and gives psychological support to these children, considered as a valid surgical procedure.

Skin infection 166 (75.5%)
Transient nerve palsy 45 (20%)
Tendon retraction 25 (11.36%)
Incomplete osteotomy 8 (3.63%)
Increased lumbar lordosis 4 (2%)
Axial deformities 10 (4.5%)
Others 55 (22%)
Distraction osteogenesis using a longitudinal corticotomy

Ma’ad F. Al-Saati • Robert A. Magnussen • Sebastien Lustig • Rodolphe Testa • Gazal Al-Saati • Faisal Al-Saati

51 patients/67 procedures (short stature 32 pt)
45 longitudinal corticotomy,
22 transverse corticotomy.

Healing index was significantly lower in the S-Z group (30.8 days/cm) than 46.8 days/cm

Mean lengthening was 6.6 cm in the S-Z group and 5.8 in the transverse group

Mean consolidation time was 6.3±2.8 vs 8.1±3.8.
22 patients (average age, 12.7 years) who underwent bilateral lower limb lengthening

22 patients with achondroplasia for whom limb lengthening was not performed.

The 2 groups were assessed using the AAOS lower limb, SF-36, and Rosenberg self esteem scores. Minimum follow up was 4.5 years

Average length was 10.21 ± 2.39 cm for the femur and 9.13 ± 2.12 cm for the tibia

123 complications occurred in 88 segments.

The surgical group had higher Rosenberg self-esteem scores but no differences in the AAOS and the SF-36 scores

The self-esteem scores decreased with the increase in the number of complications
Physeal damage occurs after limb lengthening by over 50% in achondroplasia.

This damage is a gradual process that manifests itself about 2 years after surgery, and it is most pronounced in the anterior-lateral portion of the proximal tibial physis.

In Korean children, lengthening should preferably be started at around 11 years of age.
Factors negatively impacting growth stimulation rate:

- Age at initiation of lengthening
  - bone age > 12 years in boys or 9 years in girls

- Number of lengthening procedures per segment
  - iterative lengthening, even when performed outside of the pubertal growth boost period

- Interval between lengthening procedures
  - when performed before pubertal growth boost and more than 3 years after the first procedure

- Percentage lengthening
  - more than 30% of initial segment length
28 patients (14 with fracture and 14 without)

A lucent pathway was seen in all fracture cases with concave, lateral, and atypical shapes, and there was more than 30\% lengthening and 30\% reduction of the callus width compared with the natural width of the femur, which are the warning signs for regenerate fractures.
Complications of Ilizarov leg lengthening: a comparative study between patients with leg length discrepancy and short stature

B. Vargas Barreto · J. Caton · Z. Merabet · J. C. Panisset · J. P. Pracros

during lengthening of the tibia with the Ilizarov device, approximately one in two patients requires a secondary surgical procedure not planned in the initial lengthening program

Table 2: Complications

<table>
<thead>
<tr>
<th>Category</th>
<th>Group A</th>
<th>Group B</th>
<th>Total of complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category I</td>
<td>19</td>
<td>36</td>
<td>55</td>
</tr>
<tr>
<td>Category II</td>
<td>15</td>
<td>18</td>
<td>33</td>
</tr>
<tr>
<td>Category III</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>54</td>
<td>90</td>
</tr>
</tbody>
</table>

*a Group A: patients with limb length discrepancy  
*b Group B: short stature patients
There are no established medical indications for symmetric extended limb lengthening (ELL). While it may have benefit in preventing certain orthopedic and neurological complications in some skeletal dysplasias, the procedure is primarily being performed for adaptive, cosmetic, and psychosocial reasons.
“We are a contradiction in packaging, for encased in our small bodies are not small minds, not small needs and desires, not small goals and pleasures, and not small appetites for a full and enriching life.”
54 patients, mean age 25.8 years
mean lengthening 7 cm (5 to 11) at 9 months
19 (35.2%), bilateral Achilles tendon lengthening
48% pin site infection
90% will perform the operation again
Ilizarov technique of lengthening and then nailing for height increase

Khaled Emara, Amr Farouk, Rami Diab
Department of Orthopaedic Surgery, Ain Shams University Hospitals, Cairo, Egypt

26 men and 6 women aged 21 to 47
body height of 160 to 176
mean lengthening 7.6 cm or 26%
mean duration of external fixation 96 days
4 patients had revision operations
New perspectives of DI

Byproduct advances

- Deformity analysis and nomenclature
- Prediction of limb length discrepancy (LLD), timing of epiphysiodesis and stature
- Lengthening over nail (LON), or plate (LOP) lengthening and then nailing (LATN) or plating (LATP)
- Fixator assisted nailing (FAN) and fixator assisted plating (FAP) for deformity correction

New product advances

- Modularity of monolateral external fixators
- Motorized circular external fixation
- Computer dependent external fixation
- Implantable limb lengthening
- Biological advantages and improvement of healing
The **CORA** (center of rotation and angulation) method to accurately determine the level of the Ilizarov hinge

Plane of deformity

Six axis deformity correction

Joint orientation angles in the frontal and sagittal plane.
Multi-apical planning, bilevel osteotomies
4 ACH and 2 Hypochondroplasias
Excellent results
a coefficient could be calculated for each age to represent the reciprocal of growth remaining

That coefficient was independent of percentile, race, nationality, and generation.

For the lower extremity the coefficients (multipliers) for the femur, tibia, and foot height were the same.

Therefore a single set of multipliers could be used to determine bone or limb length
Lower limb and total height growth rates were slower in achondroplastic dwarves compared with healthy persons. However, sitting height multipliers were closely related.

Predicting maturity height for achondroplastic dwarves also helps their families to decide about stature-increasing methods, such as limb lengthening and growth hormone treatments.
Lengthening over nails or plates (LON, LOP) lengthening and then nailing or plating (LATN, LATP)
Tibial lengthening over an intramedullary nail in patients with short stature or leg-length discrepancy: a comparative study

Qianchen Guo · Tao Zhang · Yongfa Zheng · Shiqing Feng · Xinlong Ma · Feng Zhao

Table 1 Patient clinical and demographic data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group A&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Group B&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>13</td>
<td>26</td>
</tr>
<tr>
<td>Number of tibia</td>
<td>23</td>
<td>51</td>
</tr>
<tr>
<td>Age in years (range)</td>
<td>22.7 (18–42)</td>
<td>25.4 (19–47)</td>
</tr>
<tr>
<td>Gender (female/male)</td>
<td>10/3</td>
<td>21/5</td>
</tr>
<tr>
<td>Bilateral (short stature)</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Congenital leg-length discrepancy</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

<sup>a</sup> Conventional Ilizarov method
<sup>b</sup> Lengthening over a nail

281.5 versus 129.0 days external fixation index (40.0 versus 17.4 day/cm). Ilizarov group had a higher complication rate (1.0 versus 0.47 per tibia)
67 patients with 101 femoral lengthening

32 with ACH

12 fractures in 101 cases (12%).

The rate of secondary interventions was markedly reduced.

Usage of one or two TENs did not influence the fracture rate
Limb lengthening over plate

Ruta Kulkarni, Nishant Singh, Govind S Kulkarni, Milind Kulkarni, Sunil Kulkarni, and Vidisha Kulkarni

15 patients (7 females, 8 males)
average age was 18.1 years (range 8–35 years).
15 tibiae and 1 femur in 15 patients.
Rate at 1 mm/day followed by distal segment fixation
with 3-4 screws on reaching the target length.

Target length was achieved in all pt (mean of 4.1 cm)
mean duration of Ex-Fix 75.3 days
mean external fixation index at 19.2 days/cm
1 patient suffered deep infection
3 patients had mild procurvatum deformities
1 patient developed mild tendo achilles contracture
Plating after tibial lengthening: unilateral monoaxial external fixator and locking plate
Soo-Min Cha, Hyun-Dae Shin, Kyung-Cheon Kim and Jae-Hwang Song

Fixator in the lateral side – plating at the medial
Application immediately after the distraction phase
Few complications – full consolidation – no infections
Fixator assisted nailing (FAN) and fixator assisted plating (FAP) for deformity correction
Distal tibial hypertrophic nonunion with deformity: treatment by fixator-assisted acute deformity correction and LCP fixation

Mahmoud A. El-Rosasy · Sameh A. El-Sallakh
CASE REPORT

A correction of windswept deformity by fixator assisted nailing

A REPORT OF TWO CASES
Modularity of monolateral external fixators
2 planes of angulation, 2 planes of translation, compression, distraction, and rotation requires only measurement of length and angular deformity on the anteroposterior and lateral x-rays.

Correction is accomplished by sequentially turning one screw to lengthen 0.25 mm 4 times per day (1 mm per d), then turning another screw to correct angulation 1° 4 times per day (4°/d).
Manual distraction (0.25 mm four times a day) in a group containing 43 tibiae was compared with motorized high frequency distraction (1/1,440 mm 1,400 times a day) in a group containing 27 tibiae.

There was no significant difference in time to union or in the incidence of complications.

improved compliance vs cost, weight (1 Kg) and possibility of mechanical failure
Computer dependent external fixation
All the patients were managed with the same protocol: placement of an external fixator, AP and lateral X-rays, and planning of the correction using dedicated software

3/36 cases with achondroplasia

healing index 38.2 days/cm.
superficial infection 22.2%
3 regenerate fractures
# Implantable limb lengthening

<table>
<thead>
<tr>
<th>Device</th>
<th>Outcomes/Complications</th>
</tr>
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<tbody>
<tr>
<td>Albizzia/ Guichet nail</td>
<td>Generally successful outcomes</td>
</tr>
<tr>
<td>ISKD (Orthofix)</td>
<td>Complications “run away nails” Inaccurate and unreliable distraction Premature consolidation</td>
</tr>
<tr>
<td>Fitbone</td>
<td></td>
</tr>
<tr>
<td>PHENIX</td>
<td>Technical problems Nerve injuries</td>
</tr>
<tr>
<td>Precise</td>
<td>Joint contractures</td>
</tr>
</tbody>
</table>
ALBIZZIA nail (1987), Guichet-advanced ALBIZZIA (2009)

Internal telescopic nail

Lengthening achieved by rotation

Rotation makes “click” noise, allowing higher accuracy

15 clicks ~ 1 mm

Can achieve 9-10 cm of lengthening
Complications of Albizzia femoral lengthening nail: an analysis of 36 cases
Philippe Mazeau, Chahine Assi, Djamel Louahem, Mohamed L'Kaisi, Marion Delport and Jérôme Cottalorda

36 cases (3 short-statured)
average lengthening 4.7 cm
faster consolidation
patient compliance

Table 2  Complications in the literature

<table>
<thead>
<tr>
<th></th>
<th>Ratcheting under anesthesia</th>
<th>Bone grafting</th>
<th>Deep infection</th>
<th>Program failure</th>
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</thead>
<tbody>
<tr>
<td>Garcia-Cimbrelo series (24 cases)</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Guichet series (41 cases)</td>
<td>12</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Our series (36 cases)</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total (101 cases)</td>
<td>25</td>
<td>7</td>
<td>3</td>
<td>8</td>
</tr>
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</table>
ISKD (INTRAMEDULLARY SKELETAL KINETIC DISTRACTOR)

Activated by polar movements through small rotation of bone segment being lengthened

Amount of length is determined pre-op and set at time of insertion

Allows 7 cm height gain
A distraction of 1 mm is achieved by 160 rotations of 3°.

The actual amount of distraction is controlled by an external handheld monitor, which measures the orientation of a magnet on the distal part of the internal threaded rod.

Maximal distraction length by the ISKD is 80 mm.
Femoral Lengthening with Lengthening over a Nail has Fewer Complications than Intramedullary Skeletal Kinetic Distraction

Shahab Mahboubian DO, MPH, Matthew Seah MBChB, Austin T. Fragomen MD, S. Robert Rozbruch MD

11 pt who had 12 femoral ISKD
21 patients with 22 femoral LON

No difference in lengthening goals
Distraction rates:
fast ISKD group: 1.7 mm/day
slow ISKD group: 0.84 mm/day
LON group: 0.88 mm/day

1 pt in LON and 6/12 pt in IKDC group
requiring additional unanticipated surgeries
FITBONE (FULLY INTEGRATED TELESCOPIC BONE)

Nail is distraction device powered by internal engine

Engine activated by hand remote

Activates distraction by sending messages to receiver below skin

Similar function as car antenna

Fitbone elongation is propelled by gear
13 femora and 11 tibiae in ten patients
mean age of 32 years
short stature in 6/10 patients

mean lengthening 40 mm (27 to 60)

mean healing index was 35 days/cm

There were no cases of implant-related infection or malunion
The mechanism is driven by a strong external magnet, can provide lengthening, shortening and bone transport.

10 patients with an average age of 25 years (6 femoral / 4 tibial), distraction goal was achieved in 8 of 10 patients.

mean lengthening 4.6 cm, distraction index 0.85 mm/day

3 patients revised due to early distraction arrest.
Precice® Nail, Ellipse Technologies Inc., Irvine, CA

Telescopic, magnet-operated device, recent FDA approval

An external remote controller (ERC) is required, which causes the magnets that are integrated into the drive thread rod to rotate, making a thinner nail element telescope out of a thicker surrounding nail.
How precise is the PRECICE compared to the ISKD in intra-medullary limb lengthening?

Reliability and safety in 26 procedures

Frank M Schiedel¹, Björn Vogl¹, Henning L Tretow¹, Britta Schuhknecht², Georg Gosheger², Melanie J Horter¹, and Robert Rödl¹

2 nails were primarily without function

24/26 nails lengthened over the desired distance (planned 38 – achieved 37)

2 nail breakages, mostly in patients with femoral lengthening

Other complications in 5 cases
Biological advantages and improvement of healing

- systemic administration of recombinant GH
- platelet-rich plasma
- concentrated bone marrow cells
- cultured periosteal cells
- recombinant human bone morphogenetic proteins
- frozen embryonic stem cells
56 bones in 20 patients (ACH 16 & HCH, 4)
24 bones in 11 patients (BMC and PRP)
32 bones in 9 patients (no cell therapy)

No differences in the length gained but average healing index of the BMC-PRP 6.89 d/cm control group 10.4 d/cm

Femoral lengthening faster healing than tibial lengthening in the BMC-PRP group

Waiting period of 9 days, and transplantation was performed 21 days after the distraction.
20 patients (40 segments), who underwent bilateral stature lengthening (familiar shortening) with the **LON technique**

10 patients received BMAC & PRP injection at tibial osteotomy site at the end of the index surgery, 10 patients no injection

Mean distraction rates similar (0.75 mm/day vs 0.72 mm/day)

No difference in mean external fixator index
Mean cortical healing indexes better in BMAC group
Full weightbearing was permitted earlier in BMAC group
Conclusions

While the first 100 years was the story of external fixation and distraction osteogenesis, the next 100 years will be the story of:

- Implantable distraction devices
- bone transport nails
- gradual deformity correction plates
- special lengthening plates
- biofeedback controls for internal and external fixation
- modulation of molecular and regenerative biology

Also many of the genetic conditions currently being treated will have medical instead of surgical solutions and new applications of distraction biology will be found